Physics 410/510:

Image Analysis

with Applications in Physics

Fall 2021

Lonely Metropolitan (detail) – Herbert Bayer, gelatin silver print, 1932

Course Description

In a large, diverse, and ever-expanding variety of fields in science and technology, we wish to extract quantitative information from images. These images may be captured by microscopes, telescopes, cell phone cameras, medical imaging devices, or other instruments, but nearly all share the characteristic of being arrays of numbers that reflect the local intensity of some sort of signal. Methods of computational image analysis are therefore very broadly applicable throughout science and technology, and we'll see some of the scientific insights they enable.

Learning Goals

Our goals will be to become familiar with techniques, algorithms, and approaches for computational image analysis; to practice and improve skills in writing code to implement image analysis methods; to learn how image analysis is governed by principles of optics and statistics; and to understand various applications of computational image analysis in the sciences.

Prerequisites and programming languages

Programming

Students should have a good grasp of some high-level programming language and should be comfortable with manipulating arrays and writing functions. I *very strongly* recommend MATLAB or Python; all of my examples will use these, and I don't expect to be able to provide useful assistance in other languages. Moreover, MATLAB and Python have useful features like logical indexing and excellent toolboxes / libraries of basic image processing functions.

The vast majority of the work in this course involves programming.

If you're unsure of whether your programming skills are adequate, please see the "Homework 0" assignment posted here:

https://pages.uoregon.edu/raghu/TeachingFiles/Homework0.pdf .

Other background

Students should have a basic understanding of diffraction and properties of light, and a good grasp of calculus, and matrix arithmetic. Other topics covered in the standard lower-level physics curriculum. Non-physics graduate students can probably brush up on diffraction before the course with a few hours of watching YouTube videos and doing practice exercises.

What this course isn't

There are a lot of excellent software packages out there, both open source and commercial. Though we'll touch on some of them, this is not a class on using those tools. Rather, we focus on writing code ourselves. This is immensely useful *even if* one uses others' software packages, because (i) writing code to transform one's data into forms that can be input into other software is often necessary or at least useful; (ii) the variety of scientific questions one can ask far exceeds the variety of pre-made analysis methods that can address them, so writing one's own tools is often necessary to tackle questions of interest; (iii) familiarity with common image processing methods is useful for planning experiments, to better assess what tasks are easy or difficult; (iv) writing code yourself can give a deep understanding of the capabilities and, especially, the pitfalls associated with various algorithms, which can be important to realize even if later using canned software.

Students should also be aware that this course will cover less physics than a typical physics course, less computer science than a typical computer science course, etc. It won't follow as much of a conceptual arc as most courses, and instead will be a collection of topics with which to become acquainted through exercises. Despite all this, people who have taken the prior "informal" versions of the course that I've taught seem to have liked it a lot, and found it useful.

Topics

The list below is roughly in chronological order, but not exactly. Some topics, like “microscopes and cameras” and “images and ethics” will be interspersed among others.

Introduction / fundamentals / thresholding
In which we consider basic properties of digital images and apply thresholds to enhance contrast

Spatial filtering
In which we examine various local filters

The point-spread function, simulated images, noise
In what way is an image different from the reality it represents? How is noise manifested, and how does that limit what we can learn from an image?

Microscopes and cameras
We look at the physics that underlies aspects of image formation, and therefore image analysis

Sub-pixel localization
How can we determine the location of a point source (such as a single molecule, a colloidal particle, or a star)? In addition to being the key issue underlying super-resolution microscopy, this is applicable to many “tracking” problems. We’ll also learn how statistical principles constrain the accuracy of localization.

Maximum Likelihood Estimation
In which we learn and apply a bit of statistics

De-noising
Can we remove noise from images? How? Why?

Morphological image processing
In which we familiarize ourselves with a useful “toolkit” of image processing operations

Hough Transformation
A clever, useful approach for finding and analyzing geometric features.

Image segmentation
One of the most important, and hardest, problems: what are the “objects” in an image, and how can we identify them – not just their centers, but their size and shape? We’ll consider approaches including “region based” methods, especially watershed segmentation.

Deconvolution
Can we reconstruct a higher resolution image than the one we have?

Machine learning methods (an introduction)
Can we get the computer to do our thinking for us? How? A *very limited* introduction to a very large topic

Images and ethics
When is it ok to “manipulate” images? How do we detect fraud in research papers? Does machine learning introduce different ethical concerns than other methods?

