CS 4476-B: Computer Vision

Instructor: James Hays
TAs: Ben Wilson (head TA), Bharat Mamidibathula, Gunhyun Park, Jonathan Leo, Otis Smith, Pranav Khorana, Sukriti Bhardwaj, Tony Zhang, Xueqing Li, Yash Kothari, Yoonwoo Kim

Image by kirkh.deviantart.com
Today’s Class

• Covid safety
• Who am I?
• What is Computer Vision?
• Specifics of this course
• Geometry of Image Formation
• Questions
New reported cases

300,000 cases

200,000

100,000


7-day average

New cases

Tests

Hospitalized

Deaths

These are days with a reporting anomaly. Read more [here](#).
ON CAMPUS
FALL 2021

Some Facts for Students
By Deven R. Desai, Scheller College
Layered Protection is the strongest protection

• Getting vaccinated is vital!
• Masking protects everyone!
• Getting tested weekly helps keep GA Tech open!
• Doing all three is the highest level of protection for you and the GA Tech community.
• Now, let’s dig in a bit.
Delta Is Different

The Delta Variant “is about a thousand times more infectious than the original strains of the virus”

Céline Gounder, a clinical assistant professor of medicine and infectious disease at NYU’s Grossman School of Medicine,
STATNews
"We know that the vaccines work," Kemp said. [Fox5-Atlanta](https://www.fox5atlanta.com/news/getting-vaccinated-is-vital"

“My family, myself, and other state leaders have all rolled up their sleeves and gotten their shot,” Kemp tweeted. “I encourage all Georgians who have concerns or questions to talk to a medical provider and get vaccinated as quickly as possible.” [U.S. News](https://www.usnews.com/news/u-s-news)
Getting vaccinated is vital!

Myth - Vaccination means no illness.

Reality: Vaccination prevents severe illness and reduces death.

Example: Provincetown outbreak - Of at least 965 positive cases that were traced to heavily vaccinated Provincetown, where around 60,000 people had gathered for the holiday weekend, not a single death was reported and just seven people were hospitalized. NY Times
Getting vaccinated is vital!

Vaccinated versus Unvaccinated outcomes

- **Total number of COVID patients at Houston Medical Center and Perry Hospital**

  - **102 Hospitalized**
    - 8 Vaccinated
    - 94 Unvaccinated
  - **28 in the ICU**
    - 3 Vaccinated
    - 25 Unvaccinated
  - **13 on Ventilators**
    - 13 Unvaccinated

**COVID Hospitalizations**
August 16, 2021
Vaccination Protects Others and Reduces the Chance of Spreading Covid.

A recent study has shown that those who are fully vaccinated may carry the virus, and therefore be contagious, for fewer days than their unvaccinated counterparts. That suggests an even bigger overall difference in transmission between places with high and low vaccination rates. -- NY Times

In short: When you are vaccinated, you ensure that you are less likely to carry Covid to your family, friends, and those you love.
Masking protects everyone!

Q: WHY WEAR A MASK? AFTER ALL, IT’S NOT REQUIRED.

A: FACTS AND LOGIC.
Masking protects everyone! Facts

Exposure Matters: “The way to think about your exposure is dose times time. So your dose is a reflection of how much virus the person is carrying, but it’s also diluted in the air around them.”

Céline Gounder, a clinical assistant professor of medicine and infectious disease at NYU’s Grossman School of Medicine, STATNews

Breathing – “Airborne transmission arises through the inhalation of aerosol droplets exhaled by an infected person and is now thought to be the primary transmission route of COVID-19.” Bazant and Bush, PNAS, 2021
1. You breathe through your nose and mouth.
2. “There's a lot of virus in my nose and throat, therefore, there's a lot of virus in the air that I cough out or breathe out.” Michael Marks, associate professor at the London School of Hygiene & Tropical Medicine, Gothamist.
3. To work, your mask **MUST** cover your NOSE and MOUTH.
Masking Protects You Inside a Room

Facts – Nerd out GA Tech Style!

“Our theoretical model quantifies the extent to which transmission risk is reduced in large rooms with high air exchange rates, increased for more vigorous respiratory activities, and dramatically reduced by the use of face masks. Consideration of a number of outbreaks yields self-consistent estimates for the infectiousness of the new coronavirus.” – Bazant and Bush, PNAS, 2021

Huh?

