ECE/CSC 506, ECE 406:
Architecture of Parallel Computers
Syllabus – Fall 2024

Lecture: Mon, Wed @ 3:00-4:15pm, EB3 2124
Instructor: Dr. Greg Byrd, Professor, ECE, gbyrd@ncsu.edu, 919-513-2508

Office Hours:
Use gbyrd.youcanbook.me to set up an in-person or Zoom appointment.

Course Content and Student Learning Outcomes

This course introduces the foundational concepts in parallel computer architecture, with a focus on shared memory multicore processors. The primary topics include cache coherence protocols, memory consistency models, synchronization mechanisms, and interconnection networks. Students will also be introduced to shared memory parallel programming

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

- Use OpenMP directives to convert sequential code to parallel.
- Explain how to partition a problem for parallel execution, and analyze the performance of various partitioning schemes.
- Analyze the scalability of a parallel program.
- Design and analyze a cache coherence protocol.
- Given a trace of memory operations, determine the actions performed under various cache coherence protocols, and analyze performance under various workloads.
- Given a trace of memory operations, determine the possible outcomes under various memory consistency models.
- Describe architectural mechanisms to enforce memory consistency models, and analyze performance under various workloads.
- Describe the implementation of atomic memory operations.
- Implement synchronization primitives using atomic memory operations, and implement higher-level synchronization using primitives.
- Explain the fundamental components and properties of high-performance network-on-chip (NOC) and system-area network (SAN) interonnects.

Attendance and Course Delivery Mode

Attending class is the best way to learn the material, because it gives you the chance to ask questions, engage with the concepts, and devote time to this specific class. While all lectures will be recorded, and the recordings will be available to all students, this is intended for review and catching up on missed classes. Unless you are in the Engineering Online (EOL) section, watching recordings is not the preferred instructional mode. We will have some in-class interactive activities, so you should bring your laptop and/or phone to every class. You may not use your laptop/phone to browse other websites, play games, or work on other classes.

However, class attendance is not mandatory, and you do not need to inform the instructor or provide an excuse for missing class. Your grade will not be penalized for missing in-class assignments.

Students in the EOL section are expected to watch the recorded lectures on a schedule that is as close as possible to the in-person lectures. Unless otherwise arranged, EOL students will have the same submission deadlines as other students. EOL students are not expected to participate in the in-class activities, but are encouraged to use those activities to enhance learning.

Exams will be held at the scheduled class times. If you have an anticipated university-excused absence for an exam, you must contact me ahead of time to make alternate arrangements. Students eligible for testing accommodations will be given extended time and will arrange a separate location/time for the exam. (For EOL students, see information about exams below.)

Prerequisites

There are no formal prerequisites (except for ECE 406), but you are expected to be comfortable with basic computer organization/architecture, instruction sets, and assembly language. You will be required to write and analyze code written in C/C++.Familiarity with digital design and operating systems will also be helpful.

The prerequisite for ECE 406 is ECE 310, but this is really a stand-in for completing one or more 300-level ECE courses. Other ECE courses that provide useful background knowledge include 209, 306, 309, 463, and 465. For CSC students, a similar list would include 230, 236, 246, 316, and 456.

GER Information

This course is *not* designated as a General Education Requirement.

Textbooks

There are one required textbooks:

- *Required*:

Yan Solihin
Fundamentals of Parallel Multicore Architecture: Multichip and Multicore Systems
Chapman and Hall/CRC, 2016. ISBN 978-1482211184.

Students will also be required to use the following tools:

- **Moodle** for accessing all course materials and announcements, and for submitting some assignments. See https://wolfware.ncsu.edu.
- **Gradescope** for submitting some assignments, and for retrieving graded exams.
- **TopHat** for in-class activities. If you already have a Top Hat account, go to https://app.tophat.com/e/068048 to be taken directly to our course. Otherwise:
    - Go to https://app.tophat.com/e/06804
    - Click on "Log in with school account" and use your NC State credentials to sign in

  Or get the Top Hat app on your device:
    - To login, specify **NC State University** as your school, and login with your NC State credentials
    - Search for this course using join code **06804**
- **Discord** for asking questions online. If you ask a question, other students can answer in addition to the TA/instructor, and everyone benefits from seeing the question and answer. We may also post hints and suggestions on assignments. You can ask a private question, with your code attached, to get individual help with assignments. See the Moodle page for a Discord invitation link.
- Projects will require programming, and will require the use of university **HPC** resources. You will be required to use **Linux** commands and tools to compile and execute programs.

