CS 5330 Pattern Recognition and Computer Vision

Syllabus — Spring 2025

Course Description

Introduces the fundamentals of extracting information from digital images. Major topics include image formation and acquisition, gray-scale and color image processing, image filters, feature detection, texture, object segmentation, classification, recognition, stereo, optical flow, motion estimation, and object detection and recognition. The course will cover both classical and modern computer vision techniques built on deep networks.

Students will learn by developing small and medium-scale vision systems to solve practical problems such as image filtering, content-based image retrieval, image stitching, augmented reality, and object recognition.

Learning Goals

1. Students understand the fundamentals of image formation and image acquisition, including camera calibration.
2. Students understand and can implement image processing algorithms such as filtering, morphological operations, connected components, and feature detection.
3. Students understand and can implement algorithms for segmentation, detection, tracking, and classification of objects.
4. Students understand and can implement systems using deep networks to solve computer vision tasks such as object recognition and localization.
5. Students work in a group to design and develop a medium-sized image analysis and computer vision application.
6. Students present algorithms and results in an organized and competent manner, both written and orally.

Textbooks

There are no great computer vision textbooks. There are good computer vision textbooks that are somewhat old (Stockman and Shapiro, or Sonka and Hlavac). There is a new CV text by E. R. Davies that is pretty good. There is a reasonable computer vision text that is free in electronic form (Szeliski). There are also a number of reference style texts, mostly covering the software OpenCV and its various language APIs. I would recommend downloading the Szeliski Book and using an OpenCV reference to get both the theoretical and practical side of computer vision. We will also be using PyTorch for the last few projects, both of which have extensive online tutorials and materials available.

How to Succeed

Each week in the lecture section we will go over new content with a combination of interactive lecture and live coding or demonstrations. To get the most out of class time, ask questions (verbally or through the chat) and read relevant material from relevant sources. If you have questions about any of the material, make use of email and office hours to get clarification. There is no substitute for spending time on the course material. As a graduate course, the expectation is 15-20 hours per week dedicated to your coursework.

Projects: Much of your learning will be through the projects. There will be six projects, with most of the projects taking two weeks. The first five projects you can work on your own or in pairs. You can work in larger teams for the final project. The expectation is that most of your time outside of class will be spent working on projects, with some spent reading relevant papers or texts. Starting the projects early and asking questions are the keys to success.

Homework: In addition to the projects, there will be short weekly homework questions or activities. These will help you to review the prior week's lecture session and prepare for assessments. Your answers will not be graded on correctness, just give a reasonable answer to each question. The answers will be made available for you to review after the submission deadline.

Exams: There will be a series of N assessments during the semester. The best way to study for them is to do the reading, homework, and projects as the semester goes along. Your best N-1 assessment scores will constitute your exam score for the semester.

Respect for Diversity

It is my intent that students from diverse backgrounds and perspectives will be successful in this course, that each student's learning needs are addressed both in and out of class, and that the diversity that each student bring to this class is viewed as a resource, strength, and benefit. I expect you to feel challenged and sometimes outside of your comfort zone in this course, but it

is my intent to present materials and activities that are inclusive and respectful of all persons, no matter their gender, sexual orientation, disability, age, socioeconomic status, ethnicity, race, culture, perspective, and other background characteristics. We should all strive for these principles both inside and outside of the classroom.

The course meeting time is Wednesday afternoon. If a class meeting conflicts with your religious observances, please let me know in the first two weeks of the class so that we can make other arrangements. Northeastern University respects the religious practices of its students, faculty, and staff and is committed to ensuring that all students are able to observe their religious beliefs without academic penalty.

Class rosters are provided to each instructor with each student's legal name. I will gladly honor your request to address you by an alternate name and/or gender pronoun. Please advise me of this early in the semester so that I may make appropriate changes to my records. Indicating your preferred name and pronouns in your zoom window also helps.

