CSC 477/577

Fall 2025

Introduction to Computer Vision

Online course

Description of the Course

Computer vision is about building systems that see. Such a system would be able to take images as input and output a representation of what is in the world in front of the camera. We are all familiar with this process as it happens whenever we look around. However, putting this capability into a machine has proven to be very difficult and is the topic of much current research. In this course we will study the basic approaches that have been developed to analyze image data in an attempt to solve this problem, and their applications to other related areas such as computer graphics and image databases.

This course should be considered by students interested in computer vision, image processing, image databases, computer graphics, artificial intelligence, and cognitive science.

Topics: Image formation including spectral and geometric camera models and calibration, physics-based vision, color, linear filtering, edge detection, texture, segmentation and grouping, local features (e.g., SIFT), recognition using pose consistency, multiple view geometry and stereo, and recognition using templates and classifiers (i.e., machine learning).

Course Prerequisites or Co-requisites

CSC 252, CSC 335, CSC 345, CSC 352, or equivalent preparation in algorithms, data structures, and programming. MATH 215 or MATH 313 or equivalent math background (basic calculus and linear algebra).

Instructor and Contact Information

Instructor:

Kobus Barnard, kobus@arizona.edu

Group office hours (optional): Likely Wednesdays, time to be decided by on-line poll.

Individual student meeting times (zoom): By appointment

Teaching assistant:

Kapilan Balagobalan, kapilanbgp@arizona.edu

Office hours: Tuesdays and Fridays, 10:00 AM to 11 AM in GS 931.

Web information:

We will use D2L and Piazza in contribution mode.

Course Format and Teaching Methods

Meeting Times: This is a fully on-line class. Some **optional** group discussion sessions may be arranged. This will typically be recorded.

Students will be responsible for monitoring the email they use in conjunction with D2L (usually NETID@arizon.edu) and D2L (especially announcements, podcasts, assignments, lecture notes, and exams).

Obtaining Help

- **Academic advising (undergrads):** If you have questions about your academic progress this semester, or your chosen degree program, consider contacting your department's academic advisor(s). Your academic advisor and the Advising Resource Center can guide you toward university resources to help you succeed. **Computer Science major students** are encouraged to email advising@cs.arizona.edu for academic advising related questions.
- **Advising (grad students):** If you have questions about your academic progress this semester, or your chosen degree program, consider contacting your graduate program coordinator and faculty advisor. Your program coordinator, faculty advisor, and the Graduate Center can guide you toward university resources to help you succeed. **Computer Science students** are encouraged to email gradadvising@cs.arizona.edu for advising related questions.
- **CS Tutor Center (undergrads):** The Department of Computer Science offers FREE tutoring for students enrolled in CSC courses. You can view tutor schedules and sign up for tutoring sessions by visiting our CS Tutoring Page.
- **Life challenges:** If you are experiencing unexpected barriers to your success in your courses, please note the Dean of Students Office is a central support resource for all students and may be helpful. The Dean of Students Office can be reached at 520-621-2057 or DOS-deanofstudents@email.arizona.edu.
- **Physical and mental-health challenges**: If you are facing physical or mental health challenges this semester, please note that Campus Health provides quality medical and mental health care. For medical appointments, call (520-621-9202. For After Hours care, call (520) 570-7898. For the Counseling & Psych Services (CAPS) 24/7 hotline, call (520) 621-3334.
- **UA Ombuds**: The UA Ombuds Office (https://ombuds.arizona.edu/) helps with a wide variety of issues, concerns, questions, conflicts, and challenges. The primary mission of the Ombuds Program is to assist individuals in resolving conflict, facilitating communication, and assisting the University by surfacing issues and providing feedback on emerging or systemic concerns. Communications with the Ombuds Committee are informal and off-the-record. The Ombuds Committee is governed by the following standards: (1) Confidentiality; (2) Impartiality: (3) Informality; and (4) Independence.

Class Recordings:

- For lecture recordings, which are used at the discretion of the instructor, students must access content in D2L only. Students may not modify content or re-use content for any purpose other than personal educational reasons. All recordings are subject to government and university regulations. Therefore, students accessing unauthorized recordings or using them in a manner inconsistent with U. Arizona values and educational policies (Code of Academic Integrity and the Student Code of Conduct) are also subject to civil action.

