ECE 569 – Spring 2017
High Performance Computing: Technology, Architecture, and Algorithms (3 credits)
TTh 9:30am-10:45am, Room: Education 432

Instructor : Ali Akoglu (www.ece.arizona.edu/~akoglu)
Office : ECE 356B
Phone : (520) 626-5149
Email : akoglu@ece.arizona.edu
Office Hours : Wednesdays 10:00am-11:00am, Thursdays 3:30pm-4:30pm

Description of Course:
ECE 569 stresses the need for and the design of high-performance computing (HPC) systems. HPC is more than just for achieving high performance - it is a compelling vision for how computation can seamlessly scale from a single processor to virtually limitless computing power. The single enabling force for HPC is the use of parallelism. The market demands general-purpose processors that deliver high single threaded performance as well as multi-core throughput for a wide variety of workloads on client, server, and high-performance computing (HPC) systems. This pressure has given us almost three decades of progress toward higher complexity and higher clock rates. Each new generation of process technology requires ever more heroic measures to improve transistor characteristics; each new core microarchitecture must work disproportionately harder to find and exploit instruction-level parallelism (ILP). New commodity parallel computing devices, bring the originally elite high performance computing into the reach of general public. To program and accelerate applications on the new high performance computing devices, we must understand both the computational architecture and the principles of program optimization. This course will (a) provide an overview of existing High-Performance Computing (HPC) software and hardware, (b) present basic software design patterns for high performance parallel computing, (c) introduce CUDA for parallel computing on the Graphics Processing Unit (GPU), (d) compare GPU programming model with the OpenMP and the Message Passing Interface (MPI) standard for leveraging parallelism on a cluster. The approach is hands-on, the students are expected to use the lecture information, a series of assignments and a final project to emerge at the end of the class with parallel programing knowledge that can be immediately applied to their research projects. We will evaluate power, memory and ILP challenges from the perspectives of Programming Model, Computational Model, Processor Architecture Model, Threading Model, Memory Model and Power Model. Therefore, this course will provide students with an in-depth analysis of these current issues in HPC systems including: (1) Parallel Computing (2) New Processor Architectures, and (3) Power-Aware Computing and Communication. In addition, we will also study parallel models of computation such as dataflow, and demand-driven computation.

Course Prerequisites:
While there are no specific prerequisites for the course, the students are expected to be well versed with basics of uniprocessor computer architecture and programming in C/C++

Course Format and Teaching Methods:
Lecture, group project, in-class discussion, online discussion, web-delivered content and assessment.

Course Management:
D2L (assignments, grades) and Piazza (announcements and online discussions).

Recommended Textbooks (See also lecture handout for other recommendations):
We are going to refer to several textbooks and online resources throughout the semester. Handout materials will be distributed in class from recent technical meetings and journals related to the field. Following books are recommended:

Course Objectives and Expected Learning Outcomes:
1. Learn how to program heterogeneous parallel computing systems and achieve
   a) High performance and energy-efficiency
   b) Functionality and maintainability
   c) Scalability across future generations
   d) Portability across vendor devices
2. Technical subjects
   a) Parallel programming API, tools and techniques
   b) Principles and patterns of parallel algorithms
   c) Processor architecture features and constraints

Relationship to Student Outcomes:
ECE 569 contributes directly to the following specific Electrical Engineering and Computer Engineering Student Outcomes of the ECE Department:

   a. an ability to apply knowledge of mathematics, science, and engineering (Medium)
   b. an ability to design and conduct experiments, as well as to analyze and interpret data (Medium)
   c. an ability to design a system, component, or process to meet desired needs within realistic constraints (High)
   d. an ability to identify, formulate, and solve engineering problems (High)
   e. an ability to communicate effectively (High)
   f. a recognition of the need for, and an ability to engage in life-long learning (High)
   g. a knowledge of contemporary issues (High)
   h. an ability to use the techniques, skills, and modern engineering tools necessary for engineering practice. (High)

Course Topics
1. Parallel Processing Concepts
   a) Levels of parallelism (instruction, transaction, task, thread, memory, function)
   b) Models (SIMD, MIMD, SIMT, SPMD, Dataflow Models, Demand-driven Computation etc)
   c) Architectures: N-wide superscalar architectures, multi-core, multi-threaded

2. Parallel Programming with CUDA
   a) Processor Architecture, Interconnect, Communication, Memory Organization, and Programming Models in high performance computing architectures
   b) Memory hierarchy and transaction specific memory design
   c) Thread Organization

3. Fundamental Design Issues in Parallel Computing
   a) Synchronization
   b) Scheduling
   c) Job Allocation
   d) Job Partitioning
   e) Dependency Analysis
f) Mapping Parallel Algorithms onto Parallel Architectures

g) Performance Analysis of Parallel Algorithms

4. Fundamental Limitations Facing Parallel Computing
   a) Bandwidth Limitations
   b) Latency Limitations
   c) Latency Hiding/Tolerating Techniques and their limitations