Grading

Assessment will be based on exams, projects, homework, and a final presentation. Attendance and participation also will not factor into your final grade. You are responsible for your own actions and the consequences of not attending class or keeping up with readings and course material.

Grade Breakdown

Projects and HW	45%
Exams	40%
Final Project and Presentation	15%

Projects will be graded and handed back with feedback. The defined and required part of the projectd will constitute about 85% of the ideal project. You can choose to stop there, or you can extend the project in ways that are of interest to you to obtain a higher grade. These self-selected tasks are called **extensions.** Extensions are your chance to customize the project to your own interests. Each project will have a set of suggested extensions, or you may choose one of your own.

All projects will be graded out of 30 points. Code functionality, code organization, and quality comments will constitute 22 points. A brief report or document with your results will constitute 4 points, and you can earn up to an additional 4 points for extensions. A 30/30 project requires perfect code, a clearly written and complete report, and meaningful or significant extensions. Note that doing lots of extensions will not make up for a poor report, code with errors, or code without comments.

Final letter grades will be assigned based on the overall percentage calculated using the weightings listed above. The minimum overall percentage required to obtain each letter grade will be no higher than the following: A (93%), A- (90%), B+ (87%), B (83%), B- (80%), C- (65%).

To progress, students are required to meet the grade point average (GPA) requirements for the MS Computer Science -- Align as determined by Khoury College of Computer Sciences (see **Khoury's website (https://www.khoury.northeastern.edu/programs/align-masters-of-science-in-computer-science/)** for more information).

Late Policy

Projects will be due as specified, usually two weeks after being assigned. You may submit any project up to a week after the regular due date and receive credit for everything except extensions. Without prior arrangements, projects submitted more than a week late will receive no credit. Contact the professor as soon as is reasonable if there are personal or health issues that will adversely affect your ability to complete the work on time.

During the semester, you have eight no fault time travel days to use as you see fit. Except for the final project, you may use your time travel days to hand in a project up to three days after any deadline (regular or late) as though you had handed it in by the deadline. You cannot use time travel days on the final project. You can use at most three days for any single project, and the time travel days are considered integers (no partial days). To use a time travel day, indicate how many you are using in the README file you submit with your project. You do not need to ask permission to use a time travel day.

Asking for Help

Computer Science can be challenging, it can be difficult, and it can be extremely satisfying when something works correctly. It should not be frustrating, because frustrating things are not challenging or fun.

Frustration occurs when you are working on something and not making progress, especially if you're not sure about what you are doing. Frustration does not facilitate learning. If you find yourself getting frustrated, stop. Go do something else, eat some dinner, take a walk, but most importantly, ask a question. Send an email to the professor, ask a question in class, talk with a classmate, or set up a 1-1 session to go over your code.

We do not expect you to complete the projects completely on your own.

Please follow the **30-minute rule:** if you have been stuck on a problem for more than 30 minutes and have made no progress, despite your best efforts, please stop and get help. Email

the professor, or consult a peer. If you don't get an answer immediately, do something else for a while. Please do not waste your time on one problem or bug in your code. Asking a question can both get you past the bug quickly and teach you how to fix it on your own next time.

Stuff Happens Clause

My goal for this course is for you to learn the computer science concepts you need to be successful. The guidelines and rules are intended to facilitate your learning, and there is no substitute for putting in the time and effort to learn the material.

Life happens, though, and sometimes it will prevent you from focusing on CS. If something happens, please communicate with the professor as soon as is feasible. I don’t need details, but we do need to develop an alternative plan that will work for you and still ensure you will learn what you need to learn. We are partners in this academic adventure, and I want you to be successful.

Academic Accommodations

If you have a documented need for an academic accommodation, please contact the professor within the first two weeks so we can have a conversation about how best to make appropriate arrangements.

If you require support during the course due to a disability please ensure that you are already registered with the University’s Disability Center, and contact your course instructors to coordinate any support needed during the course.