In short, the more vaccinated people in a room who are also masked, the lower the exposure risk.
1. The idea that you can not be masked while inside rested on everyone being vaccinated.

2. Problem: One cannot know whether everyone in the room is vaccinated.

3. Solution: When one cannot know the status of other folks, wearing your mask is the best move to
   A. Decrease the chance of becoming ill and especially severely ill (as in hospitalized)
   B. Decrease the chance you might spread Covid to family, friends, and loved ones.
Conclusion

GA Tech continues to work to protect our community, but we all need to do our part. The simplest, strongest things you can do to protect our community, you, and our ability to stay open are

1. Get vaccinated,
2. Wear a mask, and
3. Get tested weekly.
U.S. COVID-19 vaccines by age

This chart shows the percentage of the U.S. population that has received a vaccination, broken down by age.

<table>
<thead>
<tr>
<th>Age</th>
<th>Fully vaccinated</th>
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<tbody>
<tr>
<td>&lt;18</td>
<td>13.0%</td>
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<tr>
<td>18 - 24</td>
<td>46.5%</td>
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<tr>
<td>25 - 39</td>
<td>50.8%</td>
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<tr>
<td>40 - 49</td>
<td>60.0%</td>
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<tr>
<td>50 - 64</td>
<td>69.2%</td>
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<tr>
<td>65 - 74</td>
<td>83.1%</td>
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<tr>
<td>75+</td>
<td>78.7%</td>
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Percentage of the U.S. population vaccinated
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<th>City, State</th>
<th>Ranking in Computer Science</th>
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For all of these reasons, in-person attendance is **discouraged** unless you are

- Masking
- Vaccinated
- Symptom free

Even doing all of those things, there is risk, so I am happy for students to attend lecture through Bluejeans
BlueJeans Meetings Currently In Progress

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<th>Name</th>
<th>Description</th>
<th>Ends At</th>
<th>Link</th>
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Recorded BlueJeans Meetings

Note: Recording links will not work until the file has been fully processed.

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Office hours poll
How would you prefer to attend TA office hours?

- [ ] In person, indoors
- [ ] In person, outdoors
- [ ] via Bluejeans

You have not yet voted.

Revoting is allowed. Select your vote and click submit to register your vote.

Your name will not be visible to anyone.

Office hours poll closes in 2 day(s)

A total of 0 votes in 0 hours

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<th>0 (0% of users)</th>
<th>In person, indoors</th>
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Geometry of Image Formation
Questions
What type of stuff do I work on?
Scene Flow from Point Clouds with or without Learning

Jhony Kaesemodel Pontes, James Hays, Simon Lucey

https://jhonykaesemodel.com/publication/sceneflow-3dv2020/
Understanding Lidar

3D for Free: Crossmodal Transfer Learning using HD Maps
Benjamin Wilson, Zsolt Kira, James Hays
Exploring new data sources

ContactPose: A Dataset of Grasps with Object Contact and Hand Pose

Samarth Brahmbhatt, Chengcheng Tang, Christopher D. Twigg, Charles C. Kemp, James Hays

ECCV 2020
Exploring new data sources

LIDAR
- 2 roof-mounted LiDAR sensors
- Overlapping 40° vertical field of view
- Range of 200m
- On average, our LiDAR sensors produce a point cloud with ~107,000 points at 10 Hz

Cameras
- Seven high-resolution ring cameras (1920 x 1200) recording at 30 Hz with a combined 360° field of view
- Two front-view facing stereo cameras (2056 x 2464) sampled at 5 Hz

Localization
We use a city-specific coordinate system for vehicle localization. We include 6-DOF localization for each timestamp, from a combination of GPS-based and sensor-based localization methods.

Calibration
Sensor measurements for each driving session are stored in "logs." For each log, we provide intrinsic and extrinsic calibration data for LiDAR and all nine cameras.

https://www.argoverse.org/
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What is Computer Vision?

Derogatory summary of computer vision: Machine learning applied to visual data
Computer Vision

• Automatic understanding of images and video
  1. Computing properties of the 3D world from visual data
     \textit{(measurement)}

Slide credit: Kristen Grauman
1. Vision for measurement

Real-time stereo

Structure from motion

Tracking

Wang et al.

Snavely et al.

Demirdjian et al.