Topics and Reading Assignments

The following is a planned schedule of topics covered and the associated textbook chapters/sections. Most reading assignments will include a *reading quiz* on Moodle that will be part of the course grade. Pay attention to announcements in class and on Moodle; they will take priority over this plan.

Dates	***Topics***	***Reading***
Aug 19 - Aug 21	Introduction, Parallel Programming	1.2, 2.1, 2.2.1-2
Aug 24 - Sep 9	Shared Memory Programming, OpenMP	3.1-3.10
Sep 11 - Sep 16	Caches	5.1-5.7
Sep 18	Shared Memory Architecture	6.1-6.3
Sep 23 - Sep 30	Cache Coherence: Snoopy Protocols	7.1-7.5

Sep 30 - Oct 2	Synchronization	8.1-8.2
Oct 7	*Midterm Exam (EOL window: 10/7 - 10/8)*	
Oct 9 - Oct 21	Memory Consistency	9.1-9.4
Oct 23 - Oct 30	Cache Coherence: Directory Protocols	10.1-10.5
Nov 4 - Nov 6	Interconnection Networks	11.1-11.4
Nov 11 - Nov 13	Parallel Programming for Linked Data Structures, Transactional Memory	4.1-4.4, 8.3
Nov 18 - Nov 27	TBD	
Dec 11	*Final Exam (EOL window: 12/10 - 12/11*	

Assignments and Grading

The overall class grade will be a weighted average of the following components:

- Reading Quizzes (10%)
- Homework (35%)
- Projects (15%)
- Exams (40%)

Reading Quizzes (10%)

For each lecture during the semester, there is a specific reading assignment posted on Moodle. There will be a short Moodle quiz associated with each reading assignment, **due at 2:30pm** the day of the lecture. **The quiz will have a time limit**, so that you are incentivized to do the reading first, and then attempt the quiz, rather than searching the text for answers without careful reading. Completing the reading before lectures will prepare students for the topic to be discussed, which will hopefully lead to more questions and better discussions during the lecture time.

Quiz questions may be selected from a random pool of questions. You will have two attempts at each quiz, and the highest score will be used for your grade. My recommendation is: (1) Do the reading and try to summarize the main points. (2) Take the quiz. (3) If you are not satisfied with the score on the quiz, do the reading again, concentrating on the parts that gave you trouble. But remember that you may not get the same questions on a second attempt. (4) Take the quiz again, hopefully with a better result.

Quizzes must be completed individually, not as a group, and you may not copy answers from other students. Evidence of such collaboration will be investigated as a violation of the Code of Student Conduct.

Because I am mostly interested in getting you to read the material and attempt the quiz, there will be a "participation" question in each quiz that will give you points just for answering. But some portion of the quiz grade will be based on correctness of the answers, because I want you to read for learning. (Do not wait until the last minute to do the reading and quizzes!)

To account for occasional absences and other conflicts that might cause you to miss some readings, the *three lowest quiz grades will be dropped*. This includes excused absences. However, if an extended absence causes you to miss more than three quizzes, please discuss with the instructor. (If you have already missed three quizzes before your excused absence, you will probably not be allowed to drop additional quiz grades.)

EOL students will have the same deadlines for the quizzes (2:30pm), even though they will not be participating in the lectures until later.

The reading quizzes for 406 and 506 will be the same.

Homework (35%)

There will be four homework assignments during the semester. These questions will be more detailed and open-ended than what is feasible for a reading quiz, and they are intended to prepare you for the types of questions that you may see on an exam. However, a homework question may also take more time than would be reasonable for an exam question, as they will be designed to get students to solve problems and more deeply engage with the course material.

Homework assignments will be submitted via Gradescope (or Moodle), and graded homeworks will be returned electronically. There will be at least one week between the posting of a homework assignment and its due date. An assignment may be submitted up to 24 hours late with a grade penalty of 0.4% per hour, which is 9.6 for 24 hours. (You do not need to request a late submission date; just submit late, and the penalty will be automatically applied.) If you have a short excused absence, you will still be expected to submit on time, but if there are extenuating circumstances, discuss with the instructor.