Course Objectives

The broad objectives of this course are to introduce modern computer vision ideas with an emphasis on fundamental understanding, and mathematical and experimental methods which are applicable to a number of research problems (not just computer vision). Assignments and

exams will develop and evaluate both conceptual understanding and applying the methodology to practical problems.

Topics include spectral image formation, geometric image formation, physics-based vision, linear filtering, edge detection, convolutional neural networks, multiple view geometry, segmentation, tracking, and recognition.

Expected Learning Outcomes

Learning outcomes will be measured through comprehensive assignments and exams.

Concepts and methods related to the course topics listed above that will be related to assigned work and that CS 477 and CS 577 students are expected to learn include:

- computer vision is a fundamentally an under constrained problem, and general strategies for dealing with this
- how image formation (both spectral, i.e., color, and geometric, i.e., perspective) can be modeled mathematically and how those models can be applied;
- non-homogenous least squares
- how shading provides depth information
- how illumination and surface reflectance is intertwined in image formation, and how they can be decoupled using assumptions about the world (computational color constancy);
- how linear filtering can be applied to recognize patterns, detect edges, and provide texture representations and how these representations can be learned using convolutional neural networks.
- how segmentation can be achieved using clustering
- how grouping can be achieved by fitting models
- how local patterns can be defined as well as learned for effective matching of features between images;
- how geometric constraints can improve such matching;
- how multiple views can be used to infer depth (stereo);
- why (object) recognition is difficult and how modern machine learning has been leveraged for substantial gains in performance.
- homogeneous least squares
- synthetic and real data computational experiments
- random sample consensus (RANSAC)
- testing on held out data (e.g., cross validation)

Additional concepts and methods that CS 577 students (only) are expected to learn include:

- constrained non-homogenous least squares (graduate students only)
- decomposing camera matrices into extrinsic and intrinsic components
- back projection of light rays through image pixels
- using least squares estimates as a starting point for non-convex optimizations
- edge detection linking
- using convolution for OCR
- Harris corner detection
- image stitching implementation
- estimating the fundamental matrix between two cameras from images

Absence and Class Participation Policy

The UA's policy concerning Class Attendance, Participation, and Administrative Drops is available at http://catalog.arizona.edu/policy/class-attendance-participation-and-administrative-drop
The UA policy regarding absences for any sincerely held religious belief, observance or practice will be accommodated where reasonable: http://policy.arizona.edu/human-resources/religious-accommodation-policy.

Absences pre-approved by the UA Dean of Students (or dean's designee) will be honored. See https://deanofstudents.arizona.edu/absences—

As this is an on-line class, attendance will not be formally recorded. However, students should be aware that instructors have access to D2L tracking of access to materials.

Illnesses and Emergencies

- If you feel sick, or may have been in contact with someone who is infectious, stay home. Except for seeking medical care, avoid contact with others and do not travel.
- Notify your instructor(s) if you will be missing up to one week of course meetings and/or assignment deadlines.
- If you must miss the equivalent of more than one week of class and have an emergency, the Dean of Students is the proper office to contact (DOS-deanofstudents@email.arizona.edu). The Dean of Students considers the following as qualified emergencies: the birth of a child, mental health hospitalization, domestic violence matter, house fire, hospitalization for physical health (concussion/emergency surgery/coma/COVID-19 complications/ICU), death of immediate family, Title IX matters, etc.
- Please understand that there is no guarantee of an extension when you are absent from class and/or miss a deadline.

Makeup Policy for Students Who Register Late

In consultation with the instructor, students who register late can makeup for assignments that are past due with optional parts of subsequent assignments or alternative assignments. However, such students are still responsible for the intellectual content of the past due assignments which can be relevant for subsequent assignments as well as exams.

Course Communications

Online communication will be conducted using D2L, Piazza, and official UA e-mail addresses.

Required Texts or Readings

This class largely adopts material from Computer Vision: A Modern Approach, by Forsyth and Ponce. This book is recommended but not required, as all needed material for this course will be provided within lectures (which will be posted on-line via D2L) and assignments (also posted via D2L). The recommended text is no-nonsense book that offers significant insight into the topic. However, many students will find it the advanced level of presentation difficult and not so useful for an introductory foray.