Mental health issues are real and can prevent you from doing your best work. Your Khoury advisor is your primary contact for accessing University resources. Do not hesitate to make use of them as needed.

Collaboration and Academic Honesty

Computer science, both academically and professionally, is a collaborative discipline. In any collaboration, however, all parties are expected to make their own contributions and to generously credit the contributions of others. In our class, therefore, collaboration on homework and programming assignments is encouraged, but you as an individual are responsible for understanding all the material in the assignment and doing your own work. Always strive to do

your best, give generous credit to others, start early, and seek help early from both your professors and classmates.

The following rules are intended to help you get the most out of your education and to clarify the line between honest and dishonest work. The professor reserves the right to ask you to verbally explain the reasoning behind any answer or code that you turn in and to modify your project grade based on your answers. It is vitally important that you turn in work that is your own. Follow the guidelines for academic honesty or we're done.

If you have had a substantive discussion of any homework or programming solution with a classmate, then be sure to acknowledge them in your report. If you are unsure of what constitutes "substantive", then ask us or err on the side of caution. You will not be penalized for working together. You must not copy answers or code from another student either by hand or electronically. Another way to think about it is that you should be talking natural language with one another, not C++ or Python.

The following rules apply to anything you hand in for a grade.

- Any written work you submit for an exam or quiz must be written by you and without assistance from another person or large language model.
- You may not copy anyone else's code under any circumstances. This includes online sources.
- You may not permit any other student (unless they are team members) to see any part of your program.
- You may not permit yourself to see any part of another student's program, unless they are team members.
- You may not post a public question to a discussion board that contains any part of your code.
- You may consult online resources as part of your course work, but you may not copy code from online sources, unless that is explicitly allowed in the assignment. If you get an idea of how to solve a problem from an online source, include that in your project acknowledgements.
- You may, at your own risk, use code generation/completion tools built into your IDE. Using these tools may speed your development time, but it may also inhibit your learning. Figuring out and writing code yourself forces you to understand it and what it is doing, which is the skill you need to build.

The university's academic integrity policy discusses actions regarded as violations and consequences for students:

- **Office of Student Conduct and Conflict Resolution - Academic Integrity Policy (http://www.northeastern.edu/osccr/academic-integrity-policy/)**

Coding assistant tools have the potential to greatly enhance programmer productivity, as have many other innovations in computer science (assembly language, programming languages, compilers, and interpreters). While they reduce the likelihood of syntax errors, they do not

necessarily provide code that generates the correct output, especially for novel or uncommon problems. They also do not necessarily write code that is computationally efficient.

Ensuring your code produces the correct output and is computationally efficient are still your responsibility. Learning how to do those things is part of what you should be learning in this class. Writing your own code is the best way to do that: understanding each step in the process, what the computer is doing, and what the expected output should be. Vision processing is computationally demanding both in memory and speed because of the large amount of data. Therefore, efficiency in both representation and computation is critical to making real-time systems that work. I encourage you to focus on understanding your code and learning how to write it yourself so that you can make more effective use of coding productivity tools in the future.

Tutoring and Workshops by Global Learner Support (GLS)

Global Learner Support offers one-to-one tutorials for NU learners in the areas of academic writing, academic presentations, APA/MLA citation, English language conversation, and professional communication. To make a tutoring appointment, please visit the GLS booking page: https://gls.northeastern.edu/gls-tutoring/

Global Learner Support (GLS) also offers monthly virtual and in-person workshops on topics related to avoiding plagiarism, paraphrasing, APA/MLA guidelines, grammar and punctuation, academic presentations, writing professional emails, etc. Please visit https://gls.northeastern.edu/gls-workshops/ to register for upcoming workshops.

To view additional GLS services, visit our website at https://gls.northeastern.edu/

Title IX

Title IX of the Education Amendments of 1972 protects individuals from sex or gender-based discrimination, including discrimination based on gender-identity, in educational programs and activities that receive federal financial assistance.

