MDPH-607: MEDICAL IMAGING (3 credits) – Fall 2023

Course Description: This course is concerned with the principles of medical imaging as applied to conventional diagnostic radiography, X-ray computed tomography (CT), and magnetic resonance imaging (MRI). The course emphasizes a linear system approach to the formation, processing, and display of medical images.

Course Pre-Requisites: Open to graduate students registered in Medical Physics or Biological & Biomedical Engineering at McGill. Instructor approval of the instructor is required for students not registered in these programs.

Instructor: Prof. Ives Levesque, PhD, FCCPM
Room DS1.9326, Cedars Cancer Centre, Glen Site MUHC
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Location: Class will be held 100% in-person. Room to be confirmed.

Course Schedule: Monday and Wednesday, 9:00 – 10:30 am
First class: Wednesday, August 30th, 2023

Student Hours: *Regular availability to be confirmed.*

Reference texts:
Magnetic Resonance Imaging, D. Nishimura (available from www.lulu.ca)
Handbook of MRI Pulse Sequences, Bernstein, King, and Zhou (e-version available via McGill Library)
The Essential Physics of Medical Imaging, J.T. Bushberg *et al.*, Lippincott Williams & Wilkins
Medical Imaging Systems, A. Macovski, Prentice-Hall
The Fourier Transform and its Applications, R. N Bracewell, McGraw Hill

Assessment: See page 3 of this document for more details on assessment.

Health and Wellness Resources at McGill: Student well-being is a priority for the University. All of our health and wellness resources have been integrated into a single Student Wellness Hub, your one-stop shop for everything related to your physical and mental health. If you need to access services or get more information, visit the Virtual Hub at mcgill.ca/wellness-hub or drop by the Brown Student Services Building (downtown) or Centennial Centre (Macdonald Campus). Within your faculty, you can also connect with your Local Wellness Advisor (to make an appointment, visit mcgill.ca/lwa).

Land Acknowledgment

"*McGill University is on land which has long served as a site of meeting and exchange amongst Indigenous peoples, including the Haudenosaunee and Anishinabeg nations. We acknowledge and thank the diverse Indigenous peoples whose presence marks this territory on which peoples of the*

world now gather."

LEARNING OBJECTIVES

By the end of this course, the student should be able to:
1. Apply physics and linear systems theory to the study of medical imaging systems
2. Demonstrate an understanding of approaches to tomographic (CT) medical imaging
3. Understand the principles of NMR physics, MRI, and the basic architecture of an MRI system
4. Discuss applications of human medical imaging along with the underlying physical principles
5. Read and understand scientific papers in medical imaging, especially in MRI

EXPECTATIONS

- You are primarily responsible for your learning in this class.
- All course materials and key dates will be posted to MyCourses.
- I will provide notes and expect you to read these ahead of the sessions. I will also provide brief overview videos about the material, as a companion to the notes. There will be an online quiz ahead of each session.
- Sessions will be held in-person and on Zoom (depending on the public health situation).
- Sessions will be aimed at discussion the concepts in a Q&A format, and to discuss problems.

OUTLINE OF CONTENT

I. **Linear Systems:** Linear systems. Dirac delta function. Multi-dimensional functions and discretization. Sinusoids, impulses, and linear shift-invariant (LSI) systems. Fourier series. The Fourier transform and discrete Fourier transforms. The convolution theorem. Blur and resolution, point-spread function, line spread function, modulation transfer function. The Fast Fourier transform (FFT). Sampling, and aliasing.

II. **Radiographic imaging:** Overview of X-ray production and projection imaging. X-ray absorption. Scatter and grids. Detectors and response. Image quality: contrast, spatial resolution, unsharpness, and noise.

III. **Tomography and Inverse Problems:** Basics of computed tomography (CT). Imaging and inverse problems. Object and data representation. Central section theorem. Image reconstruction. Influence of detector, reconstruction, and display resolution. SNR and dose in CT. Fan-beam, multi-slice, helical, and cone-beam CT. System matrix and the forward model. Iterative solution to the inverse problem. Algebraic reconstruction technique for CT. Maximum Likelihood Expectation Maximisation (ML-EM) reconstruction for CT.

