

## CompEng 4SP4 High-Performance Programming

### COURSE OUTLINE

Please refer to course website for updated information.

#### COURSE DESCRIPTION

High-performance computing, Code optimization, Loop optimization, Performance analysis, Compilers and basic code analysis, Vectorization, Code specialization and irregular computing, Parallelism in CPU and GPUs, Cache-aware and cache-oblivious algorithms, and runtime systems.

Two lectures, one tutorial, one lab every week

#### PRE-REQUISITES AND ANTI-REQUISITES

Prerequisite(s): Registration in any Computer Engineering or Electrical Engineering Program, CompEng 2SI3

#### SCHEDULE and MODE OF DELIVERY

The material for this course will be delivered through a mixture of in-person lectures, tutorials, and labs. The lectures, tutorials and labs will NOT be recorded.

Lecture: Tuesday and Wednesday at 9:30AM – 10:20 AM

Tutorial: Tuesday at 8:30AM – 9:20AM

Lab: Monday at 2:30PM – 5:20PM (ONLINE)

#### INSTRUCTOR

Dr. Kazem Cheshmi

Email: [cheshmi@mcmaster.ca](mailto:cheshmi@mcmaster.ca)

Office: ITB-A217

Office Hours: By appointments

#### TEACHING ASSISTANTS

Names, contact information, and office hours of TAs

Hossein Albakri: [albakri@mcmaster.ca](mailto:albakri@mcmaster.ca)

Mahdi Salehi: [salehm32@mcmaster.ca](mailto:salehm32@mcmaster.ca)

Samira Jamali: [jamalids@mcmaster.ca](mailto:jamalids@mcmaster.ca)

**COURSE WEBSITE/S**

<http://avenue.mcmaster.ca>

**COURSE OBJECTIVES**

By the end of this course, students should be able to:

- Measuring performance of a code, identify bottleneck, and propose new code optimization to improve the code performance.
- Demonstrate the connection between software and hardware components, e.g., caches, accelerators, vector units, etc clearly and use those components efficiently in their code.
- Implement complex real world software applications in collaborative environments and using different types of code optimizations in their code.

**CEAB GRADUATE ATTRIBUTES (GAS)**

Note: The CEAB Graduate Attributes (GAs) defined in this section are measured throughout the course and form part of the Department’s continuous improvement process. They are a key component of the accreditation process for the program and will not be taken into consideration in determining a student’s actual grade in the course. For more information on accreditation, please ask your instructor or visit: <http://www.engineerscanada.ca>

Attributes	Indicators		Measurement Method(s)
	Number	Description	
Problem Analysis	2.1	TBD	

**ASSUMED KNOWLEDGE**

Students should have a strong understanding of data structures and the principles of programming in Python and C++. A foundational knowledge of computer architecture, including caches, memory hierarchy, and pipelining, would also be beneficial.

**COURSE MATERIALS**

Textbook: There is **NO** textbook used in this course. The main sources of information are labs, lectures and tutorials.

Calculator: No calculator will be allowed during tests and examinations.

## COURSE OVERVIEW

Week	Topic	Readings
1	Introduction and course logistics	Lecture notes
2	Performance measurement and cache efficient algorithms	Lecture notes
3-4	Vectorization	Lecture notes
5	Bently Rules	Lecture notes
6	Sparsity and bit hacks	Lecture notes
7	No Lecture (reading week)	
8	What compilers can or cannot do?	Lecture notes
9-10	Multi-threading and runtime systems	Lecture notes
11	Synchronizations	Lecture notes
12-14	Single-instruction multiple thread programming with GPUs	Lecture notes
15	Presentations	

A more detailed timeline is available on the course website.

At certain points in the course, it may make good sense to modify the schedule. The Instructor may modify elements of the course and will notify students accordingly (in class and on the course website).