Equipment and software requirements

All students will need access to a computer with the following software: web browser, Adobe Acrobat, at least one programming environment such as (*) Matlab, Python, C/C++, and Latex for creating reports in PDF format. If using Latex is not feasible for you, please contact the instructor regarding substituting Microsoft word (**).

(*) Matlab will be required for the first assignment. Students wishing to use Matlab on a personal

computer can download and install it through the U. Arizona web pages (http://softwarelicense.arizona.edu/mathworks-matlab). Python and C/C++ are both freely available for all common computer platforms.

(**) Graduate students will have to make an especially good case for not using Latex.

Required Extracurricular Activities

None.

Assignments and Examinations: Schedule/Due Dates

There will be a maximum of 13 required weekly assignments, one midterm, and a final, as detailed in the table below. Assignments will be weighted roughly equally. For maximum flexibility, I will post assignments soon after we have covered needed material. Exams will emphasize recent material, but some review and/or synthesis questions should be expected. Due dates are nominally midnight, with grace until 8am the following morning. Assignments will be graded within 4-5 days after being due as detailed below. (If assignment due dates need to adjusted, targets for returning them will be shifted by the same amount).

	Description	Due	Graded
HW1	Vision programming	09/05	09/10
HW2	Camera spectral calibration	09/12	09/17
HW3	Line fitting, perspective	09/19	09/25
HW4	Geometric camera calibration (part one)	09/26	10/02
HW5	Geometric camera calibration (part two)	10/03	10/09
HW6	Photometric stereo	10/10	10/16
HW7	Color constancy	10/17	10/23
Midterm	Up to and including material covered on 10/18: Mostly image formation (spectral and geometric), light interacting with matter, basic shading, photometric stereo, color, and color constancy	10/24	10/30
HW8	Linear filters, edge point detection	10/30	11/06
HW9	Localized feature matching, texture	11/07	11/13
HW10	Feature learning using CNN autoencoder	11/14	11/20
HW11	Segmentation and clustering; texture (grads)	11/21	11/27
HW12	RANSAC and homography	12/01	12/06
HW13	Stereo; fundamental matrix (grads)	12/08	12/12
Final	All course material, emphasis on last half	12/12	12/15

Midterm examination

The midterm exam will be an open-notes take-home exam. It will span 24 hours starting at 8AM on October 24. It will be designed to approximate an open-notes two hour in-class exam. However, if you write an exam with a time limit, then you give up at sensible points in time. Also, you likely be more prepared. Hence it is likely that some students will spend more than two hours on the exam.

Final Examination

Similar to the midterm, the final examination will be an open-notes take-home exam. It will span 24 hours starting at 8AM on Friday December 12. It will be designed to approximate an open-notes two hour in-class exam. However, if you write an exam with a time limit, then you give up at sensible points in time. Also, you likely be more prepared. Hence it is likely that some students will spend more than two hours on the exam.

The final will cover the entire course, with post midterm topics weighted more heavily. **At the discretion of the instructor, the final examination may be optional, in which case the grade of the midterm exam will be used for the final.**

Grading Scale and Policies

Assignment grading. Assignment deliverables will generally consist of two parts: 1) all code developed in response to the assignments; and 2) a report, in PDF format explaining what has done, what the results were, commenting on the results, and answering any questions posed in the assignment. The instructor will provide a document that details the expectations of the report. Assignments will be graded with respect to four criteria: 1) reproducibility (the ease by which the grader can run the code to get the reported results); 2) completeness (the extent that the work done and sufficient effort was applied); 3) correctness; and 4) the exposition (clarity, insight, and conformance to the guidelines provided). The weight of these four criteria will vary among the assignments, but students are advised that the fourth criteria will generally have substantive weight.

Assigned reading and preparatory exercises. In anticipation of a wide range of familiarity with math concepts from the required math courses, reading and/or non-graded short exercises will be assigned in advance of lectures that need the material. When possible, such assigned work will be packaged up with regular (graded) assigned work.

Non-graded required problems. Assignments may include problems that do not need to be handed in, but whose material students are responsible for. Generally, solutions will be provided for such problems.

Graduate students will be responsible for extra parts on assignments and graduate specific exam questions. In short, they will be expected to demonstrate a deeper understanding of the material, as well as explore additional aspects of it. In addition, the exposition part of the assignment will be graded more strictly for graduate students.