5. Power-Aware Computing and Communication
   a) Power-aware Processing Techniques
   b) Power-aware Memory Design
   c) Power-aware Interconnect Design
   d) Software Power Management

Class Schedule:
- Two 75-minute lecture sessions per week.
- Class activities will involve programming assignments, participation activities (reading assignments, class discussion, quizzes, and piazza participation), semester long project, and a comprehensive exam

Programming Assignments and Hardware
- The Extremely LarGe Advanced TechnOlogy (El Gato) cluster is a high performance computer jointly funded by the National Science Foundation and the University of Arizona. El Gato uses specially designed hardware to achieve high performance, including NVIDIA K20X GPUs and Intel Xeon Phi 5110p Coprocessors. El Gato is comprised of 136 compute nodes. 70 nodes are configured with NVIDIA GPUs, 20 nodes are configured with Intel Xeon Phi coprocessors, and 46 nodes are Intel Ivy Bridge with only CPUs. Each student will receive an individual account on El Gato that will be used for GPU computing, MPI-enabled parallel computing and possibly OpenMP multi-core computing. Additionally, ECE232 has CUDA capable workstations.
- Programming component of the class activities will accompany the topics covered in the lectures with hands-on exercises in which, students incrementally learn the CUDA programming model and optimization strategies on heterogeneous computing platforms.
- Students must work in groups with 2 to 4 members. Refer to “Project” in the next page on groups.
- Programming solutions should be neat, well organized, and well commented. Your score for each assignment will be between 0-100. No late submission will be accepted. Turning in your assignment should boil down to uploading at D2L a zipped (tar.gz) file. Upon unzipping, in the top directory, which should be called HW01 (for the first assignment, for instance), one should be able to find a hw01ReadMe.pdf file with compilation and execution instructions along with the results and analysis, a makefile that when run (by typing “make homework”) will generate an executable called hw01. The grader will run this executable and expect that all results you report in hw01ReadMe.pdf will be output in a file or to the screen.

Participation
- This term we will be using Piazza for class discussion. The system is highly catered to getting you help fast and efficiently from classmates and myself. Rather than emailing questions, I encourage you to post your questions on Piazza. Find our class page at: https://piazza.com/arizona/fall2016/ece369a/home
- Reading assignments may be given on the topics discussed in the lecture with challenge questions to be discussed on Piazza. Piazza participation (responding to questions of other students, posting your solutions to exercise problems prepared by the instructor) will be monitored closely. You are expected to participate actively in class discussions and to pose questions. Beyond this and in order to earn the 5% assigned to this category you will have to post at least five answers by the end of the semesters to the questions posted on the Piazza.
- Frequent quizzes will be used for checking your progress.
Project:
The project topics will be presented during the first three weeks of the semester. The topic will be introduced by the instructor or the guest researcher on campus. Students will then enroll in the project of their choice and sign up for a group on D2L. Students will also be working with their group members on programming assignments as well. The number of students allowed on a team depends on the complexity of the project. With each project, teams will be given the baseline code written in CUDA or C, and related publication(s). Each team will give a 30 minute presentation outlining results/accomplishments related to their project. Presentations will be scheduled starting April 17. Final report will be due on May 3 at 5pm.

Exam:
The exam will cover the entire material discussed in the course. You can bring along annotated copies of the documents that you have been asked to read (reading assignments). There will be no need for a computer for these tests. The best way to prepare for exams is to participate in class, learn the fundamental concepts, and work on the assignments diligently. The exam will be scored on a scale of 0 to 100. Exam will be given on April 11 (Tuesday). Date may change depending on the class progress. Exam will be held in the Education building, room 432. There is no final exam.

Accessibility and Accommodations:
It is the University’s goal that learning experiences be as accessible as possible. If you anticipate or experience physical or academic barriers based on disability or pregnancy, please let me know immediately so that we can discuss options. You are also welcome to contact Disability Resources (520-621-3268) to establish reasonable accommodations. Please be aware that the accessible table and chairs in this room should remain available for students who find that standard classroom seating is not usable.

Absence and Class Participation Policy:
The UA’s policy concerning Class Attendance, Participation, and Administrative Drops is available at: http://catalog.arizona.edu/2015-16/policies/classatten.htm.
The UA policy regarding absences for any sincerely held religious belief, observance or practice will be accommodated where reasonable, http://policy.arizona.edu/human-resources/religious-accommodation-policy. Absences pre-approved by the UA Dean of Students (or Dean Designee) will be honored. See: http://uhap.web.arizona.edu/policy/appointed-personnel/7.04.02. Participating in course and attending lectures and other course events are vital to the learning process. As such, attendance is required at all lectures and discussion section meetings. Students who miss class due to illness or emergency are required to bring documentation from their healthcare provider or other relevant, professional third parties. Failure to submit third-party documentation will result in unexcused absences.

