ASTE 499, Applied Computational Programming

Units: 3
Term: Spring 2020
Day & Time: Tuesday: 12:00 - 2:50 pm
Location: SAL 109

Instructors: Lubos Brieda & Dr. Joseph Wang

Office: TBD
Office Hours: Tuesday: 3 - 4 pm
Contact Info: **lubos.brieda@particleincell.com**

Teaching Assistant: TBD
Office: TBD
Office Hours: TBD
Contact Info: TBD

IT Help: N/A
Hours of Service: N/A
Contact Info: N/A

Course Description

This course introduces programming languages and computational methods for solving complex problems encountered in astronautics and aerospace engineering. The course focuses on development in high-performance languages such as C++, Java, Fortran, or Python that take advantage of modern hardware capabilities including multithreading, graphics cards (GPUs), and distributed computing. The course also introduces techniques for solving continuum and rarefied gas mass transport problems. Additional topics include object oriented programming, data visualization, embedded systems, and machine learning. During the course, each student will develop and implement his/her own simulation code for solving a complex problem. Prerequisite: basic programming background.

Catalogue Data: Programming of serial and parallel simulation codes with high-performance languages such as C++ and Fortran. Also covers numerical techniques for continuum and rarefied gas flows, data visualization, embedded systems, graphics cards, and genetic algorithms.

Course Goals and Objectives:

This course provides a comprehensive study on programming languages and computational methods used in astronautics and aerospace engineering. The material goes beyond the Matlabbased numerical method classes typically taught at Viterbi and focuses the application of high-performance programming languages. At the completion of the subject, students will master at least one high-performance programming language and apply it to develop and implement their own computer simulation models to solve complex problems in astronautics and aerospace engineering.

Recommened Preparation: Basic programming background / instructor permission.
Co-Requisite(s): None
Concurrent Enrollment: None

Course Notes:

Lecture notes provided by instructor.

Grading:

Course grading will be based on homework, quizzes, a literature review presentation, and a final project. Homework is assigned weekly and is due at the start of the following class. The literature review is based on finding an interesting computational journal or conference paper, and presenting a short (10 minute) summary. Several multiple choice / fill in the blanks quizzes will be used to test understanding of previously covered topics. The final project involves working in small groups to develop a simulation program relevant to research interests.

Grading Breakdown:

Assessment Tool (assignments)	Points	% of Grade
Homework		40%
Quizzes		20%
Literature Review		10%
Final Project		30%
TOTAL		100%

ASTE 499 : Applied Computational Programming -- Course Schedule

Week	Topics/Daily Activities
1	**Scientific computing crash course**. Variable types, functions, loops, input/output, multi-dimensional arrays, random numbers, compilation, and debugging are introduced in Matlab, Python, C/C++, Java, and Fortran.
2	**Numerical Integration.** Finite difference method is used to write a simulation of a ball dropped from a height and bouncing on a surface. The code is compared in several programming languages.
3	**Object Oriented Programming**. Data encapsulation, inheritance, virtual functions, and operator overloading are introduced primarily in C++. These concepts are used to generalize the simulation to support multiple bouncing objects.
4	**Web technologies.** Javascript and HTML5 canvas for "cloud" computing is introduced. Interactive in-browser version of the ball bouncing program is developed.
5	**Linear Systems.** Direct and iterative methods for matrix solving are introduced. Topics include Matlab "backslash", Thomas algorithm, Gauss-Seidel, Multigrid, and Conjugate Gradient.
6	**Discretization Schemes.** Finite Difference (FD) and Finite Volume Methods are derived. These methods are used to write a solver for the steady-state diffusion (heat) equation. Visualization of 3D data.
7	**Fluid Modeling.** Axi-symmetric solver for the unsteady diffusion equation is developed with the Crank-Nicholson scheme.
8	**Rarefied Gases.** Direct Simulation Monte Carlo (DSMC) method is used simulate rarefied gas expanding to vacuum. Macroscopic properties (density, stream velocity, temperature) are computed from particle data.
9	**Plasma Simulations.** Poisson solver and electrostatic force term are added to the code from the prior lesson to simulate plasma effects using the Particle in Cell (PIC) method.
10	**Multithreading.** Program flow separated into concurrent threads to speed up computation on multicore systems. Lesson discusses race condition, atomics, and locks.
11	**Code Testing and Documentation.** We cover uncertainty analysis, convergence studies, unit testing, and documentation systems.
12	**Distributed Computing.** This lesson discusses parallelization using multiple computers sharing data over network using the Message Passing Interface (MPI). Domain decomposition and ensemble averaging are compared.
13	**GPU programming.** Use of graphics cards for parallel processing using CUDA and OpenCL is introduced. Lesson discusses memory transfer considerations and Single Instruction Multiple Data (SIMD) strategies.
14	**Embedded Systems.** An Arduino microcontroller is used to build a temperature and humidity monitor. Field Programmable Gate Arrays (FPGAs) are also discussed.
15	**Optimization and Machine Learning.** Genetic algorithms and neural networks are reviewed. These approaches are useful for developing simulation codes that search for optimal set of input parameters, and for obtaining insight into experimental data.
16	**Final Project Presentation.**