Bonus/extra problems. Assignments might include problems that explore the material further that will be considered for modest extra credit. Undergraduates generally will be able to declare graduate problems for extra credit. In some cases, extra problems can be substituted for regular problems, but students are responsible for the content of regular problems. Each assignment grade will be capped at 120%, and the overall assignment grade will be capped at 75/70.

Undergraduates who want to do extra (grad) parts of assignments can receive modest extra credit. These caps will also apply to graduate student if bonus marks are available to them.

Grading breakdown (see above table for more detail).

Assignments:	70%
Midterm:	10%
Final Exam:	20%

90% guarantees an A, 80% guarantees a B, 70% a C, and 60% a D.

Department of Computer Science Grading Policy:

1. Instructors will explicitly promise when every assignment and exam will be graded and returned to students. These promised dates will appear in the syllabus, associated with the corresponding due dates and exam dates.
2. Graded homework will be returned before the next homework is due.
3. Exams will be returned "promptly", as defined by the instructor (and as promised in the syllabus).
4. Grading delays beyond promised return-by dates will be announced as soon as possible with an explanation for the delay.

Requests for incomplete (I) or withdrawal (W) must be made in accordance with University policies, which are available at https://catalog.arizona.edu/policy/courses-credit/grading/grading-system.

Dispute of Grade Policy. Students wishing to dispute a grade on an assignment or exam should contact the instructor within two weeks of the date that the assignment or exam was returned to the students.

Honors credit:

By UA Honors College policy, undergraduate honors credit is not available for co-convened courses, such as this one. Honors students who want alternative experience and/or credit should register for the graduate version of the course (CS 577).

Scheduled Topics/Activities target release dates

Date	Activities and topics
08/27	Lecture 1: Introduction
08/29	Lecture 2: Image formation (spectral)
08/29	Posting of HW1 (Vision Programming)
09/03	Lecture 3: Non-homogeneous least squares, and spectral camera calibration
09/05	Lecture 4: Homogenous least squares and line fitting; perspective projection
09/05	HW1 due, posting of HW2 (spectral camera calibration)
09/10	Lecture 5: Image formation (geometric camera model)
09/12	Lecture 6: Image formation (geometric camera calibration problem setup)
09/12	HW2 Due, posting of HW3 (line fitting, perspective)
09/17	Lecture 7: Geometric camera calibration inference, intrinsic/extrinsic
09/19	Lecture 8: Ambiguity in interpreting images, light interacting with the world
09/19	HW3 due, Posting of HW4 (Geometric camera calibration, part one)
09/24	Lecture 9: Shape from shading
09/26	Lecture 10: Photometric stereo
09/26	HW4 due, posting of HW5 (Geometric camera calibration, part two)
10/01	Lecture 11: Color and color constancy
10/03	Lecture 12: Color constancy continued
10/03	HW5 due, posting of HW6 (photometric stereo)
10/08	Lecture 13: Linear filters, correlation and convolution
10/10	Lecture 14: Filtering for finding edges, edge point linking
10/10	HW6 due, HW7 posted (color constancy)
10/15	Lecture 15A: Image representation and bases
10/17	Lecture 15B: SIFT.
10/17	HW7 due, next HW due in two weeks to provide space for midterm prep.
10/22	Lecture 16: Review, big picture
10/24	Midterm (may be take-home)
10/24	HW8 posted (filtering, edge point detection)
10/29	Lecture 17: Texture (textons, HOG)
10/31	Lecture 18: Neural network basics
10/31	HW8 due, HW9 posted (Localized feature matching, texture)
11/05	Lecture 19: Convolutional neural networks

11/07	Lecture 20: Grouping
11/07	HW9 due, HW10 posted (Feature learning using CNN autoencoder)
11/12	Lecture 21: Grouping by clustering
11/14	Lecture 22: Grouping by fitting a model, RANSAC
11/14	HW10 due, HW11 posted (Segmentation and clustering; texture (grads))
11/19	Lecture 23: Homography and matching
11/21	Lecture 24: Multiple view geometry
11/21	HW11 due, HW12 posted (RANSAC and homography)
11/25	Lecture 25: More on the fundamental matrix
11/27	Thanksgiving
12/01	HW12 due, HW13 posted (Stereo; fundamental matrix (grads))
12/01	Lecture 26: Stereo (note Monday posting due to TG)
12/03	Lecture 27: Structure from motion (Wednesday posting due to TG)
12/08	HW13 due
12/08	Lecture 28: TBD
12/10	Official last day of classes
12/11	Dead day (no exams or assignments due)
12/12	Final exam. 8:00AM-7:59AM next day (take-home, possibly optional)

