Course Rubric & Title:

PHYS 498CMP: Computational Physics

Course Description:

1. This is an immersive advanced computational physics course. Your goals in this class are to program, simulate, and understand the physics within fours (plus one) projects described below — these projects will span much of class-time and all of your homework. My goal is to help you accomplish those tasks. To the extent necessary this will include some lecturing (usually ≪30≪30 minutes per class), some one-on-one interaction in class, and a lot of individual work in and out of class. This is inverted from the typical approach where lectures are designed to teach and problem sets are designed to test your understanding of the material. You should come to class (and office hours). These projects are not designed to be do-able without our help; trying to do them without asking questions and having us help you will make your life much harder.
2. While there will be some lecturing, lectures will not cover all the information you need to complete the projects. Instead, you will need to use resources mentioned on the web-site (and others) to make progress, especially depending on your physics and computing background.
3. You will write programs and run simulations. Programming will be done in python and C++ (maybe we will optionally test Julia — come see me if you are interested in that). You need to get python and C++ running on your computer; see help in project 0 below.
4. This is one of the first times this course has been run, meaning it is a work in progress. Projects will be a little rough as many bumps are still being worked out. Let us know if there is a problem or something we can do to improve things. Don't read too literally, and try to answer the questions we are asking, not the ones we've necessarily written. As a rule of thumb, don't spend more than 30 minutes trying to decipher a problem on your own; come to us for clarification.

Prerequisites and Corequisites:

None

Credit Hours: 3

Course Instructors:

Sp2020: B. Clark

Course Website (current):

https://courses.physics.illinois.edu/phys498cmp/sp2020/

Texts and Supplies: None

Collaboration and resource-use policy

- You are allowed to collaborate with others but must write and submit your own work. Please write on top of your work with whom you've collaborated.
- You are allowed to look things up online (including coding things). If you are using code from online, you must
  - make sure that it is freely available to be used;
  - document in your code when and where you are using it.
- While you can look up things online, you're not allowed to directly look up an answer. So if we ask "write code that simulates a quantum computer in python" you're not allowed to type into google "python code for simulating a quantum computer" and then copy it.
- Please do not post your code on a public website, such as a public github page.

Academic Integrity

All activities in this course are subject to the Academic Integrity rules as described in Article 1, Part 4, Academic Integrity, of the Student Code.

Infractions include, but are not limited to:

- Cheating, plagiarism, fabrication
- facilitating infractions of academic integrity.
- academic interference
- computer-related infractions
- unauthorized use of university resources
- sale of class materials or notes

Violations of any of these rules will be prosecuted and reported to the student's home college in compliance with the Student Code: Article 1, Part 4, Academic Integrity, of the Student Code.

All aspects of the course are covered by these rules

Course Grading:

Course grading will proceed in compliance with University policy as given in Article 3, Part 1 of the Student Code.

Gradebook

Students will be able to view their grades on all components of the course using the course grade book.

Students are responsible for reporting any discrepancies found in their student grade book to the attention of their section instructor immediately.

Grading

- The grading in this class is somewhat atypical. There are 4+1 projects, each about three weeks long.

- You will get points for the parts of the project that you complete successfully but not for partial credit for incorrect results. To compensate for this we are going to spend a lot of class-time + office hours trying to help you get through these projects.

- Grading will be done in person. You will need to show one of the course staff your work in person and convince them it's right. It is an important skill that you learn to determine on your own whether your code produces the correct result and to be able to make a convincing argument that you have the right answer. Therefore you should tell us that your code is correct and explain how you know that (maybe you've done some tests or validated it somehow). You can get graded either when the project is over or as you complete separate pages of the project.

- Two additional points:
    - It is required that you put together a document (we have a template) that shows the summary of your results. It will mainly consist of pasted plots and output. This is primarily to expedite and facilitate grading. When you show us your assignment for grading, we will look through your document as well as ask you other questions/look at aspects of your code/etc.
    - It is required that you submit your code (including your git repository) and document by the time of the project's deadline. Each of you will have a separate box folder set up for you where you will place these files.

- The grading is not linear. Getting through 40% of the points for a project does not mean you've made it through 40% of the material for the project. Grading is designed to give you more points early on in the project.

- The grading checkpoints are marked in the assignments. Each assignment has the fraction of the grade for which it counts on it.
- There is no late submission but there is a make-up week at the end of the semester.
- We will not post solutions.

- Attendance is 5% of the grade.

Final Grade

The following table will be used to assign final grades.

Final Grade	Minimum Points
A+	100+
A	90-100
A-	80-90
B+	70-80
B	60-70
B-	50-60
C+	40-50
C	35-40
C-	30-35
D+	25-30
D	20-25
D-	10-20
F	0-10

Disability Access
(https://www.disability.illinois.edu/academic-support/instructor-information/examples-disability-statements-syllabus)
The Department of Physics is committed to being an open and welcoming environment for all of our students. We are committed to helping all of our students succeed in our courses.

