MDPH-607: MEDICAL IMAGING (3 credits) – Fall 2024

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 all others.

Instructor: Prof. Ives Levesque, PhD, FCCPM
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Location: Class will be held 100% in-person in room DS1.1427, MUHC Glen Site (unless otherwise noted).

Course Schedule: Monday and Wednesday, 9:00 – 10:30 am
First class: Wednesday, August 28th, 2024

Student Hours: Wednesday 10:30 am to 11:30 am, or by appointment.

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. 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. For 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 class notes and brief overview videos about the material. There will be an online quiz linked to each session (except the opening session).
- Sessions will be held in-person. I will present the material with the intent to stimulate discussion of the concepts and imaging 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. Detectability and diagnostic efficacy.

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

Assessment in this class will consist of several parts, including regular quizzes, a few assignments, and two exams. The grading scheme will combine all of these assessments into a final grade out of 100, which will be converted to a letter grade (https://www.mcgill.ca/dise/resources/instructor-resources/gradgrade)

Quizzes: Graded quizzes will be completed (on MyCourses) anytime, including after each class session. Quizzes are intended to ensure that you keep up with the concepts presented in class and are required. The quiz for a given class is available for 24 hours after the end of that class.

Assignments: I will propose up to 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. The due date for each will be clearly indicated on MyCourses.

Presentation: Students will take on a literature research project that will result in 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. The mid-term exam will be held in person and closed book. The date and time for the exam will be indicated MyCourses and in the table on the next page.

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 held in person and closed book. The date and time for the exam will be indicated MyCourses and in the table on the next page.

Assessment	Available Assessment Points
Quizzes (required)	5
Assignments (each worth 5 points; up to 4 will be offered)	$(4 \times 5 =)$ 20
Project	20
Exam 1	25
Exam 2	30
Total	100

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	READING
28-Aug-24	1	Introduction and overview	Part 1: 1-13
2-Sep-24		NO CLASS – Labour Day	
4-Sep-24	2	Linear systems 1 **(room D02.1312)**	Part 1: 14-37
9-Sep-24	3	Linear systems 2	Part 1: 38-62
11-Sep-24	4	Linear systems 3	Part 1: 63-84
16-Sep-24	5	Radiography: basics	Part 2: 1-19
18-Sep-24	6	Radiography: image quality	Part 2: 20-36
23-Sep-24	7	Computed tomography	Part 3: 1-16
25-Sep-24	8	Tomographic reconstruction	Part 3: 17-37
30-Sept-24	9	Iterative tomographic reconstruction **(START @ 9:30)**	Part 3: 38-59
2-Oct-24	10	Advanced CT, image quality in CT	Part 3: 60-73
7-Oct-24	11	*Tour of CT & MRI*	
9-Oct-24	12	**EXAM 1 (in class)**	
14,16-Oct		NO CLASS – Thanksgiving & Fall break	
21-Oct-24	13	Spin physics	Part 4: 1-22
23-Oct-24	14	B1 field, pulsed MR, excitation	Part 4: 23-37
28-Oct-24	15	Relaxation, signal detection	Part 4: 38-55
30-Oct-24	16	Echoes, sequences, spectroscopy	Part 4: 56-74
4-Nov-24	17	Gradients, signal equation	Part 5: 1-16
6-Nov-24	18	2D MRI and phase encoding	Part 5: 17-34
11-Nov-24	19	Selective excitation **(room TBC)**	Part 5: 35-49
13-Nov-24	20	Imaging pulse sequences **(room TBC)**	Part 5: 50-74
18-Nov-24	21	Sampling, resolution, imaging time	Part 5: 75-89
20-Nov-24	22	Noise & SNR	Part 5: 90-103
25-Nov-24	23	MRI systems and safety	*Notes handout*
27-Nov-24	24	Advanced MRI reconstruction	*Notes handout*
2-Dec-24	25	**Project presentations**	
4-Dec-24	26	**Project presentations**	
9-Dec-24		**EXAM 2 (DS1.1427)**	**9:00–14:00**

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

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.

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

Measures around infectious disease and 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. Whooping cough is also 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 respiratory infections within the hospital. At times, slightly 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 test positive or have symptoms of COVID, symptoms of whooping cough, or come in close contact with someone who has tested positive for COVID, do not come to class in person. If you have mild cold symptoms (runny nose, cough, sore throat), wear a mask in the hospital. Bring this up with me as soon as possible so that we can follow the required procedure of the MUHC and discuss accommodations.