IV. **Nuclear magnetic resonance:** Quantum mechanical and classical NMR theory. Precession. Net magnetization. Relaxation. The Bloch equation. Excitation and induction. Signal detection. Spin echo. Chemical shift. NMR spectroscopy.

V. **Magnetic resonance imaging:** Magnetic field gradients. Signal equation for MRI. Image space and k-space interpretation of MRI. Projection and 2DFT imaging. Sampling, field-of-view and resolution. R.F. and gradient pulse sequences. Selective excitation. MRI noise and noise

properties. Gradient and spin echo imaging. Inversion preparation, multi-echo MRI. Image contrast. Fast imaging, spoiling, single-shot imaging. NMR spectroscopy and imaging of other nuclei. Typical system description for proton imaging. Image reconstruction.

ASSESSMENT

The grading scheme will follow a flexible arrangement. The only component that is required from everyone are the regular quizzes. For the rest, you will be offered a number of assessment opportunities, which you can choose to complete. You can choose among options from take-home assignments, a writing project, and 2 exams (Exams 1 and 2, non-cumulative). Each assessment carries a specific number of Assessment Points. To qualify for a final grade, you must complete a minimum of 65 Assessment Points. At the end of the course, your final grade will be calculated relative to the total number of Assessment Points that you have completed, and converted to a letter grade (https://www.mcgill.ca/dise/resources/instructor-resources/gradgrade)

Why? The flexible assessment scheme is intended to give you flexibility in choosing which form of assessment you prefer, how much work you are willing to complete for the course, while giving you ample opportunity to earn a solid grade.

Quizzes: Weekly graded quizzes to be completed (on MyCourses) before the start of each class session. Quizzes are required.

Assignments: I will propose at least 4 assignments. These will consist of problem sets or open-ended questions to review the material or to explore certain topics in greater detail. Assignments may include programming in MATLAB. The due date will be clearly indicated on each MyCourses.

Writing project: Students can produce a project that will consist of a written paper and a short in-class presentation. Details, including dates of project milestones, will be distributed separately.

Exams:
Exam 1 (mid-term) will cover the material of the first half of the course. At this time, it is expected to be in a take-home format and is scheduled for Thursday, October 13th.
Exam 2 (end-of-term) will cover the second half of the course (non-cumulative). It will be held during the exam period and will be in a format compatible with the public health situation at the time. It is expected to be in a take-home format and is scheduled for Monday, December 12th.

Assessment	Available Assessment Points
Quizzes (required)	5
Assignments (each worth 5 points; at least 4 will be offered)	(5 × 5 =) 25
Writing Project	25
Exam 1	25
Exam 2	25

Total available	100

An example: Student A decides to complete 2 graded assignments (10 Assessment Points), the writing project (25 Assessment Points), and Exam 2 (25 Assessment Points). They obtain marks of (4.5/5 on quizzes; 4/5 and 5/5 on the assignments, 22/25 on the project; and 20/25 on exam 2). Their final grade is (4.5+4+5+22+20)/(5+5+5+25+25) = (55.5/65) = 85.4%, which converts to an A.

Barring exceptional circumstances, late submission of assessments with due dates will be assessed a penalty of 10% per day (or fraction of a day). Please plan ahead.