To obtain disability-related academic adjustments and/or auxiliary aids, students with disabilities must contact the course instructor and the Disability Resources and Educational Services (DRES) as soon as possible. To contact DRES, you may visit 1207 S. Oak St., Champaign, call 333-4603, e-mail disability@illinois.edu or go to the DRES website. If you are concerned you have a disability-related condition that is impacting your academic progress, there are academic screening appointments available on campus that can help diagnosis a previously undiagnosed disability by visiting the DRES website and selecting “Sign-Up for an Academic Screening” at the bottom of the page.

If you are interested in obtaining information to improve writing, study skills, time management or organization, the following campus resources are available to all students:

Writer’s Workshop
Undergrad Library
217-333-8796
http://www.cws.illinois.edu/workshop

https://www.disability.illinois.edu/strategies

http://www.counselingcenter.illinois.edu/self-help-brochures/

Also, most college offices and academic deans provide academic skills support and assistance for academically related and personal problems. Links to the appropriate college contact can be found by going to this website and selecting your college or school: http://illinois.edu/colleges/colleges.html

If you are experiencing symptoms of anxiety or depression or are feeling overwhelmed, stressed, or in crisis, you can seek help through the following campus resources:

Counseling Center

206 Fred H. Turner Student Services Building
7:50 a.m.-5:00 p.m., Monday through Friday
Phone: 333-3704

McKinley Mental Health

313 McKinley Health Center
8:00 a.m.-5:00 p.m., Monday through Friday
Phone: 333-2705

McKinley Health Education offers individual consultations for students interested in learning relaxation and other stress/time management skills, call 333-2714.

Course Component Breakdown:
2 courses per week (80 minutes each)

Conceptual objectives:

- ***From simple rules, comes complicated phenomena:*** One quantum mechanical equation gives us all of chemistry, superconductivity, topological insulators, etc.; from firing neurons arises thinking; from evolution arises complicated life. Computation is the best way I know how to shed insight on all of these topics. Computers allow you to simulate the emergence of complex phenomena from simple laws, and I know no better way to understand physics than by teaching your computer how to do physics.
- ***You can understand the universe from simple models:*** By this time in your physics career you're probably used to this truism, but think about it for a minute; why don't you need string theory to understand the pressure in a balloon? There is a deep reason for this which goes by the names *universality* and *the renormalization group.* The statistical mechanics section of this course is designed to provide a first pass at universality by having you write simulations that compute universal critical exponents and numerically implement a renormalization group calculation on the Ising model.
- ***Quantum computers are more powerful than classical computers:*** Or in other words, quantum mechanics is hard to simulate. For many years, the idea that all computing machines in the universe computed equally well (the modified Church–Turing thesis) was one of the core tenets of computer science. This means that anything that is computatable in the universe is computable at (about) the same speed on your macbook. Quantum computing broke this paradigm, for reasons which you will come to deeply understand both by writing a quantum computing simulator as well as trying to simulate quantum mechanics!

Course Topics and Learning Objectives:

Project 0: Getting up and Running - Cellular Automata

Due: January 29 (*5% of grade*)

Learning Objectives: Learn about universality and cellular automata; Figure out how to compile and write python and C++ code on your machine.

Project 1: Quantum Computing

Quantum mechanics allows you to compute some things exponentially faster than classical physics.

Due: February 23 (*24% of the grade*)

Build a quantum computer simulator and simulate Shor's algorithm to factor 21.

Quantum computing is probably the most important revolution in computing in the last fifty years.

If you've seen quantum mechanics, great! If not, in my (slightly biased) viewpoint, this is the amongst the best ways to learn quantum mechanics.

Learning Objectives: Quantum computing; universality of quantum gates; dirac notation; quantum fourier transform; phase estimation; Shor's Algorithm; BQP \in PSPACE;

Project 2: Statistical Mechanics, Universality, and the Renormalization group

The world is comprehensible even if we don't know the basic rules.

Due: March 17 (*22% of the grade*)

Simulate the Ising model using Monte Carlo and the Renormalization group

Statistical Mechanics is the study of how you go from microscopic to macroscopic phenomena. Renormalization group is the deepest idea in physics

Learning Objectives: Statistical Mechanics; Ising Model; Renormalization Group; Critical Exponents; Workflow management; Markov Chain Monte Carlo; Error bars; stochasticity;

Project 3: Thinking

Things Think

Due: April 14 (*22% of the grade*)

Neural networks: Build a minimal model of memory; learn about machine learning.

Learning Objectives: Understanding how the Ising model lets you generate a number of machine learning architectures. Understand concept of learning. Learn a model of memory. See quantitatively how to estimate memory capacity. Understand restricted Boltzmann machines.

Project 4: Condensed Matter

From simple laws, come exotic materials

Due**:** (*Day of Final*) (*22% of the grade*)

Learning Objectives: Understand topological insulators; tight-binding models; graphene; band-structures; chern number