Instructions: (Please read carefully!)
In this session, we will learn to use Pyomo modeling language and software. We will start with very simple exercises in order to gain familiarity with the syntax of the language. Since we will be using Pyomo in the next few labs as well, it is important to understand and learn its correct usage.
Instructions for Setting up Pyomo and Google Colab: Pyomo is a Python based modelling language that we will use to write and solve optimisation problems. We will write the code in Google colab notebook. The steps to use Pyomo in Google Colab have been provided in the videos posted earlier. Use those instructions to perform the following steps:

- Sign in to Google colab using your e-mail id of the form `rollnumber@iitb.ac.in`
- You will be redirected to a Single Sign On (SSO) page. Please provide the proper credentials and the authenticator code and sign in.
- Now you are redirected to the Google Colab page which is displayed as shown in Figure 1.

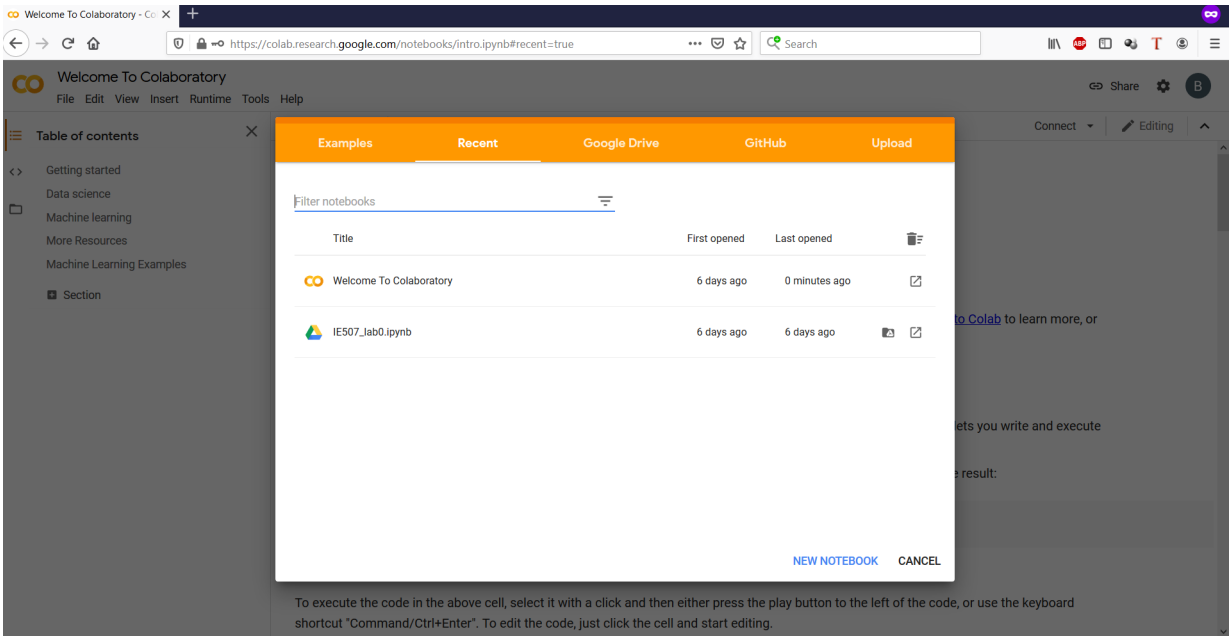

Figure 1: Screenshot of Goole Colab upon sign in

- Now click on `NEW NOTEBOOK` and you will be redirected to a new Colab notebook where you need to type your code for the exercise problems.
- Please use same notebook for solving all problems.
- If you need to open the sample file `IE507_lab0.ipynb` shared with you earlier, you can click File, then click New Notebook and once a new notebook opens in a new tab, again click File and then click Open. You can now open the file. You can use the file as your reference. These steps have been posted in a different video.
- Rename your notebook as `YOURROLLNUMBER_IE507_Lab1.ipynb`. The steps to rename a file have also been posted in the video.
- Create zip file `YOURROLLNUMBER_IE507_Lab1.zip` with all relevant files and submit only the zip file in moodle.

- e-mail submissions will not be considered.
- Please contact TAs/Instructors to discuss your doubts so that TAs can clarify.

For more details on pyomo, please consult https://pyomo.readthedocs.io/en/stable/index.html.
You are now ready to solve this lab's Exercise problems. Try to answer all the questions in this Exercise. Only the questions marked [**R**] need to be answered in the notebook. You can either print the answers using `print` command in your code or you can write the text in a separate text tab. To add text in your notebook, click `+Text`.