Slide credit: Kristen Grauman
Computer Vision

• Automatic understanding of images and video
  1. Computing properties of the 3D world from visual data
     \textit{(measurement)}
  2. Algorithms and representations to allow a machine to recognize objects, people, scenes, and activities.
     \textit{(perception and interpretation)}
2. Vision for perception, interpretation

Slide credit: Kristen Grauman
Computer Vision

• Automatic understanding of images and video
  1. Computing properties of the 3D world from visual data (*measurement*)
  2. Algorithms and representations to allow a machine to recognize objects, people, scenes, and activities. (*perception and interpretation*)
  3. Algorithms to mine, search, and interact with visual data (*search and organization*)

Slide credit: Kristen Grauman
3. Visual search, organization

Query → Image or video archives → Relevant content

Slide credit: Kristen Grauman
Related disciplines

- Artificial intelligence
- Machine learning
- Cognitive science
- Graphics
- Image processing
- Algorithms

Computer vision

Slide credit: Kristen Grauman
Vision and graphics

Inverse problems: analysis and synthesis.

Slide credit: Kristen Grauman
What humans see

Slide credit: Larry Zitnick
What computers see
What do humans see?

Slide credit: Larry Zitnick
Vision is really hard

- Vision is an amazing feat of natural intelligence
  - Visual cortex occupies about 50% of Macaque brain
  - One third of human brain devoted to vision (more than anything else)

Is that a queen or a bishop?
Ridiculously brief history of computer vision

- 1966: Minsky assigns computer vision as an undergrad summer project
- 1960’s: interpretation of synthetic worlds
- 1970’s: some progress on interpreting selected images
- 1980’s: ANNs come and go; shift toward geometry and increased mathematical rigor
- 1990’s: face recognition; statistical analysis in vogue
- 2000’s: broader recognition; large annotated datasets available; video processing starts
- 2010’s: Deep learning with ConvNets
- 2020’s: Widespread autonomous vehicles?
- 2030’s: robot uprising?
How vision is used now

- Examples of real-world applications
Optical character recognition (OCR)

Technology to convert scanned docs to text
• If you have a scanner, it probably came with OCR software

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

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

- Digital cameras detect faces
Vision in space

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.

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

https://www.inaturalist.org/pages/computer_vision_demo
Skydio

https://www.skydio.com/
Given the camera feeds, we compute several important outputs on

https://www.youtube.com/watch?v=BVRMh9NO9Cs
State of the art today?

With enough training data, computer vision nearly matches human vision at most recognition tasks.

Deep learning has been an enormous disruption to the field. More and more techniques are being “deepified”.
Wired 100
Who's Shaping the Digital World?
73. DJ Khaled

*Snapchat icon; DJ and producer*

Louisiana-born Khaled Mohamed Khaled, aka DJ Khaled, cut his musical chops in the early 00s as a host for Miami urban music radio WEDR. He proceeded to build a solid if not dazzling career as a mixtape DJ and music producer (he founded his label We The Best Music Group in 2008, and was appointed president of Def Jam South in 2009).
69. Geoffrey Hinton

Psychologist, computer scientist; researcher, Google Toronto

British-born Hinton has been dubbed the "godfather of deep learning". The Cambridge-educated cognitive psychologist and computer scientist started being an ardent believer in the potential of neural networks and deep learning in the 80s, when those technologies enjoyed little support in the wider AI community.

But he soldiered on: in 2004, with support from the Canadian Institute for Advanced Research, he launched a University of Toronto programme in neural computation and adaptive perception, where, with a group of researchers, he carried on investigating how to create computers that could behave like brains.

Hinton’s work – in particular his algorithms that train multilayered neural networks – caught the attention of tech giants in Silicon Valley, which realised how deep learning could be applied to voice recognition, predictive search and machine vision.

The spike in interest prompted him to launch a free course on neural networks on e-learning platform Coursera in 2012. Today, 68-year-old Hinton is chair of machine learning at the University of Toronto and moonlights at Google, where he has been using deep learning to help build internet tools since 2013.
63. Yann LeCun

Director of AI research, Facebook, Menlo Park

LeCun is a leading expert in deep learning and heads up what, for Facebook, could be a hugely significant source of revenue: understanding its user’s intentions.

62. Richard Branson

Founder, Virgin Group, London

Branson saw his personal fortune grow £550 million when Alaska Air bought Virgin America for $2.6 billion in April. He is pressing on with civilian space travel with Virgin Galactic.

