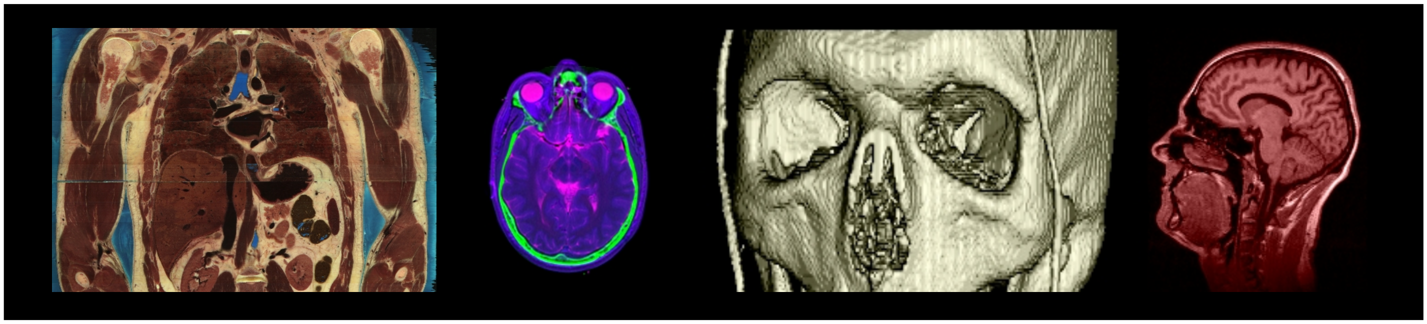
# CS 473 / CS 673 – Medical Image Processing

# Winter 2016



## Course Information

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|---|---|
| Professor: | Jeff Orchard |
| Office: | DC 3615 |
| Phone: | 519-888-4567 ext 35037 |
| E-Mail: | jorchard@uwaterloo.ca |
| Office Hours: | check http://www.cs.uwaterloo.ca/~jorchard/contact.html |
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| Course Web Page: | http://www.cs.uwaterloo.ca/~jorchard/cs473/ (public) |
| | http://learn.uwaterloo.ca (for grades and submitting assignments) |
| | http://piazza.com/uwaterloo.ca/winter2016/cs473/home (for everything else) |
| | |
| Lecture time: | Wednesday/Friday 1:00-2:20pm |
| Location: | DWE 1515 |
| | |
| Prerequisites: | One of (AMATH 242/341, CM 271, CS 371 or CS 370) |
| Cross-listed as: | offered with CS 673 |
| Required Text: | none |

## References

*Introduction to the Mathematics of Medical Imaging*, C.L. Epstein, Prentice Hall, 2003.

*Digital Image Processing*, K.R. Castleman, Prentice Hall, 1996.

*Digital Image Processing*, R.C. Gonzalez and R.E. Woods, Prentice Hall, 2002.

*Digital Image Processing using Matlab*, R.C. Gonzalez, R.E. Woods and S.L. Eddins, Prentice Hall, 2004.

*Numerical Geometry of Images*, R. Kimmel, Springer, 2004.

*Geometric Partial Differential Equations and Image Analysis*, G. Sapiro, Cambridge Univ. Press, 2001.

*Insight Into Images, Terry Yoo (editor), A. K. Peters; Wellesley, Massachusetts, 2004.*

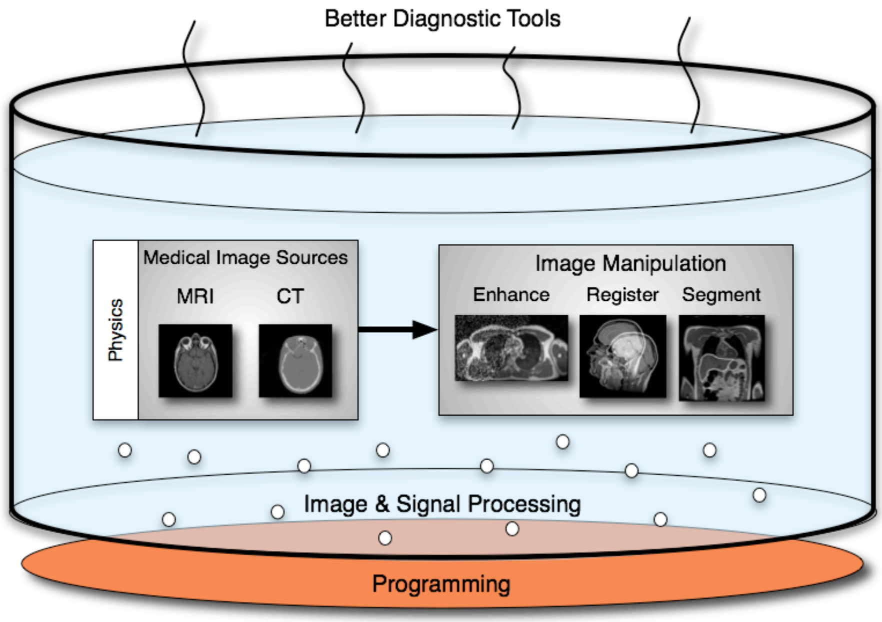
## Objectives

The objective of this course is to provide students with an overview of the computational and mathematical methods in medical image processing. The course covers the main sources of medical imaging data (CT, MRI, PET, and ultrasound). We will study many of the current methods used to enhance and extract useful information from medical images. A variety of radiological diagnostic scenarios will be used as examples to motivate the methods.