Homework assignments must be completed individually, not as a group, and you may not copy answers from other students. You are allowed to discuss homework questions with other students and on the Discord server, as long as specific answers are not shared. (See section on Academic Integrity.) Evidence of such collaboration will be investigated as a violation of the Code of Student Conduct. **The minimum penalty for cheating on a homework assignment is a grade of zero on the assignment.**

There may be certain questions, or parts of questions, that are required for 506 students but not for 406 students.

Projects (15%)

Two projects will be assigned during the semester. Projects require programming effort, both for writing parallel programs and for writing simulators that model the behavior of parallel computers.

Projects will be submitted via Gradescope (or Moodle), and graded projects will be returned electronically. There will be at least three weeks between the posting of a project and its due date. A project may be submitted up to 48 hours late with a grade penalty of 0.4% per hour, which is 19.2% for 48 hrs. (You do not need to request a late submission date; just submit late, and the penalty will be automatically applied.) If you have a short excused absence, you will still be expected to submit on time, but if there are extenuating circumstances, discuss with the instructor.

Projects must be completed individually, not as a group, and you may not copy answers from other students. You are allowed to discuss projects with other students and on the Discord server, as long as specific answers are not shared. (See section on Academic Integrity.) Evidence of such collaboration will be investigated as a violation of the Code of Student Conduct. **The minimum penalty for cheating on a programming assignment is a grade of zero on the assignment.**

There may be certain components of the project that are required for 506 students but not for 406 students.

Exams (40%)

There will be one midterm and one final exam, each worth 20% of your grade.

Evidence of cheating on any exam will be investigated. If there is sufficient cause, the incident will be referred to the Office of Student Conduct as an Academic Integrity violation. **The minimum penalty for cheating on a quiz is a grade of zero on that quiz.** See the NCSU Code of Student Conduct for information about what constitutes cheating.

If you miss an exam because of an excused absence, talk with the instructor as soon as possible. At the instructor's discretion, you may be required to take a makeup exam, or there may be some other arrangement regarding the exam grade. (A makeup exam is much more likely.)

For on-campus students, exams will take place during the normal class period, in the same classroom as lectures.

For EOL students, exams must be proctored by an approved, in person proctor, according to the policies and procedures established by the Engineering Online program. **Students should submit a proctor request to the Engineering Online Exams Office within the first three weeks of the semester**.

Use the Engineering Online Student Center to identify what proctor you will use. (This must be done every semester!) A proctor must be approved by Engineering Online staff to administer quizzes and exams. The proctor is responsible for adhering to all NC State, Engineering Online and instructor policies regarding exam administration. No exams will be made available to students who do not have an approved proctor.

There may be certain questions, or parts of questions, that are required for 506 students but not for 406 students.

Exam dates:

- Midterm: Oct 7 (subject to change), 3:00pm - 4:15pm, EOL window: Oct 7-8
- Final: Dec 11, 3:30pm - 6:00pm, EOL window: Dec 10-11

Final Course Grade

The final grade for the course will be based on a weighted average of the above components. The +/- grading system will be used for this course. These score breakpoints are specific and absolute; *grades will not be rounded up*. There are always adjustments made on exam grades throughout the semester, and any sort of rounding has already been baked into your final grade.

Numerical Score	Letter Grade	Numerical Score	Letter Grade
97 ≤ score ≤ 100	A+	77 ≤ score < 80	C+
92 ≤ score < 97	A	72 ≤ score < 77	C
90 ≤ score < 92	A-	70 ≤ score < 72	C-
87 ≤ score < 90	B+	66 ≤ score < 70	D+
82 ≤ score < 87	B	60 ≤ score < 66	D
80 ≤ score < 82	B-	55 ≤ score < 60	D-
		0 ≤ score < 55	F

Class Policies and Resources

Computer Resources

Course web site: http://wolfware.ncsu.edu

All class announcements will be posted to the Announcement Forum on Moodle. The Moodle site will also contain lecture notes, past exams, and other relevant information. Every student in the class is automatically subscribed to receive notifications from the Announcements forum. Make sure that these emails are not going to your spam folder, and please read the announcements when they are posted. (I promise to only use the Announcements forum for information relevant to all students.)

