# CS 442 / 542: Introduction to Parallel Processing

Fall 2023

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| **Instructor:** | Prof. Amanda Bienz | **Email:** | bienz@unm.edu |
| **Classroom:** | MechE 218 | **Class Time:** | M/W/F 11:00 – 11:50 |
| **Office:** | FEC 3500 | **Office Hours:** | TBD |

**Course Description:** CS 442/542 is a senior and graduate level course in parallel programming, covering shared memory, distributed memory, and heterogeneous systems. The course focuses on understanding parallel concepts, reformulating algorithms for parallelism, and modeling and optimizing the performance of parallel applications. At the end of the semester, you should be able to model the performance of a parallel application, determine performance bottlenecks, and reduce bottlenecks found in the models.

**Course Goals:** Students will learn how to use parallel computing systems at CARC, the basics of message-passing interface (MPI) programming, and how to improve the performance and scalability of parallel applications.

**Course Outcomes:** This course covers many topics in parallelism, including:

- Concept of parallelism in programming
- Parallel performance models
- Distributed memory parallelism
  - Message-Passing Interface (MPI)
  - Distributed system topologies
  - Performance versus scalability
  - Collectives
  - Point-to-point communication
  - Dense and sparse linear algebra
  - Distributed system performance models
  - Reliability and Fault Tolerance
  - Parallel I/O
- MPI+X
  - Shared memory parallelism
  - Threading and OpenMP for shared memory systems
  - State-of-the-art CPU + GPU systems
  - CUDA overview (brief)
  - OpenMP for accelerators
  - Heterogeneous performance models
- Recent research in parallel computing

**Course Format:** This is a fully face-to-face course. The course will not be live-streamed online. However, all classes will be recorded, and recordings will be posted within 24 hours of the end of class. If you are unable to find a recording, please send an email to bienz@unm.edu. In the event that a recording is unsuccessful, you will be responsible for finding notes for missed material.

**Undergraduate Requirements:** Students will complete term projects, researching a topic related to parallel processing. Grades are given based on the standard 10-point scale (90-100 A, 80-89 B, etc.). There will be pluses and minuses (e.g. 90-93 is A-). There will be no curve for the course. The grades are broken down as follows:

- In-class questions (10%)
- Midterm Exam (15%)
- Homework assignments (40%)
- Final project (35%)

**Graduate Requirements:** Students will complete term projects, researching a topic related to parallel processing. Graduate students will also be required to complete extra homework questions. Grades are given based on the standard 10-point scale (90-100 A, 80-89 B, etc.). There will be pluses and minuses (e.g. 90-93 is A-). There will be no curve for the course. The grades are broken down as follows:

- In-class questions (10%)
- Midterm Exam (15%)
- Programming Challenges (20%)
- Homework assignments (20%)
- Final project (35%)

**Course Materials:** There is no textbook required for this course. However, the following books are helpful resources.

- Parallel and High Performance Computing by Robert Robey and Yuliana Zamora
  **ISBN 9781617296468**
- Introduction to High Performance Computing for Scientists and Engineers by Georg Hager and Gerhard Wellein
  **ISBN 9781439811924**
- Introduction to Parallel Computing (2nd Edition) by Ananth Grama, George Karypis, Vipin Kumar, and Anshul Gupta
  **ISBN 9780201648652**

The class will loosely follow "Parallel and High Performance Computing" (listed above).

**Prerequisites:** As a senior and graduate level class, it is expected that you have basic programming experience and are able to program in either C, C++, or Fortran as these are the languages that support OpenMP and MPI. You will be able to use Python instead at times, but there may be assignments requiring either C, C++, or Fortran. You will be allowed to do homework assignments in the language of your choice, but C or C++ are recommended if you plan to utilize office hours. Finally, as all parallel programs will be compiled and run on UNIX systems, command line experience is useful. Instructions will be given for how to compile and run a simple program on these systems. Students are expected to have varying backgrounds in the topics of computer architecture, Parallel programming, and numerical methods. Prior to taking this course, each student should have experience with at least one of the following topics.