Logistics

Class Times	TuTh 10:00 - 11:50 pm, Straub 254 We'll probably use the second half of Thursday's time (11:00-11:50 am) as an optional office hours / question period.
Instructor	**Professor Raghuveer Parthasarathy** (**Par**-tha-**sa**-ra-thē) Email: *raghu@uoregon.edu* Office: 362 Willamette Hall
Teaching Assistant	**Piyush Amitabh** Email: pamitabh@uoregon.edu
Office Hours	**Prof. Parthasarathy:** Thursday 1:30-2:20 pm, Friday 1:00-1:50 pm **Piyush Amitabh:** Tuesday: 1-2pm PSC B010 (Physics Room in the Science Library); Friday 2:00-2:50pm (WIL 143) *Office hour times may change*, both by request (if particular times are not good for many students) and due to scheduling conflicts that arise.
Canvas	We will be using Canvas in this course distribute and collect course materials. Log on to canvas.uoregon.edu using your DuckID. If you have questions about accessing and using Canvas, visit the Canvas support page. Canvas and Technology Support also is available at: 541-346-4357 & livehelp.uoregon.edu If you face Internet access challenges, visit Information Services' web page on going remote. **Google Drive.** If sharing files via Canvas is cumbersome, we may make use of Google Drive or other services.
Textbook	**There is no required textbook.** The lectures and supplemental readings will be sufficient. The following are useful books: • Digital Image Processing, 4th edition, by Rafael C. Gonzalez, Richard E. Woods (Pearson; 2018) • Digital Image Processing Using MATLAB, 2nd edition, by Rafael C. Gonzalez, Richard E. Woods, and Steven L. Eddins (Gatesmark Publishing; 2009)
Zoom	The class is "**in person.**" For two students attending remotely from outside Eugene (for non-Covid reasons), I'll have Zoom running during class and will record the sessions. This may also be useful and in case anyone is affected by quarantine rules during the term. I don't expect the recordings to be great! Meeting ID 970 9719 9762 / passcode 871253 Link: https://uoregon.zoom.us/j/97097199762?pwd=OHBOejNxQnpDZlVwc2hveGdwS0dBdz09

Course structure and assignments

HOMEWORK	There will be homework assignments approximately every week. You are encouraged to discuss the questions with others, but of course, the work you submit and the code you write should be your own. Assignments will be submitted online, via Canvas. No late homework will be accepted. The assignments will mostly involve writing programs. In many cases, the result will be an image or graph that you submit, along with text, and it will not be necessary to submit your code. In some cases, we will ask for the code itself. Don't hesitate to ask if instructions are unclear. **Be prepared to explain and discuss your homework results in class.**
CLASS PARTICIPATION	I'm a strong proponent of active learning in general, rather than having classes filled with monotonous lecturing, as a tool for fostering learning and engagement. In this course especially, based on past "informal" iterations, active participation crucial – discussing what worked and didn't work in your implementations of image analysis exercises, or other observations, allows everyone to benefit from each other's experiences, and this is a topic that is very much learned through experiences. Therefore there is a class participation grade – you will be expected to contribute to discussions, and I will gently communicate with you if you are consistently not contributing.
FINAL PROJECT	There will be a final project that involves investigating and implementing an image analysis method, submitting a written report on it, and giving a presentation to the class. This will be done in groups, with details described later in the course.
EXAMS	There will be no exams.
GRADING	The various grade components and their weights for the final grade are: • *Weekly Homework Assignments: 65%* • *Class participation: 10%* • *Final Project: 25%* **Overall Grade:** A=[90, 100]%; B=[80,90)%; C=[70,80)%; D=[60,70)%; F<60%.
410/510 GRADING	This course is both an undergraduate (410) and graduate (510) course. The homework assignments will contain questions that are required for the 510 students, and not for the 410 students, and the specific requirements for the final project will also be different.
THINGS THAT MIGHT CHANGE	This is a draft version of the course structure. I might insert some quizzes – to be determined...

Other policies

ACADEMIC INTEGRITY	Students are expected to abide by university policies on academic honesty, avoiding unauthorized help on assignments and examinations, the use of sources without acknowledgment plagiarism, fabrication, and cheating of all types. The Student Conduct Code (https://dos.uoregon.edu/conduct) provides definitions of these terms and explanations of the university policy on the subject. I take academic misconduct very seriously, as it is disrespectful to your fellow students, your instructor, and society. I will report misconduct to the Office of Student Conduct and Community Standards—consequences can include failure of the course.
STUDENTS WITH DISABILITIES	All of us at the University of Oregon are working to create inclusive learning environments. Please notify me if there are aspects of the instruction or design of this course that result in disability-related barriers to your participation. You are also encouraged to contact the Accessible Education Center at 541-346-1155 or uoaec@uoregon.edu.
CHANGES TO THE SYLLABUS	As the university community continues to respond to the COVID-19 pandemic, **course requirements, deadlines, and grading percentages are subject to change.** I will be mindful of the impacts any unfolding events may be having on you. I encourage you to talk with me about what you are experiencing so we can work together to help you succeed in this course.
COVID POLICIES	Please see the "University COVID Policies" page on the class Canvas site. Note UO's vaccination policy – I hope everyone is vaccinated! – and mask policies. Please contact me if you have any questions or concerns.