General policies:
- NO LATE ASSIGNMENTS WILL BE ACCEPTED, except under extreme non-academic circumstances discussed with the instructor at least one week before the assignment is due.
- Make-ups for assignments and exams may be arranged if a student's absence is caused by documented illness or personal emergency. A written explanation (including supporting documentation) must be submitted to your instructor; if the explanation is acceptable, an alternative to the graded activity will be arranged. When possible, make-up arrangements must be completed prior to the scheduled activity.
- Any extenuating circumstances that have an impact on your participation in the course should be discussed with your instructor as soon as those circumstances are known.
- Inquiries about graded material have to be turned in within 3 days of receiving a grade.
- Approximate weight of each reading and laboratory assignment will be specified when the assignment is handed out.

Grading Scale and Policies:
University policy regarding grades and grading systems is available at, http://catalog.arizona.edu/2015-16/policies/grade.htm
Evaluation

- Exam: 15%
- Quiz: 15%
- Assignments: 20%
- Project: (40% total)
  - Presentation: 15%
  - Final paper: 25%
- Participation: 10%

Class Participation (5%) and Piazza participation (5%)

Grading Policy

- Overall points \( \geq 85\% \): A
- \( 70\% \leq \) Overall points < \( 85\% \): B
- \( 50\% \leq \) Overall points < \( 70\% \): C
- Overall points < \( 50\% \): F

Requests for incompletes (I) and withdrawal (W) must be made in accordance with University policies which are available at [http://catalog.arizona.edu/2015-16/policies/grade.htm#I](http://catalog.arizona.edu/2015-16/policies/grade.htm#I) and [http://catalog.arizona.edu/2015-16/policies/grade.htm#W](http://catalog.arizona.edu/2015-16/policies/grade.htm#W) respectively.

Honors Credit:

Students wishing to contract this course for Honors Credit should email me to set up an appointment to discuss the terms of the contract and to sign the Honors Course Contract Request Form. The form is available at: [http://www.honors.arizona.edu/documents/students/ContractRequestFrom.pdf](http://www.honors.arizona.edu/documents/students/ContractRequestFrom.pdf)

Threatening Behavior Policy:

The UA Threatening Behavior by Students Policy prohibits threats of physical harm to any member of the University community, including to one’s self. See: [http://policy.arizona.edu/education-and-student-affairs/threatening-behavior-students](http://policy.arizona.edu/education-and-student-affairs/threatening-behavior-students).

Accessibility and Accommodations:

Our goal in this classroom is that learning experiences be as accessible as possible. If you anticipate or experience physical or academic barriers based on disability, please let me know immediately so that we can discuss options. You are also welcome to contact Disability Resources (520-621-3268) to establish reasonable accommodations. For additional information on Disability Resources and reasonable accommodations, please visit [http://drc.arizona.edu/](http://drc.arizona.edu/).

If you have reasonable accommodations, please plan to meet with me by appointment or during office hours to discuss accommodations and how my course requirements and activities may impact your ability to fully participate.

Please be aware that the accessible table and chairs in this room should remain available for students who find that standard classroom seating is not usable.

Code of Academic Integrity:

Students are encouraged to share intellectual views and discuss freely the principles and applications of course materials. However, graded work/exercises must be the product of independent effort unless otherwise instructed. Students are expected to adhere to the UA Code of Academic Integrity as described in the UA General Catalog. See: [http://deanofstudents.arizona.edu/academic-integrity/students/academic-integrity](http://deanofstudents.arizona.edu/academic-integrity/students/academic-integrity).

The University Libraries have some excellent tips for avoiding plagiarism available at: [http://www.library.arizona.edu/help/tutorials/plagiarism/index.html](http://www.library.arizona.edu/help/tutorials/plagiarism/index.html).
UA Nondiscrimination and Anti-harassment Policy:
The University is committed to creating and maintaining an environment free of discrimination, http://policy.arizona.edu/human-resources/nondiscrimination-and-anti-harassment-policy

Our classroom is a place where everyone is encouraged to express well-formed opinions and their reasons for those opinions. We also want to create a tolerant and open environment where such opinions can be expressed without resorting to bullying or discrimination of others.

Subject to Change Statement:
Information contained in the course syllabus, other than the grade and absence policy, may be subject to change with advance notice, as deemed appropriate by the instructor.

Philosophy:

"I never did anything by accident, nor did any of my inventions come by accident; they came by work." Thomas Alva Edison.

- Read before the class
- Participate and ask questions
- Manage your time (3 hours outside class for each credit hour)
- Start working on assignments early