## LABORATORY OVERVIEW

**Labs are NOT held during the first week of term.**

Week	Topic	Readings
2	No Lab	
3	Lab 1. Working with the server, performance measurement	Lab Manual
4	Lab 1. Cache-tiling and Vectorization	Lab Manual
5	No Lab (holding office hours on other days instead)	
6	Lab 2. Sparsity	Lab Manual
7	No Lab (reading week)	
8	Lab 2. Vectorization for Sparsity	Lab Manual
9	Lab 2. Tiling for Sparsity	Lab Manual
10	Lab 3. Multi-threading using Pthread	Lab Manual
11	Lab 3. Multi-threading using OpenMP and TBB	Lab Manual
12	Lab 4. Getting started with GPUs	Lab Manual
13	Lab 4. Matrix multiplication on GPU	Lab Manual
14	Lab 4. Matrix multiplication on GPU	Lab Manual
15	Cross examination	Lab Manual

## LABORATORY OPERATION

- Each student in the course is required to pass the **lab safety** quiz prior to attempting any of the laboratories. The quiz will be on Avenue to Learn.
- The information on accessing and using the lab can be found on the webpage: <https://www.eng.mcmaster.ca/ece/labs-and-health-safety#Labs-Access-and-Use>
- There will be four labs that students will work on a weekly basis. The labs will cover the basics of high-performance programming followed by an end-to-end implementation of real-world applications. Labs also include analysis questions and students should report their analysis and measurement.
- You are allowed to work in **groups of two**. You must submit your source code and written reports for all labs.
- Although there are only 4 labs, each lab requires weekly progress as stated in the lab manual.
- Students are expected to exhibit honesty and use ethical behaviour in all aspects of the learning process, particularly during, but not limited to, the group work for lab and project deliverables. Note that these deliverables (including source code, and lab and lab reports) are forbidden from sharing in public repositories. Only the two partners from the same group should have access to their group's private repositories.

#### ASSESSMENT

Component	Weight
Quiz	5%
Midterm	25%
Presentation	10%
Labs	60%
Total	100%

- Students who miss the quiz and have a valid excuse will have a 5% larger weight allocated to the mid-term examination component of the final grade. Students who miss the midterm and have a valid excuse will be subjected to a make-up test. Anything (worth credit) missed without a valid excuse will be given zero marks. Please note that the instructor reserves the right to choose the format (e.g., written or oral) of any deferred midterm or exam in this course. Announcements concerning graded material may be made in any format (e.g., announcements may be made only in class).
- Before the "Last day for withdrawing from courses without failure by default" date, you will receive marks for some labs, constituting at least 25% of the final grade. Conversion from percentage to letter grade will be through the standard scale used in the Office of the Registrar. To pass the course, you must also obtain at least 40% on the midterm examination and at least 40% on labs. Statistical adjustments will not normally be used.

#### ACADEMIC INTEGRITY

You are expected to exhibit honesty and use ethical behaviour in all aspects of the learning process. The academic credentials you earn are rooted in principles of honesty and academic integrity. It is your responsibility to understand what constitutes academic dishonesty.

Academic dishonesty is to knowingly act or fail to act in a way that results or could result in unearned academic credit or advantage. This behaviour can result in serious consequences, e.g., the grade of zero on an assignment, loss of credit with a notation on the transcript (notation reads: "Grade of F assigned for academic dishonesty"), and/or suspension or expulsion from the University. For information on the various types of academic dishonesty, please refer to the Academic Integrity Policy, located at <https://secretariat.mcmaster.ca/university-policies-proceduresguidelines/>

The following illustrates only three forms of academic dishonesty:

- plagiarism, e.g., the submission of work that is not one's own or for which other credit has been obtained.
- improper collaboration in group work.
- copying or using unauthorized aids in tests and examinations.

#### **AUTHENTICITY / PLAGIARISM DETECTION**

Some courses may use a web-based service (Turnitin.com) to reveal authenticity and ownership of student-submitted work. For courses using such software, students will be expected to submit their work electronically either directly to Turnitin.com or via an online learning platform (e.g., A2L, etc.) using plagiarism detection (a service supported by Turnitin.com) so it can be checked for academic dishonesty.

Students who do not wish their work to be submitted through the plagiarism detection software must inform the Instructor before the assignment is due. No penalty will be assigned to a student who does not submit work to the plagiarism detection software. All submitted work is subject to normal verification that standards of academic integrity have been upheld (e.g., online search, other software, etc.). For more details about McMaster's use of Turnitin.com, please go to [www.mcmaster.ca/academicintegrity](http://www.mcmaster.ca/academicintegrity).