Students interested in medical imaging, as well as health and medicine, will find this course useful. The course has some crossover with other fields of image and signal processing, and students interested in remote sensing and computer graphics might also find this course helpful.

### Concept Map

On the next page, you'll find the concept map for the course. The figure represents the relationships between the ideas and goals of the course.




## Learning Outcomes

This course is designed such that, by the end of the course, you will be able to:

- give at least 3 examples of medical conditions that benefit from medical image processing.
- illustrate (summarize) the physics of MRI and CT, and their reconstruction algorithms
- create a small library of code implementing each of: a resampling method, a spatial transformation, a filtering method (convolution), image registration, image segmentation
- choose an appropriate registration or segmentation scheme in the context of a given scenario.

## Approximate Schedule of Topics

| Topic | Hours | Assessment Method |
|---|---|---|
| Introduction | 1 | |
| Image and Signal Processing | 6 | Programming & Written Assignment, Test, Final |
| Sources of Medical Images | 4 | Written Assignment, Test, Final |
| Image Enhancement | 4 | Programming Assignment, Test, Final |
| Image Registration (alignment) | 9 | Programming Assignment, Final |
| Image Segmentation (tissue classification) | 7 | Programming Assignment, Final |
| Reconstruction Methods | 5 | Final exam |

## Student Assessment

| Weight | Assessment Method |
| --- | --- |
| 50% | Assignments (7 in total) |
| 15% | Midterm Test |
| 35% | Final Exam |

In this course, you will build a small library of image processing programs. The programs that you'll write are part of the work assigned in the four **programming assignments**. The programs will be written in Matlab, a scientific programming language that takes care of a lot of the mundane image manipulation tasks so you can focus your attention on the more interesting aspects of medical image processing. Alternatively, you can program in Octave, a free Matlab work-alike. There will also be one **written assignment**. Programming assignments will be submitted online, while the written assignment will be submitted in class. The evaluation of programming assignments will be returned by e-mail. Written assignments will be returned at the beginning of class, or picked up during Prof. Orchard's office hours.

A short **midterm test** will take place approximately half-way through the term, scheduled during class time.

A **final exam** will test your understanding of the course content, as well as how the different pieces fit together to form better diagnostic tools. Naturally, not much programming will be expected on the exam, but small programming-related questions are fair game.

If you are registered in CS 673, the graduate-level version of the course, there are some additional requirements for you in the course assessment. Each assignment (both written and programming), and the final exam might have an extra question that you will answer. If you are a graduate student, and you wish to do a final project – worth 25% of your final grade – then your final exam will only be worth 10%.

## Learning Methods

Most classes will be lectures, involving hand-written mathematical derivations, slide presentations to show graphical concepts, and Matlab demonstrations.

However, since all the lectures are already online (see the public course page), we can also do some "flipped" classes, where you watch the video lecture on your own time and come to class to work on short group exercises. For these classes, it would be helpful if you have a laptop to bring to class.

We will also use Piazza (piazza.com) as a messaging system, and might use Kahoot (kahoot.it) for in-class assessment.

## Outline of Topics

### Image & Signal Processing

Sampling theory, and a variety of interpolation methods, including nearest-neighbour, linear, cubic & higher-order, and Fourier (using the FFT). We will use these methods to implement spatial image transformations (rigid and non-rigid).

### Sources of Medical Images

Briefly discuss the physics of X-ray, CT, PET, MRI, and ultrasound. We will study the properties of the resulting images, and discuss the advantages and disadvantages of each imaging modality.

### Image Enhancement

Contrast adjustment, denoising (convolution, FFT), deblurring (solving an ill-conditioned sparse linear system), edge detection (numerical approximation to a partial derivative), anisotropic diffusion (numerical solution of partial differential equations), super-resolution.

### Registration (alignment)

We will study intensity-based methods, including a variety of cost functions (correlation, least squares, mutual information, robust estimators), and optimization techniques (fixed-point iteration, gradient descent, Nelder-Mead simplex method, etc.). Implement registration for rigid and non-rigid transformations. MRI motion compensation.