Department of Computer Science Code of Conduct

The Department of Computer Science is committed to providing and maintaining a supportive educational environment for all. We strive to be welcoming and inclusive, respect privacy and confidentiality, behave respectfully and courteously, and practice intellectual honesty. Disruptive behaviors (such as physical or emotional harassment, dismissive attitudes, and abuse of department resources) will not be tolerated. The complete Code of Conduct is available on our department web site. We expect that you will adhere to this code, as well as the UA Student Code of Conduct, while you are a member of this class.

Classroom Behavior Policy

To foster a positive learning environment, students and instructors have a shared responsibility. We want a safe, welcoming, and inclusive environment where all of us feel comfortable with each other and where we can challenge ourselves to succeed. To that end, our focus is on the tasks at hand and not on extraneous activities (e.g., texting, chatting, reading a newspaper, making phone calls, web surfing, etc.).

Students are asked to refrain from disruptive conversations with people sitting around them during lecture. Students observed engaging in disruptive activity will be asked to cease this behavior. Those who continue to disrupt the class will be asked to leave lecture or discussion and may be reported to the Dean of Students.

Some learning styles are best served by using personal electronics, such as laptops and iPads. These devices can be distracting to other learners. Therefore, students who prefer to use electronic devices for note-taking during lecture should sit towards the back of the class, or an area of the classroom agreed upon between the instructor and students.

Threatening Behavior Policy

The UA Threatening Behavior by Students Policy prohibits threats of physical harm to any member of the University community, including to oneself. See http://policy.arizona.edu/education-and-student-affairs/threatening-behavior-students.

Accessibility and Accommodations

At the University of Arizona, we strive to make learning experiences as accessible as possible. If you anticipate or experience barriers based on disability or pregnancy, please contact the Disability Resource Center (520-621-3268, https://drc.arizona.edu/) to establish reasonable accommodations.

Code of Academic Integrity

Students are encouraged to share intellectual views and discuss freely the principles and applications of course materials. However, graded work/exercises must be the product of independent effort unless otherwise instructed. Students are expected to adhere to the UA Code of Academic Integrity as described in the UA General Catalog. See http://deanofstudents.arizona.edu/academic-integrity/students/academic-integrity.

Use of artificial intelligence (AI) tools. AI tools are not likely to be helpful in this course. However, if you do use such tools to generate text for your writeups, you must clearly indicate any text that you did not write yourself, and cite the tool you used and how you used (e.g., what prompts you provide a text generator). In addition, if you used AI tools to help you code more efficiently, then you must indicate that in your writeup as well. The instructor reserves the right to change this policy if it appears to interfere with learning goals.

Uploading material from this course to a website other than D2L (or the class piazza) is strictly prohibited and will be considered a violation of the course policy and a violation of the code of academic integrity. Obtaining material associated with this course (or previous offerings of this course) on a site other than D2L (or the class piazza), such as Chegg, Course Hero, etc. or accessing these sites during a quiz or exam is a violation of the code of academic integrity. Any student determined to have uploaded or accessed material in an unauthorized manner will be reported to the Dean of Students for a Code of Academic Integrity violation, with a recommended sanction of a failing grade in the course.

The University Libraries have some excellent tips for avoiding plagiarism, available at http://www.library.arizona.edu/help/tutorials/plagiarism/index.html.

Sharing solution keys with others (e.g., students who might take the class in a future term, or who are taking the class in a future term) is considered by the instructor to be a serious violation of academic integrity.

Selling class notes and/or other course materials to other students or to a third party for resale is not permitted without the instructor's express written consent. Violations to this and other course rules are subject to the Code of Academic Integrity and may result in course sanctions. Additionally, students who use D2L or UA e-mail to sell or buy these copyrighted materials are subject to Code of Conduct Violations for misuse of student e-mail addresses. This conduct may also constitute copyright infringement.

