Spring HSSP Class Syllabus

Modeling Mechanics, Chemistry, and Circuits via Differential Equations and JavaScript

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Course Description:

Science comes down to models of the super complicated world around us; and the best models, are the ones we use to this day to send rockets into space, create electrical systems, and invest in the stock market. And as we'll find in this course, some of the most famous and applicable models don't even need to be that complicated to be useful!

This course will give a broad outlook on modeling electrical and mechanical systems using first and second-order differential equations and coding up small simulations to visualize our mathematical predictions. On a typical class day, we will start with a system, analyze it mathematically in the first half, and program a simulation in the second half.

Prerequisites:

- Calculus 1
  - Basic differentiation
  - General understanding of *what* a differential equation is (don't need to know how to solve any type)
- Physics 1
  - Conceptual and mathematical understanding of displacement, velocity, and acceleration
  - Newton's 2nd Law
  - Calculus-based physics may prove helpful, but the above skills should suffice
- Programming experience is not necessary! We will take the simulations nice and slow.
- Please bring a laptop to sessions!

Sessions: 1.5-hour length

Quick Links:

- Weekly breakdown

Week	Links
1 - 02/25	Lec Notes Finished Code

2 - 03/04	Lec Notes Starter Code Finished Code
3 - 03/11	Lec Notes Starter Code Finished Code
4 - 03/25	Lec Notes Starter Code Finished Code
5 - 04/01	Lec Notes Starter Code Finished Code
6 - 04/08	Lec Notes Starter Code Finished Code

- Other:
    - P5 library reference

Course Schedule

- Week 1: Introductions and Ramp-up
    - Intro to modeling via Ohm's Law
    - Review
        - Math
            - Derivatives of cos(x), sin(x), exp
            - Chain and product rules
            - Imaginary numbers and plane
        - Physics
            - Displacement, velocity, acceleration
            - N2L
                - Spring (Hooke's) Law
                - Simple Drag Equation
    - Glitch set-up, test demo on next week's SHO simulation
- Week 2: Simple Harmonic Spring Oscillator
    - Derivation of the differential equation from N2L
    - General solution to the differential equation
        - Gives us governing equation for displacement
    - Program simulator they saw last time in Glitch

- Week 3: Simple Harmonic Oscillator Model for Molecular Bonds
    - Spring analogy through bonds
    - Vibrational energy
        - Reduced mass
        - Fundamental frequency
    - Comparing simple harmonic oscillator model with electron wavefunction
    - Simulation with water: Improve upon spring from last week and replace mass with diatomic pair
- Week 4: Not so Simple (Damped) Spring System
    - Review of derivation of SHO spring system
    - Extra drag term introduced into last week's differential equation
    - Introduces some… complications (3 cases via quadratic equation)
        - For this class, let's assume the underdamped case… it's the most interesting case!
    - Code up simulation from governing position equation
    - Challenge: come up with code that determines in which of the 3 cases we fall. Underdamped, overdamped, or critically damped? How does the position equation change depending on which of the 3 cases we're in?
- Week 5: Introduction to circuit theory
    - KVL, KCL
    - Resistors, inductors, capacitors
        - Device laws
        - Intuitive understanding of memory devices
    - Simulation: charging capacitor
- Week 6: Series RLC Circuit
    - Derive differential equation, compare with damped spring oscillator system
        - KVL, sum of device laws, equal currents
    - Derive governing equation for the voltage across capacitor
        - Specifically interested in damped case
        - Compare with DE we derived in week 4 for the underdamped oscillator
    - Code up energy distribution across inductor and capacitor with resistive element
        - Simulation
    - If time permits
        - Outlook - what to look at next if interested
            - Math
                - Separation of variables, variation of parameters for time-dependent coefficient ODEs
                - Exponential response and the Fourier series
            - Circuits:
                - Impulse response

        - Mechanical (impedance and mobility) analogies
    - Chemistry:
        - Spectroscopy
        - Quantization of energy levels in Bohr model
    - Physics:
        - 2D oscillators
        - Coupled systems
- Instructor AMA