Proposed outline of classes

Date	Session #	TOPIC	ROOM	READING
30-Aug-23	1	Introduction and overview	DS1.5034	
4-Sep-23		NO CLASS – Labour Day		
6-Sep-23	2	Linear systems 1	DS1.1427	Part 1: 1-25
11-Sep-23	3	Linear systems 2	DS1.1427	Part 1: 26-50
13-Sep-23	4	Linear systems 3	B02.9390 or B08.3019	Part 1: 51-72
18-Sep-23	5	Radiography: basics	DS1.1427	Part 2: 1-19
20-Sep-23	6	Radiography: image quality	DS1.1427	Part 2: 20-36
25-Sep-23	7	Computed tomography	DS1.1427	Part 3: 1-16
27-Sep-23	8	Tomographic reconstruction	B02.9390 or B08.3019	Part 3: 17-37
2-Oct-23	9	Iterative tomographic reconstruction	DS1.1427	Part 3: 38-59
4-Oct-23	10	Advanced CT, image quality in CT	DS1.1427	Part 3: 60-73
9,11-Oct		NO CLASS – Thanksgiving & Fall break		
12-Oct-23	11	**EXAM 1 (note: this is a Thursday)**	**DS1.1427**	**14:00 – 17:00**
16-Oct-23	12	Spin physics	DS1.1427	Part 4: 1-22
18-Oct-23	13	B1 field, pulsed MR, excitation	DS1.1427	Part 4: 23-37
23-Oct-23	14	Relaxation, signal detection	DS1.1427	Part 4: 38-55
25-Oct-23	15	Echoes, sequences, spectroscopy	DS1.1427	Part 4: 56-74
30-Oct-23	16	Gradients, signal equation	DS1.1427	Part 5: 1-16
1-Nov-23	17	2D MRI and phase encoding	DS1.1427	Part 5: 17-34
6-Nov-23	18	Selective excitation	DS1.1427	Part 5: 35-49
8-Nov-23	19	Imaging pulse sequences	DS1.1427	Part 5: 50-74

13-Nov-23	20	Sampling, resolution, imaging time	DS1.1427	Part 5: 75-89
15-Nov-23	21	Noise & SNR	DS1.1427	Part 5: 90-103
20-Nov-23	23	MRI systems and safety	DS1.1427	*Notes handout*
22-Nov-23	23	Advanced MRI reconstruction	DS1.1427	*Notes handout*
27-Nov-23	24	**Project presentations**	DS1.1427	-
29-Nov-23	25	**Project presentations**	DS1.1427	
4-Dec-23	26	*Review session*	DS1.1427	-
8-Dec-23		**EXAM 2 (note: this is a Friday)**	**D02.1312**	**14:00–17:00**

Important — measures around infectious disease, and in particular respiratory illnesses:

COVID-19 disrupted our lives in a major way, and for some more than others. Pandemic measures have been eliminated at McGill, and for the purposes of this class, accommodations for COVID-19 will be the same as for all other respiratory illnesses. In the aftermath of the pandemic, it remains the case that if you find yourself struggling with material or keeping up with the work, let me know as early as possible so that I can help.

The location of our classes within the MUHC does mean that we have a responsibility to prevent the spread of infection. At times, stricter public health measures are in effect within the MUHC. You are expected to monitor your symptoms before coming to the MUHC Glen Site, and to follow public health measures applied by the MUHC, including wearing a mask when required. No food or drink is allowed in meeting rooms, except for water.

If you have a fever, stay home. If you have symptoms of a respiratory illness (runny nose, mild cough, mild sore throat), wear a mask in the hospital. If you test positive for COVID, have symptoms, or come in close contact with someone who has tested positive, do not come to class in person. Bring this up with me as soon as possible so that we can follow the required procedure of the MUHC and discuss accommodations. If you wish to discuss your concerns confidentially with someone else, refer to our Graduate Program Coordinator, Ms. Margery Knewstubb (margery.knewstubb@mcgill.ca).

McGill Policies:

1) *"In accord with McGill University's Charter of Student Rights, students in this course have the right to submit in English or in French any written work that is to be graded. This does not apply to courses in which acquiring proficiency in a language is one of the objectives." (Approved by Senate on 21 January 2009)*

« Conformément à la Charte des droits de l'étudiant de l'Université McGill, chaque étudiant a le droit de soumettre en français ou en anglais tout travail écrit devant être noté, sauf dans le cas des cours dont l'un des objets est la maîtrise d'une langue. »

2) *McGill University values academic integrity. Therefore all students must understand the meaning and consequences of cheating, plagiarism and other academic offences under the Code of Student Conduct and Disciplinary Procedures (see www.mcgill.ca/students/srr/honest/) for more information).*

NOTES

Under extreme circumstances, the contents of this document can be modified at any time by the instructor to allow for adjustments in the course.

Students are responsible for being aware of key dates and deadlines for the class and for the university, including deadlines for registration, course Add/Drop, and course withdrawal. Accommodations outside of these policies will only be supported in circumstances beyond the student's control.