ASTE 499 : Course Project

Course project: The purpose of the class project is to practice developing a simulation program for conducting academic research. This project is envisioned to be completed in groups of 2-4 persons. The group is expected to suggest a topic relevant to individual interests, with sample topics provided if needed. All members are expected to contribute

equally, with tasks divided among code development, testing, and documentation. Deliverables to include the code, preliminary results, user's guide outlining the numerical model, input files, and a report similar to a conference paper.

Project Timeline:

- Week 3: Identify team members and project topics
- Week 6: Proposal due (team member, topics and milestone)
- Week 8: Mid-term report due (code layout, test cases, preliminary results, draft documentation)
- Week 14: Project presentation (open to all faculty and students)
- Final: Final report due (problem statement, algorithm description, validation, major discovery, lessons learned)

Sample project: *The ESA ExoMars Rover mission is planning to use an ion mass spectrometer to investigate the Martian soil composition. The spectrometer uses a laser beam to desorb ions off a soil sample held at Mars atmospheric pressure. Above the sample is a long "straw" leading to a vacuum cavity containing the mass spectrometer. A sliding valve opens during the laser operation. The resulting pressure gradient accelerates the ambient gas molecules into the vacuum cavity, with ions becoming entrained in the gas flow due to collisional coupling. The objective of the project is to use techniques such as PIC and DSMC to investigate this ion and neutral gas transport.*

Grading breakdown of the course project*:*

- Proposal: 5%
- Mid-term report: 5%
- Final report: 5%
- Presentation: 10%
- Code and user's guide: 5%

Statement on Academic Conduct and Support Systems

Academic Conduct:

Plagiarism – presenting someone else's ideas as your own, either verbatim or recast in your own words – is a serious academic offense with serious consequences. Please familiarize yourself with the discussion of plagiarism in SCampus in Part B, Section 11, "Behavior Violating University Standards" policy.usc.edu/scampus-part-b. Other forms of academic dishonesty are equally unacceptable. See additional information in SCampus and university policies on scientific misconduct, policy.usc.edu/scientific-misconduct.

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Counseling and Mental Health - (213) 740-9355 – 24/7 on call
studenthealth.usc.edu/counseling
Free and confidential mental health treatment for students, including short-term psychotherapy, group counseling, stress fitness workshops, and crisis intervention.

National Suicide Prevention Lifeline - 1 (800) 273-8255 – 24/7 on call
suicidepreventionlifeline.org
Free and confidential emotional support to people in suicidal crisis or emotional distress 24 hours a day, 7 days a week.

Relationship and Sexual Violence Prevention and Services (RSVP) - (213) 740-9355(WELL), press "0" after hours – 24/7 on call
studenthealth.usc.edu/sexual-assault
Free and confidential therapy services, workshops, and training for situations related to gender-based harm.

Office of Equity and Diversity (OED)- (213) 740-5086 | Title IX – (213) 821-8298
equity.usc.edu, titleix.usc.edu
Information about how to get help or help someone affected by harassment or discrimination, rights of protected classes, reporting options, and additional resources for students, faculty, staff, visitors, and applicants. The university prohibits discrimination or harassment based on the following *protected characteristics*: race, color, national origin, ancestry, religion, sex, gender, gender identity, gender expression, sexual orientation, age, physical disability, medical condition, mental disability, marital status, pregnancy, veteran status, genetic information, and any other characteristic which may be specified in applicable laws and governmental regulations. The university also prohibits sexual assault, non-consensual sexual contact, sexual misconduct, intimate partner violence, stalking, malicious dissuasion, retaliation, and violation of interim measures.

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usc-advocate.symplicity.com/care_report
Avenue to report incidents of bias, hate crimes, and microaggressions to the Office of Equity and Diversity |Title IX for appropriate investigation, supportive measures, and response.

The Office of Disability Services and Programs - (213) 740-0776
dsp.usc.edu
Support and accommodations for students with disabilities. Services include assistance in providing readers/notetakers/interpreters, special accommodations for test taking needs, assistance with architectural barriers, assistive technology, and support for individual needs.

USC Support and Advocacy - (213) 821-4710
uscsa.usc.edu
Assists students and families in resolving complex personal, financial, and academic issues adversely affecting their success as a student.

Diversity at USC - (213) 740-2101
diversity.usc.edu
Information on events, programs and training, the Provost's Diversity and Inclusion Council, Diversity Liaisons for each academic school, chronology, participation, and various resources for students.

USC Emergency - UPC: (213) 740-4321, HSC: (323) 442-1000 – 24/7 on call
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dps.usc.edu
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