Discord will be used for class discussion. Rather than emailing questions to the teaching staff, I encourage you to post your questions on the forums. When asking for help with a project, post a *private* message with your code attached.

Please make sure that posted material is appropriate and course-related. Do not post insulting jokes, offensive material, job listings, for-sale ads, virus alerts, etc. **Do not post quiz/homework solutions. Do not post any code that may be used for projects.** Any post that contains specific code must be private. If the forums are abused, they will be deleted, and the abusers will be referred to the Office of Student Conduct.

If you want to post a question that only the TAs and I can see, make it a private post. Use this, for example, if you have specific questions about code, or questions that contain code. Again, this is better than email, because all of us will see the question, and we will all see the responses, as well.

Office Hours

Individual office hours are by appointment. It is very easy to book an appointment -- just go to `gbyrd.youcanbook.me` to select an available slot. Bookings are for 30-minute slots. These slots are synched with my calendar. A new appointment will appear on my calendar, and will send me an email. I can meet with you in person or via Zoom. Specify what sort of meeting you want. (If you want to discuss code, Zoom would be the best choice, so that we can use screen sharing.)

If you set up a Zoom meeting with me, my preference is that you enable your video. It's your choice, but I would much rather see the person with whom I am talking.

My personal Zoom meeting room is set up to use a Waiting Room. This allows me to control when someone connects. If I am having a private meeting with someone else (e.g., discussing grades or some other personal information), you may end up waiting for a bit. Please be patient -- I will connect with you as soon as it is appropriate.

Late Submissions and Absences

Both homework and project assignments may be submitted late, with a reduction in grade. Quizzes may not be submitted late.

Homework: Up to 24 hours late, with 0.4% grade reduction per hour

Project: Up to 48 hours late, with a 0.4% grade reduction per hour

You do not need to request a late submission for homework or projects. Just submit within the allowed timeframe and the grading reduction will be automatically applied. (Please do not email me to ask permission to submit late!)

An extended absence may be justification for a late submission, but this must be discussed with the instructor. There is ample time to complete the assignment after the announcement, and I strongly recommend that you start working early to avoid

issues with unexpected absences. (For example, if you get sick on the last day before a project is due, I will expect to see that you have made significant progress prior to the absence.)

Reading quizzes will not be made up and cannot be submitted late. Your three lowest quiz grades will be dropped, which allows for up to three absences. For extended absences or other extenuating circumstances, discuss this with the instructor.

If you miss an exam because of an excused absence, talk with the instructor as soon as possible. At the instructor's discretion, you may be required to take a makeup exam, or there may be some other arrangement regarding the exam grade. (A makeup exam is much more likely.)

For more information about University-approved absences, see:
https://policies.ncsu.edu/regulation/reg-02-20-03-attendance-regulations/

Incomplete Grades

An incomplete grade will be assigned when a student cannot complete the course due to *unforeseeable* conflicts or obstacles. Per University policy, the incomplete must be resolved by the end of the next enrolled regular semester. For more information about IN grades, see this NC State policy: https://policies.ncsu.edu/regulation/reg-02-50-03/.

Academic Integrity

High-level discussions with other students on homework and projects is allowed, but copying of solutions or source code is not. Students may discuss high-level concepts and strategies only, not specific solutions or code. You must be very careful to avoid sharing code and/or solutions with other students. **Only the TAs or I may look at your code.** There are **no exceptions** to this policy; do not show your code to anyone, including your friends, parents, tutor, mentors, therapist, random people on the Internet, etc.

Example of high-level discussion (allowed): "First find the maximum value in the array. Then look at each value in the array, and increment a counter if the max is a multiple of that value."

Example of code-level discussion **(not allowed)**: "Write a for-loop that makes i go from 1 to n-1. Create a variable named max and initialize it to x[0]. Inside the loop, compare x[i] to max to see if it's greater…"

Example of code-level discussion **(not allowed)**: "Please look at my code and help me figure out what's going wrong."

