An image processing reading course

Raghuveer Parthasarathy
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Course Goals

Students will learn about a variety of algorithms for computational image analysis, and will practice writing code to implement them. The methods we'll explore are very broadly applicable in many areas of science and technology, and we'll note especially insights they enable in biophysics, soft condensed matter, and microscopy (or other fields of interest to students).

Course structure

Since this is a reading course, and since I've got lots of other things to do (e.g. my real course[1]), my own involvement will be fairly minimal. We will all meet once a week to introduce topics and discuss the work of the past week, but students will be expected to read papers on their own, to initiate discussions, and to develop implementations of algorithms quite independently.

Prerequisites

Students should have a good grasp of MATLAB, meaning familiarity with array operations, logical indexing, and functions[2]. (Other programming languages are fine, but don't expect help. Also, note that MATLAB's toolbox of basic image manipulation functions is extremely useful, and we'll build on it.) **The course will move very quickly**, reading and implementing at least one new method per week.

Sources

The syllabus is based largely on:

Stanford EE 368 / CS 232 (Bernd Girod): http://www.stanford.edu/class/ee368/index.html
Notes and handouts at http://www.stanford.edu/class/ee368/handouts.html

Gonzalez and Woods -- *Digital Image Processing Using MATLAB* (We have a copy in the lab.)
Images, etc., at http://www.imageprocessingplace.com/

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1 http://physics-server.uoregon.edu/~raghu/TeachingFiles/Physics%20of%20Life%20expanded%20description%202012.pdf

2 If you're not already, you should become familiar with how to make MATLAB code fast – avoiding for-loops, preallocating memory, etc. See e.g. http://www.csc.kth.se/utbildning/kth/kurser/DN2255/ndiff13/matopt.pdf , http://web.cecs.pdx.edu/~gerry/MATLAB/programming/performance.html

Draft Syllabus

Please note: My selection of topics is certainly malleable; if there's something you'd like to learn about, we can include it!

1 Introduction / fundamentals / point operation

Readings

- Gonzalez and Woods, Chp. 2
- Girod EE368, Handouts #1 and #2

Assignment: tbd

2 Histograms, adaptive thresholding

In which we apply simple global and local thresholds to enhance image contrast and deal with (variable) backgrounds

Readings

- Gonzalez and Woods, Chp. 3
- Girod EE368, Handout #4
- Girod EE368, Handout #6

Assignment: tbd, probably writing simple adaptive threshold functions, and seeing how they behave [Merge with #1?]

3 Filtering

In which we examine smoothing, and low- and high- spatial-frequency filters, and examine a recent paper on filtering-based optical sectioning

Readings

- Gonzalez and Woods, Chp. 3-4
- Girod EE368, Handout #8
- Merz et al. "HiLo" papers, e.g. Merz and Kim, *Journal of Biomedical Optics* **15**, 016027 (2010)

Assignment: "HiLo" structured illumination: implement and assess.

4 Morphological image processing

In which we familiarize ourselves with the "toolkit" of a lot of image processing

Readings

- Gonzalez and Woods, Chp. 10
- Girod, Handout #7

Assignment: tbd

5 Image segmentation; Watershed segmentation; Level Sets

One of the most important, and hardest, problems: what are the "objects" in an image, and how can we identify them? How do we identify cells, for example?

Readings

- Gonzalez and Woods, Chp. 11
- Girod, Handout #6
- Amat et al. article?

Assignment: Implement segmentation algorithms on dense 3D packings of cells (zebrafish) – how does it fail? Parameter dependence?
(Two weeks, probably)

6 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?
Readings

- M. Gu, *Advanced Optical Imaging Theory* [just a bit, on point-spread-functions] RP has this book.
- R.J. Ober et al. *Biophys. J.* 86:1185–200 (2004)
- Parthasarathy and Small (review paper), *Annu. Rev. Phys. Chem*. 2014. 65:107–25

Assignment: Simulate point object images; calculated Cramer-Rao bound on localization precision. Rotational accuracy?

7 Sub-pixel localization
How can we accurately determine the location of a point source (e.g. a single molecule, or a colloidal particle)? In addition to being the key issue underlying super-resolution microscopy, this is applicable to many "tracking" problems.
Readings

- Parthasarathy and Small (2014), and papers it cites

Assignment: Implement one or two localization methods. Maybe extend to object pairs?

8 De-noising
Can we remove noise from images? How?
Readings

- Boulanger et al., "Patch-based non-local functional for denoising fluorescence microscopy image sequences"

Readings

- Old papers...

Assignment: Implement this.
Maybe move earlier, or omit

9 Hough transformation
A fun, clever way to find the center of circles; generalizable.
Maybe omit? Or move to week 1!
Assignment: Implement this. Maybe look at floating particle or emulsion data.

10 Machine learning (introduction)
Can we develop classification approaches for image data?
Readings

- Hsu et al. "A Practical Guide to Support Vector Classification"

Assignment: tbd. Probably something with bacteria data.

Omitted topics:

Template matching, eigenimages
Girod, Handout #9, 10