Nondiscrimination and Anti-harassment Policy

The University of Arizona is committed to creating and maintaining an environment free of discrimination. In support of this commitment, the University prohibits discrimination, including harassment and retaliation, based on a protected classification, including race, color, religion, sex, national origin, age, disability, veteran status, sexual orientation, gender identity, or genetic information. For more information, including how to report a concern, please see http://policy.arizona.edu/human-resources/nondiscrimination-and-anti-harassment-policy.

Our classroom is a place where everyone is encouraged to express well-formed opinions and their reasons for those opinions. We also want to create a tolerant and open environment where such opinions can be expressed without resorting to bullying or discrimination of others.

Additional Resources for Students

UA Academic policies and procedures are available at http://catalog.arizona.edu/policies

Visit the UArizona COVID-19 page for regular updates.

Campus Health
http://www.health.arizona.edu/
Campus Health provides quality medical and mental health care services through virtual and in-person care. Voluntary, free, and convenient COVID-19 testing is available for students on Main Campus. COVID-19 vaccine is available for all students at Campus Health.
Phone: 520-621-9202

Counseling and Psych Services (CAPS)
https://health.arizona.edu/counseling-psych-services
CAPS provides mental health care, including short-term counseling services.
Phone: 520-621-3334

The Dean of Students Office's Student Assistance Program
http://deanofstudents.arizona.edu/student-assistance/students/student-assistance
Student Assistance helps students manage crises, life traumas, and other barriers that impede success. The staff addresses the needs of students who experience issues related to social adjustment, academic challenges, psychological health, physical health, victimization, and relationship issues, through a variety of interventions, referrals, and follow up services.
Email: DOS-deanofstudents@email.arizona.edu
Phone: 520-621-7057

Survivor Advocacy Program
https://survivoradvocacy.arizona.edu/
The Survivor Advocacy Program provides confidential support and advocacy services to student survivors of sexual and gender-based violence. The Program can also advise students about relevant non-UA resources available within the local community for support.
Email: survivoradvocacy@email.arizona.edu
Phone: 520-621-5767

Campus Pantry

Any student who has difficulty affording groceries or accessing sufficient food to eat every day, or who lacks a safe and stable place to live and believes this may affect their performance in the course, is urged to contact the Dean of Students for support. In addition, the University of Arizona Campus Pantry is open for students to receive supplemental groceries at no cost. Please see their website at: *campuspantry.arizona.edu* for open times.

Preferred Names and Pronouns

This course affirms people of all gender expressions and gender identities. If you prefer to be called a different name than what is on the class roster, please let me know. Feel free to correct instructors on your preferred gender pronoun. If you have any questions or concerns, please do not hesitate to contact me directly in class or via email (instructor email). If you wish to change your preferred name or pronoun in the UAccess system, please use the following guidelines:

Preferred name: University of Arizona students may choose to identify themselves within the University community using a preferred first name that differs from their official/legal name. A student's preferred name will appear instead of the person's official/legal first name in select University-related systems and documents, provided that the name is not being used for the purpose of misrepresentation. Students are able to update their preferred names in UAccess.

Pronouns: Students may designate pronouns they use to identify themselves. Instructors and staff are encouraged to use pronouns for people that they use for themselves as a sign of respect and inclusion. Students are able to update and edit their pronouns in UAccess.

More information on updating your preferred name and pronouns is available on the Office of the Registrar site at https://www.registrar.arizona.edu/.

Safety on Campus and in the Classroom

For a list of emergency procedures for all types of incidents, please visit the website of the Critical Incident Response Team (CIRT): https://cirt.arizona.edu/case-emergency/overview

Also watch the video available at

https://arizona.sabacloud.com/Saba/Web_spf/NA7P1PRD161/app/me/ledetail;spf-url=common%2Flearningeventdetail%2Fcrtfy000000000003841

Confidentiality of Student Records

http://www.registrar.arizona.edu/ferpa

Land Acknowledgement Statement

We respectfully acknowledge the University of Arizona is on the land and territories of Indigenous peoples. Today, Arizona is home to 22 federally recognized tribes, with Tucson being home to the O'odham and the Yaqui. Committed to diversity and inclusion, the University strives to build sustainable relationships with sovereign Native Nations and Indigenous communities through education offerings, partnerships, and community service.

Subject to Change Statement

Information contained in the course syllabus, other than the grade and absence policy, may be subject to change with advance notice, as deemed appropriate by the instructor.