Class Assignments

The main objective of this class is to teach the basics of control engineering to life science students. As such the primary deliverable for the class is a control design of a dynamical model of a biological system. This could be a biochemical pathway, a model of cell interactions (e.g., the immune system), or an ecosystem. I expect that you will start with a model in a published paper. The [BioModels](https://www.ebi.ac.uk/biomodels/search?query=*%3A*+AND+curationstatus%3A%22Manually+curated%22&domain=biomodels) repository has about 1,000 curated models in the community standard Systems Biology Markup Language (SBML) that are an excellent starting point.

The final project will have the following sections:

1. **Problem description and system definition**. You will describe the problem you are solving, the control objectives (e.g., regulation, settling times, eliminate oscillations), system inputs and outputs, and a controllability analysis.
2. **System identification**. You will fit a transfer function to your system. You will further evaluate the effect of common compensation (changes) to the system, such as adding or removing a reaction.
3. **Testbed construction and control design.** You will design a controller and/or compensations to achieve the control objectives in your problem description. Your design will include a root locus plot to guide the design process.

The course assignments are:

* **Homework 1: Do (1) above**. Rubric
  + Problem description & control objectives (10 pt). Write a short narrative that describes how the problem you’re solving is addressed by control objectives. You should have at least 2 control objectives. Examples are: regulate the output for setpoints within the range [a, b]; eliminate oscillations; settling times (convergence to steady state) occurs within 2 sec.
  + System definition (15 pts). Plot a staircase function of the input over the operating region. Write a short narrative describing how the plot indicates that the control objectives can be achieved over the operating region. Address all of the following: SBML model, system output, system input, directional effect of the input on the output, operating region for the input, range of outputs that can be achieved (feasible setpoints).
* **Homework 2: Do (2) above.**
* **Homework 3 (Course project).** This homework is submitted as a Jupyter notebook that includes the sections done previously in Homework 1 (problem description and system identification) and Homework 2 (system identification). The submission should include updates to these sections from feedback provided on homework 1 and homework 2. Here are the details by section. ***Homework 3 is due by midnight March 8, 2024.***
  + **Problem description and system identification (5 pt).** This is a copy of what you did in Homework 1 with revisions as appropriate.
  + **System identification (5 pt).** This is a copy of what you did in Homework 1 with revisions as appropriate. If your system has a negative relationship between the input and output and controlSBML fails to do a reasonable system identification, write a short narrative about why you believe that the system identification is inadequate.
  + **Testbed construction and control design (40 pt).**
    - Part 1: Testbed construction (10 pt)
      * Extend the antimony of your model to include a PI control that has constants that allow for separately setting the values of kP, kI, and setpoint.
      * Manually explore the design space for kP and kI and provide a short narrative about the quality of the designs you find and the effect of kP and kI.
    - Part 2: Root locus analysis. (10 pt)
      * Construct two root locus plots. One for P-control and one for I-control. Use the system identification from homework 2 (even if the fit was poor).
      * For each root locus plot, explain how increasing the design parameter affects stability, oscillations, and settling times. Based on your control objectives, describe a strategy for exploring values of kP and kI.
    - Part 3: Grid search (10 pt)
      * Do a grid search for values of kP and kI. This requires writing code that produces metric(s) related to your design. The grid search may report multiple results if you have multiple objectives.
      * Plot the step response for each candidate design. The plot is structured as: x-axis is time; lines for setpoint, output, and input.
      * Evaluate the candidate designs based on your control objectives and whether the step response is within the operating region.
  + **Discussion (10 pt)**. Describe the parts of control design the presented the most challenge to you and the tools/techniques that you found most helpful. You should have at least two responses.

All homeworks is submitted as Jupyter notebooks.

[This folder](https://drive.google.com/drive/folders/1oT4vq5HP69cPaVRmLDfha26O-q2LypKA) contains examples of completed projects.