- Computer architecture (CS341)
- Big data computing (CS567)
- Scientific computing (CS471 / MATH471)

**Attendance Policy:** All classes will be held in person. Attendance is not required, but you will be responsible for material covered during each class. In the event you are unable to attend a course, a recording of the class should be posted online within 24 hours. If a recording is not available, please send an email to bienz@unm.edu. In the event that a recording is unsuccessful for any reason, you will be responsible to find notes that cover content for days not attended. All slides will be posted online before each class.

There will be in-class questions due at the end of many classes. Missed in-class questions cannot be made up, but the lowest score will be dropped. The purpose of the in-class questions is to determine the level of understanding of class material and whether further time should be spent on a topic.

**Incomplete and Late Assignments:** All homework assignments are due on Fridays at 5pm. Grading of assignments will not begin before Monday at 9am. Late assignments will be accepted for full credit if turned in before grading begins. However, emails and discord questions about assignments are not guaranteed to be answered after the Friday 5pm deadline. Late assignments are accepted but penalized until grades are returned unless a valid excuse is communicated before the deadline. If the deadline is missed due to unforeseeable circumstances, we will work something out. Barring a valid excuse, an assignment will be accepted for a 50% reduction once grading has begun. Once grades have been returned, assignments will no longer be accepted. Grades will typically be returned within 2 weeks of the deadline.

**Regrading Requests:** Requests for regrading of assignments or exams should be made within one week of the date from which the assignment is returned. Assignments will not be regraded after that point. Regrading requests can be made via email.

**Academic Integrity:** Each student is expected to maintain the highest standards of honesty and integrity in academic and professional matters. The University reserves the right to take disciplinary action, up to and including dismissal, against any student who is found guilty of academic dishonesty or otherwise fails to meet the standards. Any student judged to have engaged in academic dishonesty in course work may receive a reduced or failing grade for the work in question and/or for the

course. Academic dishonesty includes, but is not limited to, dishonesty in quizzes, tests, or assignments; claiming credit for work not done or done by others; hindering the academic work of other students; misrepresenting academic or professional qualifications within or without the University; and nondisclosure or misrepresentation in filling out applications or other University records.

**Online Resources:** This class has a zero tolerance policy for Chegg and similar online resources. Course assignments, in-class questions, and exams should not be redistributed or posted online without permission. If you are caught using Chegg or a similar resource, you will automatically fail the course.

ChatGPT can be used as a resource (e.g. help you debug) but you are expected to understand all code that you submit for homework. You will be expected to answer questions about code that you submit for the course and your homework grade will be subject to these answers.

You will use github for tutorials and semester projects. You are welcome to make these repositories public, and I encourage you to showcase your semester projects!

**Accommodations for Disabilities:** UNM is committed to providing courses that are inclusive and accessible for all participants. As your instructor, it is my objective to facilitate an accessible classroom setting, in which students have full access and opportunity. If you are experiencing physical or academic barriers, or concerns related to mental health, physical health and/or COVID-19, please consult with me after class, via email/phone or during office/check-in hours (I am not legally permitted to inquire about the need for accommodations). We can meet your needs in collaboration with the Accessibility Resource Center (https://arc.unm.edu/) at arcsrvs@unm.edu or by phone (505) 277-3506.
**Support:** Contact me at bienz@unm.edu or in office hours and contact Accessibility Resource Center (https://arc.unm.edu/) at arcsrvs@unm.edu (505) 277-3506 . **Credit-Hours:** This is a three credit-

hour course. Class meets for three 50-minute sessions of direct instruction for fifteen weeks during the semester. Please plan for a minimum of six hours of out-of-class work (or homework, study, assignment completion, and class preparation) each week.