Northeastern's Title IX Policy prohibits Prohibited Offenses, which are defined as sexual harassment, sexual assault, relationship or domestic violence, and stalking. The Title IX Policy applies to the entire community, including male, female, transgender students, faculty and staff.

If you or someone you know has been a survivor of a Prohibited Offense, confidential support and guidance can be found through **University Health and Counseling Services staff**

(https://www.northeastern.edu/uhcs/) and the Center for Spirituality, Dialogue, and Service (https://www.northeastern.edu/spirituallife/) clergy members. By law, those employees are not required to report allegations of sex or gender-based discrimination to the University.

Alleged violations can be reported non-confidentially to the Title IX Coordinator within The Office for University Equity and Compliance (https://www.northeastern.edu/ouec/) at: titleix@northeastern.edu (mailto:titleix@northeastern.edu) and/or through NUPD (Emergency 617.373.3333; Non-Emergency 617.373.2121). Reporting Prohibited Offenses to NUPD does NOT commit the victim/affected party to future legal action.

Faculty members are considered "responsible employees" at Northeastern University, meaning they are required to report all allegations of sex or gender-based discrimination to the Title IX Coordinator.

In case of an emergency, please call campus police.

Please visit the Office for University Equity and Compliance for a complete list of reporting options and resources (https://www.northeastern.edu/ouec/reporting-options/titleix-prohibited-offenses/) both on- and off-campus.

Recording Policy

This course, or parts of this course, may be recorded for educational purposes. Prior to starting any recordings, the instructor will ask if anyone objects recording the session. If anyone objects, no recording will be made. These recordings will be made available only to students enrolled in the course, the instructor of record, and any teaching assistants assigned to the course.

Only students who have arranged an accommodation with the Disability Resource Center may use mechanical or electronic transcribing, recording, or communication devices in the classroom. Students with disabilities who believe they may need such an accommodation may contact the Disabilities Resource Center.

COVID-19 Guidelines and Class Safety

This course will be synchronous online and follow the current Northeastern University guidelines.

Topics

Week	Topics	Project	Readings
1: 2025-01-08	Syllabus and class overview Imaging pipeline Image representations Filtering Filters as features	Project 1: Real-time filtering	Szeliski Ch 1, 2.2.3, 2.3, 3.1, 3.2 Maxwell Ch 1 (https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1) , Ch 2 (https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1) Real-time cartoonization (https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1)
2: 2025-01-15	Practical Filtering Useful filters Fourier Transform Convolution Layers	Complete project 1	Szeliski Ch 3.3, 3.4, 3.5 Fast Bilateral Filtering (https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1) Fast Fourier Color Constancy (https://northeastern.instructure.com/courses/206145/files/32133 download_frd=1)
3: 2025-01-22	Visible light Pinhole camera model Human visual system Aliasing Color spaces and chromaticity Histograms	Project 2: Image Matching	Szeliski Ch 2.3.1, 5.1.1, 5.3.1, 6.2.3, A.1.1, A.1.2 Stockman and Shapiro Ch 4 Maxwell Ch 3.5 (https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1)
4: 2025-01-29	Histogram distance metrics Matching: Nearest-neighbor, K-NN Principal Components	Complete project 2	Szeliski Ch 3.3.1, 5.2 Maxwell Ch 3 (https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1) Stockman and Shapiro Ch 3, 4, 7