After completing this lab's exercises, click File → Download .ipynb and save your file to your local laptop/desktop. Then upload the file in Moodle. These instructions are also provided in the video.

The deadline for today's lab is **11:59 PM, tomorrow**.

All questions must be solved. There are only 3 exercise problems. 2 extra marks will be awarded for following the systematic procedures described above.

Exercise 1: A Simple Linear Program. [6 Marks] Consider the optimization problem.

$$\begin{aligned}
\min\ & -3x_1 - 2x_2 + 8x_3 - 7x_4 + 0.19x_5 + 11x_6 + 20.2x_7 \\
\text{s.t.}\ & \sum_{i=1}^{7} x_i = 256, \\
& -x_2 + x_3 \geq 10, \\
& -3x_1 + x_5 - 12x_6 \leq 105, \\
& 18.5x_2 + 30.5x_4 - x_7 \geq 28, \\
& -x_3 - 4x_5 + x_7 \geq 31, \\
& x_1 \geq -5, \\
& x_2 \geq 0, \\
& x_3 \geq 5, \\
& x_4 \geq -3, \\
& x_5 \geq -4, \\
& x_6 \geq 0, \\
& x_7 \geq 10.
\end{aligned}$$

1. Solve this optimisation problem.
2. Verify whether the optimal point obtained satisfies all the constraints.
3. [**R**] Report the objective function value, the values of all decision variables at the optimal point.
4. [**R**] Report the constraint activities (the value of left hand side (LHS) in a constraint and if the constraint is satisfied to equality) for first five constraints.

Exercise 2: LP Reformulation. [6 Marks] Consider the following optimisation problem:

$$\begin{aligned}
\max\, & 0.082x_1 + 0.036x_2 + 0.0156x_3 + 0.033x_4 + 0.054x_5 + 0.0125y \\
\text{s.t. } & 3x_1 - 3x_2 + 5x_3 - x_4 + x_5 - y \leq 80 \\
& x_3 + 2x_4 + 4y \geq 30 \\
& \frac{3x_1 - 1.5x_3 + 2x_4 + 1.8x_5 + 6x_6}{-x_2 - x_4 + x_5} \leq 3.6 \\
& \frac{x_1 - 2x_2 + 3x_3 + 4x_4 + 5x_5}{-x_1 + x_3 + x_6 - 2y} \leq 6 \\
& x_1, x_2, x_3, x_4, x_5, x_6 \geq 0 \\
& y \in [-0.2, 5.5]
\end{aligned}$$

1. [**R**] Rewrite this optimisation problem as a linear program, and include it in your notebook. Did you make suitable assumptions when you constructed the linear program? If so, explain those assumptions.

2. Solve the optimization problem.

3. [**R**] Report the optimal solution value, the values of variables at the optimal solution and the activities of all constraints of the LP model.

4. [**R**] Suppose you have made some assumptions in formulating the LP, explain if all your assumptions are validated at the optimal point using appropriate justifications.

Exercise 3: Your (possibly) first LP modeling problem. [10 Marks] Jen Industries produces two products P and Q that are sold as raw materials to companies manufacturing kitchen appliances. Based on an analysis of current inventory level and potential demand for the month of September 2022, the management of Jen Industries has specified that the combined production for products P and Q should be at least 145 Kgs. Additionally, a major customer has placed an order for 105 Kgs of product P and 125 Kgs of product Q. Product P requires 2.18 hours of manufacturing time per Kg and product Q requires 65 minutes of manufacturing time per Kg. For the month of September 2022, 980 hours of manufacturing time are available. Jen Industries aims at satisfying these requirements at a minimum total production cost. Production costs are Rupees 1200 per Kg for product P and Rupees 2580 per Kg for product Q.

1. [**R**] Formulate the problem as a linear program. Explain your formulation (the variables used, objective function and constraints).
2. Solve your optimization problem using pyomo.
3. [**R**] Report the optimal values of decision variables and the corresponding optimal cost and the activities of all constraints of the LP model.
4. [**R**] Suppose at the last moment, Jen industries receives another order from a different customer. The customer has placed an order of 42 Kgs of product P and 97 Kgs of product Q. Introduce this new requirement into your formulation and explain how your linear program formulation will change.
5. Solve your new optimization problem using pyomo.
6. [**R**] Report the the optimal values of decision variables and the corresponding optimal cost and the activities of all constraints of the LP model. Explain your observations about the results obtained. Based on the results obtained, what would you advise Jen Industries about the new requirement?