61. Taylor Swift

Entertainer, Los Angeles
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Grading

• 80% programming projects (5 total)
• 20% Quizzes or Problem sets
Scope of CS 4476

Image Processing
Geometric Reasoning
Recognition
Deep Learning

Computer Vision

Robotics
Human Computer Interaction
Medical Imaging
Neuroscience
Optics
Computational Photography
Graphics
Machine Learning
Textbook


© 2020 Richard Szeliski, Facebook

http://szeliski.org/Book/
Prerequisites

• **Linear algebra**, basic calculus, and probability
• Experience with image processing will help but is not necessary
• Experience with Python or Python-like languages will help
Projects

• Image Filtering and Hybrid Images
• Local Feature Matching
• Camera Calibration and Fundamental Matrix Estimation with RANSAC
• Image Classification with Deep Learning
• Semantic Segmentation with Deep Learning
Proj1: Image Filtering and Hybrid Images

• Implement image filtering to separate high and low frequencies
• Combine high frequencies and low frequencies from different images to create an image with scale-dependent interpretation
Proj2: Local Feature Matching

• Implement interest point detector, SIFT-like local feature descriptor, and simple matching algorithm.
Course Syllabus (tentative)

http://www.cc.gatech.edu/~hays/compvision
Your work must be your own. We’ll look for cheating. Don’t talk at the level of code with other students.
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The Geometry of Image Formation

Mapping between image and world coordinates
  – Pinhole camera model
  – Projective geometry
    • Vanishing points and lines
  – Projection matrix
What do you need to make a camera from scratch?
Let’s design a camera
  – Idea 1: put a piece of film in front of an object
  – Do we get a reasonable image?

Slide source: Seitz
Pinhole camera

Idea 2: add a barrier to block off most of the rays
  – This reduces blurring
  – The opening known as the aperture

Slide source: Seitz
Pinhole camera

\[ f = \text{focal length} \]
\[ c = \text{center of the camera} \]
Camera obscura: the pre-camera

- Known during classical period in China and Greece (e.g. Mo-Ti, China, 470BC to 390BC)
Camera Obscurea used for Tracing

Lens Based Camera Obscurea, 1568
Accidental Pinhole and Pinspeck Cameras
Revealing the scene outside the picture.
Antonio Torralba, William T. Freeman
Accidental Cameras

a) Input (occluder present)

b) Reference (occluder absent)

c) Difference image (b-a)

d) Crop upside down

e) True view
First Photograph

Oldest surviving photograph
– Took 8 hours on pewter plate

Joseph Niepce, 1826

Photograph of the first photograph

Stored at UT Austin

Niepce later teamed up with Daguerre, who eventually created Daguerrotypes
“Louis Daguerre—the inventor of daguerreotype—shot what is not only the world's oldest photograph of Paris, but also the first photo with humans. The 10-minute long exposure was taken in 1839 in Place de la République and it's just possible to make out two blurry figures in the left-hand corner.”

Source
Camera and World Geometry

How tall is this woman?
How high is the camera?
What is the camera rotation?
What is the focal length of the camera?

Which ball is closer?
Dimensionality Reduction Machine (3D to 2D)

3D world  

2D image

Point of observation

Figures © Stephen E. Palmer, 2002
Projection can be tricky...
Projection can be tricky...
Projective Geometry

What is lost?

• Length

Who is taller?
Which is closer?
Length and area are not preserved
Projective Geometry

What is lost?

• Length
• Angles
Projective Geometry

What is preserved?

- Straight lines are still straight
Vanishing points and lines

Parallel lines in the world intersect in the image at a “vanishing point”
Vanishing points and lines

Vanishing Line

Vanishing Point

Vanishing Point
Vanishing points and lines

Vanishing point

Vertical vanishing point (at infinity)

Vanishing point

Slide from Efros, Photo from Criminisi
• Project 1 will be out soon
• Read Szeliski 2.1, especially 2.1.4
• Image projection
• Filtering
Projection: world coordinates $\rightarrow$ image coordinates

If $X = 2$, $Y = 3$, $Z = 5$, and $f = 2$
What are $U$ and $V$?

$$x = \begin{bmatrix} u' \\ v' \end{bmatrix}$$

$$u' = -x \frac{f}{z}$$
$$v' = -y \frac{f}{z}$$

$$u' = -2 \times \frac{2}{5}$$
$$v' = -3 \times \frac{2}{5}$$