	Analysis CNN Embedding Spaces Texture Filter-banks		**Eigenfaces** **(https://northeastern.instructure.com/courses/206145/files/31639** **(https://northeastern.instructure.com/courses/206145/files/31639** **download_frd=1)** Learning visual similarity **Texture Energy Measures** **(https://northeastern.instructure.com/courses/206145/files/31639** **(https://northeastern.instructure.com/courses/206145/files/31639** **download_frd=1)**
5: 2025-02-05	K-Means Clustering Thresholding / ISODATA Morphological Processing Median Filtering Segmentation Grassfire Transform Shape features (moments++)	Project 3: Real-time Object Recognition	Szeliski Ch 2.1, 2.2, 7.5 Stockman and Shapiro Ch 10 **Texture Classification** **(https://northeastern.instructure.com/courses/206145/files/31639** **(https://northeastern.instructure.com/courses/206145/files/31639** **download_frd=1)**
6: 2025-02-12	Physics of Reflection BIDR Model and Log Space Chromaticity Geometry of Imaging Calibration Augmented Reality RANSAC	Complete project 3	Szeliski Ch 12.1, 12.3, 12.4, 12.8 **Trucco and Veri** **(https://northeastern.instructure.com/courses/206145/files/31639** **(https://northeastern.instructure.com/courses/206145/files/31639** **download_frd=1)** **BIDR Model** **(https://northeastern.instructure.com/courses/206145/files/31639** **(https://northeastern.instructure.com/courses/206145/files/31639** **download_frd=1)** **Removing road shadows** **(https://northeastern.instructure.com/courses/206145/files/31639** **(https://northeastern.instructure.com/courses/206145/files/31639** **download_frd=1)** **Log RGB Image Classification** **(https://northeastern.instructure.com/courses/206145/files/31639**

			(https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1)
7: 2025-02-19	Stereo Rectification Depth estimation from a single image Differential motion Background models Optical flow Image Pyramids	Project 4: Augmented Reality	Szeliski Ch 9.4 Monocular Depth Depth Anything V1 (https://northeastern.instructure.com/courses/206145/files/32133 (https://northeastern.instructure.com/courses/206145/files/32133 download_frd=1) Depth Anything V2 (https://northeastern.instructure.com/courses/206145/files/32133 (https://northeastern.instructure.com/courses/206145/files/32133 download_frd=1)
8: 2025-02-26	Features for tracking Tracking Kalman Filtering SLAM	Complete project 4	Szeliski Ch 11 SLAM Survey paper (https://northeastern.instructure.com/courses/206145/files/32134 (https://northeastern.instructure.com/courses/206145/files/32134 download_frd=1)
9: 2025-03-05	Spring Break		
10: 2025-03-12	Face Recognition Using Cascade Classifiers Features spaces Adaboost Non-Maxima Suppression Confusion Matrix Precision/Recall Graphs Body Part Recognition Early ANNs (Driving, Faces)	Project 5: Digit and Character Recognition	Szeliski 5.3, 5.4 Viola and Jones (https://northeastern.instructure.com/courses/206145/files/31639 (https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1) ALVINN (https://northeastern.instructure.com/courses/206145/fil wrap=1) (https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1) Rowley and Baluja (https://northeastern.instructure.com/courses/206145/files/31639 (https://northeastern.instructure.com/courses/206145/files/31639 download_frd=1)
11: 2025-	Convolutional Networks	Complete project 5	Szeliski Ch 5.3, 5.4, 6.2 CNN Papers

03-19	Commonly Used Layers MNIST Digita Recognition AlexNet Standard Backbone Architectures Transfer Learning Bias/Variance		
12: 2025-03-26	Object Detection and Recognition R-CNN, Fast-RCNN, Faster-RCNN YOLO Mask-RCNN IOU Matching Face Recognition Contrastive Learning	Final Project	Szeliski 6.3, 6.4 CNN Papers
13: 2025-04-02	Depth Anything Teacher/Student concept Synthetic Data Generative Adversarial Networks Example GANs Latent Spaces	Work on final project	Relevant papers
14: 2025-04-09	Style and Style Transfer Networks as measurement devices Deep Network Properties Adversarial Images	Work on final project	Relevant papers

	Useful v. Robust Features Analyzing Networks		
15: 2025-04-16	Transformers Foundation Models Object Recognition using Transformers Combining language and vision models Diffusion: removing noise Deep Network tools for CV	Work on final project	Relevant papers
16: 2025-04-23	Final Presentations	Complete final project	