### Segmentation (tissue classification)

Discuss simple methods such as thresholding, region growing and watershed. More depth on the method of snakes (adaptive mesh), level set method (numerical solution of partial differential equations), and clustering (classifiers).

### Reconstruction Methods

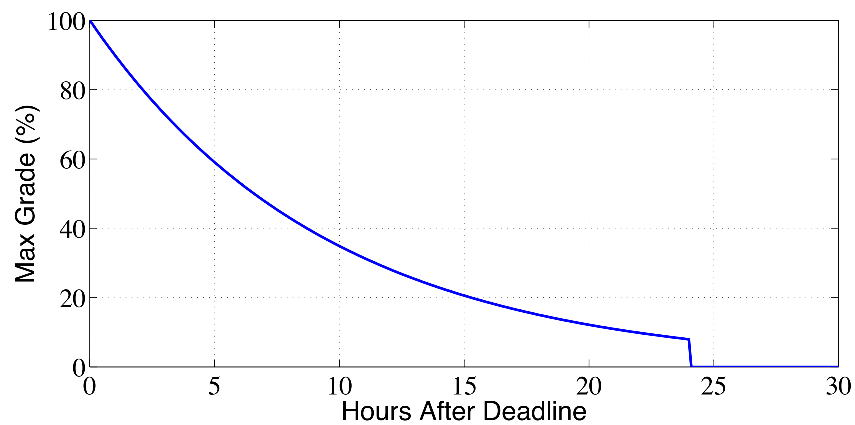
Reconstruction techniques for CT (filtered back projection) and MRI (using the FFT). We will also include a section on the theory of the Radon transform, the Fourier transform, and how they relate to each other.

## Policies

### Late Policy

On the due date of an assignment, the work done to date should be submitted online by the requested time. If the deadline has passed, you will lose 10% of the remaining grades per hour until it is handed in, or until it is 24 hours late, at which point you will get zero. That is, if $t$ is the number of hours after the deadline, then the maximum grade you can get (shown in the figure) is

$$\text{maximum grade} = \begin{cases} 0.9^t & \text{if } t \le 24 \text{ hours} \\ 0 & \text{if } t > 24 \text{ hours.} \end{cases}$$




**Missed Exam:** You are responsible for knowing the University of Waterloo's policy for missed exams. This policy will be strictly adhered to. Please see the university calendar, or visit Examination regulations and related matters.

**Collaboration:** You are encouraged to discuss assignments with other classmates. However, the submitted assignment should be your own work. Note that current School of Computer Science policy states that a mark of -100% can be recorded for the assignment for all parties involved in a case of blatant cheating/copying.

**Academic Integrity:** In order to maintain a culture of academic integrity, members of the University of Waterloo community are expected to promote honesty, trust, fairness, respect and responsibility. Check the Office of Academic Integrity's website for more information.

All members of the UW community are expected to hold to the highest standard of academic integrity in their studies, teaching, and research. This site explains why academic integrity is important and how students can avoid academic misconduct. It also identifies resources available on campus for students and faculty to help achieve academic integrity in — and out — of the classroom.

**Grievance:** A student who believes that a decision affecting some aspect of his/her university life has been unfair or unreasonable may have grounds for initiating a grievance. Read Policy 70 — Student Petitions and Grievances, Section 4. When in doubt please be certain to contact the department's administrative assistant who will provide further assistance.

**Discipline:** A student is expected to know what constitutes academic integrity, to avoid committing academic offenses, and to take responsibility for his/her actions. A student who is unsure whether an action constitutes an offense, or who needs help in learning how to avoid offenses (e.g., plagiarism, cheating) or about "rules" for group work/collaboration should seek guidance from the course professor, academic advisor, or the Undergraduate Associate Dean. For information on categories of offenses and types of penalties, students should refer to Policy 71 — Student Discipline. For typical penalties, check Guidelines for the Assessment of Penalties.

**Avoiding Academic Offenses:** Most students are unaware of the line between acceptable and unacceptable academic behaviour, especially when discussing assignments with classmates and using the work of other students. For information on commonly misunderstood academic offenses and how to avoid them, students should refer to the Faculty of Mathematics Cheating and Student Academic Discipline Policy.

**Appeals:** A decision made or a penalty imposed under Policy 70, Student Petitions and Grievances (other than a petition) or Policy 71, Student Discipline may be appealed if there is a ground. A student who believes he/she has a ground for an appeal should refer to Policy 72 — Student Appeals.

**Note for students with disabilities:** AccessAbility Services (formerly the Office for Persons with Disabilities or OPD), located in Needles Hall, Room 1401, collaborates with all academic departments to arrange appropriate accommodations for students with disabilities without compromising the academic integrity of the curriculum. If you require academic accommodations to lessen the impact of your disability, please register with AccessAbility Services at the beginning of each academic term.