**Sexual Harassment and Title XI:** Our classroom and our university should always be spaces of mutual respect, kindness, and support, without fear of discrimination, harassment, or violence. Should you ever need assistance or have concerns about incidents that violate this principle, please access the resources available to you on campus. Please note that, because UNM faculty, TAs, and GAs are considered "responsible employees" by the Department of Education, any disclosure of gender discrimination (including sexual harassment, sexual misconduct, and sexual violence) made to a faculty member, TA, or GA must be reported by that faculty member, TA, or GA to the university's Title IX coordinator. For more information on the campus policy regarding sexual misconduct, please see: https://policy.unm.edu/university-policies/2000/2740.html.

**COVID-19:** UNM is a mask friendly, but not a mask required, community. To be registered or employed at UNM, Students, faculty, and staff must all meet UNM's Administrative Mandate on Required COVID-19 vaccination. If you are experiencing COVID-19 symptoms, please do not come to class. If you have a positive COVID-19 test, please stay home for five days and isolate yourself from others, per the Centers for Disease Control (CDC) guidelines. If you do need to stay home, please communicate with me at bienz@unm.edu; I can work with you to provide alternatives for course participation and completion. UNM faculty and staff know that these are challenging times.

Please let us know that you need support so that we can connect you to the right resources and please be aware that UNM will publish information on websites and email about any changes to our public health status and community response.

Support:

Student Health and Counseling (SHAC) at (505) 277-3136. If you are having active respiratory symptoms (e.g., fever, cough, sore throat, etc.) AND need testing for COVID-19; OR If you recently tested positive and may need oral treatment, call SHAC.

LoboRESPECT Advocacy Center (505) 277-2911 can offer help with contacting faculty and managing challenges that impact your UNM experience.

**Tentative Class Schedule** The following is an example of what the course schedule may look like. This schedule will be adjusted as needed throughout the semester. For an up-to-date schedule, check out the course webpage www.amandabienz.com/cs442. If you have any additional topics related to parallelism that you would like to cover, please let me know!

| Week | Day | Content |
|---|---|---|
| 1 | Monday | Course Info, Introduction to Parallel Processing |
| 1 | Wednesday | Distributed Systems |
| 1 | Friday | CARC System Overview |
| 2 | Monday | Point-to-point Communication |
| 2 | Wednesday | Collective Communication |
| 2 | Friday | Parallel Debugging |
| 3 | Monday | **Labor Day – No Class** |
| 3 | Wednesday | Distributed Matrix Multiplication |
| 3 | Friday | Advanced Point-to-Point Communication |
| 4 | Monday | Sparse Matrices and Irregular Communication |
| 4 | Wednesday | Parallel Performance |
| 4 | Friday | Profiling and Tracing |
| 5 | Monday | Parallel Performance Modeling |
| 5 | Wednesday | Collective Algorithms |
| 5 | Friday | Performance of Collective Algorithms |
| 6 | Monday | MPI Communicators and Topologies |
| 6 | Wednesday | Parallel I/O |
| 6 | Friday | MPI I/O |
| 7 | Monday | One-Sided Communication |
| 7 | Wednesday | MPI Research Topics |
| 7 | Friday | MidTerm Review |

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| 8 | Monday | Tentative Midterm Data – **Date likely to move!** |
| 8 | Wednesday | Shared Memory Programming - OpenMP |
| 8 | Friday | **Fall Break – No Class** |
| 9 | Monday | OpenMP False Sharing |
| 9 | Wednesday | OpenMP Performance Modeling |
| 9 | Friday | OpenMP Numa Regions |
| 10 | Monday | GPU Introduction |
| 10 | Wednesday | All about CUDA |
| 10 | Friday | Sandia Guest Lecture – **Date likely to move!** |
| 11 | Monday | OpenMP Offloading |
| 11 | Wednesday | MPI + X |
| 11 | Friday | MPI Shared Memory |
| 12 | Monday | Heterogeneous Performance |
| 12 | Wednesday | Kokkos |
| 12 | Monday | Charm++ |
| 13 | Wednesday | |
| 13 | Friday | |
| 13 | Monday | |
| 14 | Wednesday | |
| 14 | Friday | **Thanksgiving Break – No Class** |
| 15 | Monday | |
| 15 | Wednesday | |
| 15 | Friday | |
| 16 | | Final Presentation Week |