#### **COURSES WITH AN ONLINE ELEMENT**

Some courses may use online elements (e.g., email, Avenue to Learn (A2L), LearnLink, web pages, capa, Moodle, ThinkingCap, etc.). Students should be aware that, when they access the electronic components of a course using these elements, private information such as first and last names, user names for the McMaster email accounts, and program affiliation may become apparent to all other students in the same course. The available information is dependent on the technology used. Continuation in a course that uses online elements will be deemed consent to this disclosure. If you have any questions or concerns about such disclosure, please discuss this with the course instructor.

Some courses may use online proctoring software for tests and exams. This software may require students to turn on their video camera, present identification, monitor and record their computer activities, and/or lock/restrict their browser or other applications/software during tests or exams. This software may be required to be installed before the test/exam begins.

#### **COPYRIGHT AND RECORDING**

Students are advised that lectures, demonstrations, performances, and any other course material provided by an instructor include copyright-protected works. The Copyright Act and copyright law protect every original literary, dramatic, musical, and artistic work, including lectures by University instructors.

The recording of lectures, tutorials, or other methods of instruction may occur during a course. Recording may be done by either the Instructor for the purpose of authorized distribution or by a student for the purpose of personal study. Students should be aware that their voice and/or image may be recorded by others during the class. Please speak with the Instructor if this is a concern for you.

#### **CONDUCT EXPECTATIONS**

As a McMaster student, you have the right to experience and the responsibility to demonstrate respectful and dignified interactions within all of our living, learning, and working communities. These expectations are described in the Code of Student Rights & Responsibilities (the "Code"). All students share the responsibility of maintaining a positive environment for the academic and personal growth of all McMaster community members, whether in person or online. It is essential that students be mindful of their interactions online, as the Code remains in effect in virtual learning environments. The Code applies to any interactions that adversely affect, disrupt, or interfere with reasonable participation in University activities. Student disruptions or behaviours that interfere with university functions on online platforms (e.g., use of Avenue 2 Learn, WebEx or Zoom for delivery), will be taken very seriously and will be investigated. Outcomes may include restriction or removal of the involved students' access to these platforms.

#### **ACADEMIC ACCOMMODATIONS**

Students with disabilities who require academic accommodation must contact Student Accessibility Services (SAS) at 905-525-9140 ext. 28652 or [sas@mcmaster.ca](mailto:sas@mcmaster.ca) to make arrangements with a Program Coordinator. For further information, consult McMaster University's Academic Accommodation of Students with Disabilities policy.

Students requiring academic accommodation based on religious, indigenous or spiritual observances should follow the procedures set out in the RISO policy. Students should submit their request to their Faculty Office normally within 10 working days of the beginning of term in which they anticipate a need for accommodation or to the Registrar's Office prior to their

examinations. Students should also contact their instructors as soon as possible to make alternative arrangements for classes, assignments, and tests.

#### REQUESTS FOR RELIEF FOR MISSED ACADEMIC WORK

McMaster Student Absence Form (MSAF): In the event of an absence for medical or other reasons, students should review and follow the Academic Regulation in the Undergraduate Calendar "Requests for Relief for Missed Academic Term Work".

#### EXTREME CIRCUMSTANCES

The University reserves the right to change the dates and deadlines for any or all courses in extreme circumstances (e.g., severe weather, labour disruptions, etc.). Changes will be communicated through regular McMaster communication channels, such as McMaster Daily News, A2L and/or McMaster email.

[www.eng.mcmaster.ca/ece](http://www.eng.mcmaster.ca/ece)

## Electrical and Computer Engineering Lab Safety

### Information for Laboratory Safety and Important Contacts

This document provides important information for the healthy and safe operation of ECE instructional laboratories. This document is required reading for all laboratory supervisors, instructors, researchers, staff, and students working in or managing instructional laboratories in ECE. It is expected that revisions and updates to this document will be done continually. A McMaster University lab manual is also available to read in every laboratory and online <https://hr.mcmaster.ca/app/uploads/2019/07/2019-McMaster-Lab-Manual.pdf>

### General Health and Safety Principles

Good laboratory practice requires that every laboratory worker and supervisor observe the following whether conducting lab work at school or at home:

1. Food and beverages are not permitted in the instructional laboratories.
2. A Laboratory Information Sheet on each lab door identifying potential hazards and

emergency contact names should be known.

