CS231-A 2015

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: 151
  - Office hour: Monday 4-5pm or under appoint.

• **CAs:**
  - Sam Corbett-Davies (head CA)
  - Saumitro Dasgupta
  - Christopher B. Choy
  - Phillip Lee
  - Aditya Srinivas Timmaraju

• **Class Time & Location**
  - M-W 11:00—12:15PM – Gates B1
Prerequisites

• This course requires knowledge of linear algebra, probability, statistics and familiarity with machine learning and computer vision. Also, decent programming skills are required. 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:

Recommended:
Course assignments

• 1 warm up problem set (HW-0)
• 4 problem sets (first problem released next week!)
• 1 mid-term exam (take home, 48 hours)
• 1 project

• Look up class schedule for release and due dates.
Grading policy

• Homeworks: 42%
  – 4 homeworks (2% grade for HW0)

• 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...
Grading policy

• Late policy home works:
  – If 1 day late, 50% off the grade for that homework
  – Zero credits if more than one day.
  – A "48-hours one-time late submission bonus" is available; that is, you can use this bonus to submit your HW late after at most 48 hours. This is one time bonus: After you use your bonus, you must adhere to the standard late submission policy.
  – No exceptions will be made.
  – No "late submission bonus" is allowed when submitting your exam or project.

• 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

• 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.
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 presentation

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

• Form your team:
  – 1-4 people
  – the quality is judged regardless of the number of people on the team
  – be nice to your partner: do you plan to drop the course?

• Evaluation
  – Project proposal report
  – Quality of the project (including writing)
  – Final project presentation (~3 minutes spotlight presentations)
• Add expectations
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
Computer vision

Image/video

Object 1
- semantic
- geometry

... Object N
- semantic
- geometry
Computer vision

Image/video

Object 1
- semantic
- geometry

... Object N
- semantic
- geometry

spatial & temporal relations
Computer vision

Image/video

Object 1

- semantic
- geometry

Object N

- semantic
- geometry

spatial & temporal relations

Scene

-Semantic
- geometry
Computer vision

Computer vision studies the **tools and theories** that enable the design of machines that can **extract useful information from imagery data** (images and videos) toward the goal of **interpreting the world**.

- **Information**: features, 3D structure, motion flows, etc...
- **Interpretation**: recognize objects, scenes, actions, events

![Diagram showing the process from sensing device to computational device with arrows indicating the flow of information](image)
Have we reached humans?

... not yet

- computer vision is still no match for human perception
- but catching up, particularly in certain areas
Computer vision and Applications
Fingerprint biometrics
Augmentation with 3D computer graphics
3D object prototyping
Computer vision and Applications

- New features detector/descriptors
- CV leverages machine learning

1990

EosSystems
brick stream
2d3 sensing
digitalPersona.
Autostich
Nikon
TAAZ
Photosynth

2000

2010
Face detection

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 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

1. Upload your photo
2. Apply some makeup
3. Choose a hairstyle

Photometria
Panoramic Photography

![AutoStitch](image1)

![Panorama](image2)

5580 x 3040

Cloudburst Research

HumanEyes

kolor
3D modeling of landmarks
Computer vision and Applications

- Large scale image matching
- Efficient SLAM/SFM
- Better clouds 😊
- More bandwidth
- Increase computational power
Image search engines
Visual search and landmarks recognition

Google Goggles
Visual search and landmarks recognition
Augmented reality
Motion sensing and gesture recognition
Mobileye: Vision systems in high-end BMW, GM, Volvo models

Source: A. Shashua, S. Seitz
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
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

3D Reconstruction

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

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
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Rusinkiewic et al., 02
Nistér, 04
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- Object detection
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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
43
Current state of computer vision

2D Recognition

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2D Recognition
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- Target tracking
- Activity recognition

Perceiving the World in 3D!
Visual processing in the brain

where pathway
(dorsal stream)

what pathway
(ventral stream)
Visual processing in the brain

where pathway
(dorsal stream)

what pathway
(ventral stream)

Pre-frontal
cortex

V1
1. Geometry
   - How to extract 3d information?
   - Which cues are useful?
   - What are the mathematical tools?

2. Semantics
Camera systems

Establish a mapping from 3D to 2D
How to calibrate a camera

Estimate camera parameters such as 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
Mathematical tools

Epipolar geometry

Tomasi & Kanade (1993)

Photoconsistency
Structure from motion

Courtesy of Exford Visual Geometry Group
3D Models

Scanning Michelangelo’s “The David”

- The Digital Michelangelo Project
- 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 recognize what humans are doing?
Object recognition and categorization

- Building
- Pedestrians crossing street
- Downtown Chicago
- Clock
- Person
- Car
Classification:
Is this an forest?

No!
Classification:
Does this image contain a building? [yes/no]

Yes!
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

Building
45 degree
10 meters away

Person, back

Car, side view,
3 meters away
Challenges: viewpoint variation
Challenges: illumination

image credit: J. Koenderink
Challenges: scale
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 |
Activity understanding
Activity understanding

queuing

talking
CS 231A course overview

1. Geometry
2. Semantics

Joint recovery of geometry and semantics!
Joint reconstruction and recognition

Input images
Joint reconstruction and recognition

Input images
“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

<table>
<thead>
<tr>
<th>Lecture</th>
<th>Topic</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Introduction</td>
</tr>
<tr>
<td>2</td>
<td>Camera models</td>
</tr>
<tr>
<td>3</td>
<td>Camera calibration</td>
</tr>
<tr>
<td>4</td>
<td>Single view metrology</td>
</tr>
<tr>
<td>5</td>
<td>Epipolar geometry</td>
</tr>
<tr>
<td>6</td>
<td>Multi-view geometry</td>
</tr>
<tr>
<td>7</td>
<td>Structure from motion/ SLAM</td>
</tr>
<tr>
<td>8</td>
<td>Volumetric stereo</td>
</tr>
<tr>
<td>9</td>
<td>Fitting and Matching</td>
</tr>
<tr>
<td>10</td>
<td>Detector and Descriptors</td>
</tr>
<tr>
<td>11</td>
<td>Introduction to Recognition; Object classification I</td>
</tr>
<tr>
<td>12</td>
<td>Object classification II</td>
</tr>
<tr>
<td>13</td>
<td>2D Object detection</td>
</tr>
<tr>
<td>14</td>
<td>3D Object recognition</td>
</tr>
<tr>
<td>15</td>
<td>Scene understanding &amp; segmentation</td>
</tr>
<tr>
<td>16</td>
<td>3D Scene understanding</td>
</tr>
</tbody>
</table>

### Timeline

- **January:**
  - Introduction
  - Camera models
  - Camera calibration
  - Single view metrology
  - Epipolar geometry
  - Multi-view geometry
  - Structure from motion/ SLAM
  - Volumetric stereo

- **February:**
  - Fitting and Matching
  - Detector and Descriptors
  - Introduction to Recognition; Object classification I
  - Object classification II

- **March:**
  - 2D Object detection
  - 3D Object recognition
  - Scene understanding & segmentation
  - 3D Scene understanding

- **Proposal due:**
  - Project presentations
CS231

Introduction to Computer Vision

Next lecture: Camera systems