If in doubt, stop talking!!! If your classmate keeps asking detailed questions or wants to see your code, tell him or her to talk with me or a TA. You may want to help, but you are expected to comply with the NCSU Code of Student Conduct, and with the academic integrity policies of this class. Do not, under any circumstances, look at anyone else's code or give your code to anyone else.

Private tutors are allowed and encouraged. But the policy above applies to those people. They can help you understand concepts or discuss high-level design, but they are not allowed to help you debug or write code. Talk to them like you would talk to another student to get suggestions on how to get started or how to approach a problem. Tutors may be used to help you understand material. They can help you understand what you missed on an exam. They can help you figure out how to study more effectively. They are not resources for completing assignments.

Any work submitted for this class (quiz, homework, exam, project) is subject to the *Honor Pledge*: "I have neither given nor received unauthorized aid on this test or assignment." An Honor Pledge statement must be explicitly signed for every exam. For other assignments, it is the understanding and expectation of the instructor that the submission of work with your name on it means that you neither gave nor received unauthorized aid.

Evidence of copying or any other use of unauthorized aid on exams, homework, quizzes, or projects will be investigated and potentially referred to the Office of Student Conduct as a violation of the Code of Student Conduct.

For more information on the Code of Student Conduct, see:
https://studentconduct.dasa.ncsu.edu/
http://policies.ncsu.edu/policy/pol-11-35-01

We will use electronic tools to check for cheating on programming assignments. Submissions with high levels of similarity will be investigated and potentially referred to the Office of Student Conduct.

Discrimination, Harassment, and Violence

NC State University is committed to eliminating sexual harassment, sexual violence and interpersonal violence. NC State complies fully with Title IX, a federal law that prohibits gender-based discrimination of both employees and students. If you are affected, you can find resources and/or file a report at https://oied.ncsu.edu/divweb/safe/. Resources include medical and counseling services, academic and housing support, referrals to legal and confidential advocacy organizations and more.

I am committed to creating and maintaining an environment free of discrimination and harassment of any kind.

I am open and available to discuss any incidents involving discrimination, harassment, or violence, and I will help you find resources for help. However, I cannot be a confidential resource. I am required to report incidents of sexual discrimination, sexual violence, and other misconduct to the Title IX coordinator. You do have the right to request confidentiality from the University, and you may share information confidentially with the Counseling Center, Student Health Center, or a religious counselor.

Students with Disabilities

Reasonable accommodations will be made for students with verifiable disabilities. In order to take advantage of available accommodations, Raleigh campus students must register with the Disability Resources Office, 515-7653. http://dro.dasa.ncsu.edu/ (For students at other campuses, please consult with your program coordinator and your disability services office.)

If you are eligible and wish to have additional time on exams, you must make arrangements with me well in advance. Such exams will be administered at the DRO or the DELTA testing center. (Students at other campuses, please consult with your program coordinator.)

For more information on NC State's policy on working with students with disabilities, please see: http://dro.dasa.ncsu.edu/

Course Evaluations

Online class evaluations will be available for students to complete during the last several days of class. Students will receive an email message directing them to a website where they can login using their Unity ID and complete evaluations. All evaluations are confidential; instructors will never know how any one student responded to any question, and students will never know the ratings for any particular instructors.

Evaluation website: https://classeval.ncsu.edu Student help desk: classeval@ncsu.edu
More information about ClassEval: https://isa.ncsu.edu/for-the-pack/classeval/

Laboratory Safety, Physical Activity, and Field Trips

There is no laboratory, physical activity, or field trip associated with this course.

Extra Expenses

There are no expenses, except for required textbooks.

Transportation

As there are no field trips or internships associated with this course, there are no expected transportation requirements.

Important Dates

Aug 19	First day of class
Sept 2	Labor Day – no classes
Oct 7	Mid-term exam (tentative)
Oct 7-8	EOL mid-term exam (tentative)
Oct 14-15	Fall Break -- no classes
Oct 17	Last day to drop (406, 506) or change to S/U grading (406)
Nov 22 - Dec 3	"Dead Week" – no **new** assignments or exams during this week.
Nov 27-29	Thanksgiving Holiday -- no classes
Dec 3	Last day of class
Dec 11	Final Exam, 3:30-6:00pm
Dec 10-11	EOL final exam