3. Laboratory equipment should only be used for its designed purpose.
4. Proper and safe use of lab equipment should be known before using it.
5. The course TA leading the lab should be informed of any unsafe conditions.
6. The location and correct use of all available safety equipment should be known.
7. Potential hazards and appropriate safety precautions should be determined, and the sufficiency of existing safety equipment should be confirmed before beginning new operations.
8. Proper waste disposal procedures should be followed.
9. Personal ergonomics should be practiced when conducting lab work. <https://bit.ly/3fOE71E>
10. Current University health and safety issues and protocol should be known. <https://hr.mcmaster.ca/resources/covid19/workplace-health-and-safety-guidance-during-covid-19/>

## Location of Safety Equipment

### Fire Extinguisher

On walls in halls outside of labs

### First Aid Kit

ITB A111, or dial "88" after 4:30 p.m.

### Telephone

On the wall of every lab near the door

### Fire Alarm Pulls

Near all building exit doors on all floors

## Who to Contact

**Emergency Medical / Security:** On McMaster University campus, call Security at extension **88** or **905-522-4135** from a cell phone.

**Non-Emergency Accident or Incident:** Immediately inform the TA on duty or Course Instructor.

**University Security (Enquiries / Non-Emergency):** Dial 24281 on a McMaster phone or dial 905-525-9140 ext. 24281 from a cell phone.

**See TA or Instructor:** For problems with heat, ventilation, fire extinguishers, or immediate repairs

**Environmental & Occupational Health Support Services (EOHSS):** For health and safety questions dial 24352 on a McMaster phone or dial 905-525-9140 ext. 24352 from a cell phone.

**ECE Specific Instructional Laboratory Concerns:** For non-emergency questions specific to the ECE laboratories, please contact 24103.

## In Case of a Fire (On Campus Dial 88)

When calling to report a fire, give name, exact location, and building.

1. Immediately vacate the building via the nearest Exit Route. Do not use elevators!
2. Everyone is responsible for knowing the location of the nearest fire extinguisher, the fire alarm, and the nearest fire escape.



3. The safety of all people in the vicinity of a fire is of foremost importance. But do not endanger yourself!
4. In the event of a fire in your work area shout "*Fire!*" and pull the nearest fire alarm.
5. Do not attempt to extinguish a fire unless you are confident it can be done in a prompt and safe manner utilizing a hand-held fire extinguisher. Use the appropriate fire extinguisher for the specific type of fire. Most labs are equipped with Class A, B, and C extinguishers. Do not attempt to extinguish Class D fires which involve combustible metals such as magnesium, titanium, sodium, potassium, zirconium, lithium, and any other finely divided metals which are oxidizable. Use a fire sand bucket for Class D fires.
6. Do not attempt to fight a major fire on your own.
7. If possible, make sure the room is evacuated; close but do not lock the door and safely exit the building.

## Clothing on Fire

Do not use a fire extinguisher on people

1. Douse with water from safety shower immediately or
2. Roll on floor and scream for help or
3. Wrap with fire blanket to smother flame (a coat or other nonflammable fiber may be used if blanket is unavailable). Do not wrap a standing person; rather, lay the victim down to extinguish the fire. The blanket should be removed once the fire is out to disperse the heat.

## Equipment Failure or Hazard

Failure of equipment may be indicative of a safety hazard - You must report all incidents.

Should you observe excessive heat, excessive noise, damage, and/or abnormal behaviour of the lab equipment:

1. Immediately discontinue use of the equipment.
2. In power labs, press the wall-mounted emergency shut-off button.
3. Inform your TA of the problem.
4. Wait for further instructions from your TA.
5. TA must file an incident report.

## Protocol For Safe Laboratory Practice

Leave equipment in a safe state for the next person - if you're not sure, ask!

In general, leave equipment in a safe state when you finish with it. When in doubt, consult the course TA.

## Defined Roles

TA	The first point of contact for lab supervision	
ECE Lab Supervisor	Steve Spencer - ITB 147	<a href="mailto:steve@mail.ece.mcmaster.ca">steve@mail.ece.mcmaster.ca</a>
ECE Chair	Mohamed Bakr - ITB A111	<a href="mailto:mbakr@mcmaster.ca">mbakr@mcmaster.ca</a>
ECE Administrator	Shelby Gaudrault - ITB A111	<a href="mailto:gaudraus@mcmaster.ca">gaudraus@mcmaster.ca</a>

ECE Course Instructor	Kazem Cheshmi – ITB A217	<a href="mailto:cheshmi@mcmaster.ca">cheshmi@mcmaster.ca</a>
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