Lecture 1: Introduction to Programming
Programming and Numerical Methods for Economics—ECNM10115

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This Class

Course Organization

Why Economists Program?

Survey

Learning Programming

Programming language: Python

Infrastructure

Course Organization

Syllabus

- Week 1: Introduction to programming.
- Week 2: Fundamentals of programming in Python.
- Week 3: Data manipulation and data analysis.
- Week 4: From data to models.
- Week 5: Numerical Methods I.
- Week 6: Numerical Methods II.
- Week 7: Numerical Methods III.
- Week 8: Economic models.
- Week 9: Model estimation.
- Week 10: Advanced topics.

Some references and useful resources

- Numerical Methods in Economics, by Kenneth L. Judd, 1998. Main reference for weeks 4-8.
- Quantitative Economics founded by T. Sargent and J. Stachurski. Main reference.
- Advanced: Lecture notes by Jesús Fernandez-Villaverde. Computational Methods for Economists, University of Pennsylvania.
- For data analysis: Stata to Python equivalences by Daniel Sullivan.
- Python-Julia (and Matlab) cheatsheet.

Lectures, tutorials, and grading

- **Lectures:** cover the material. Always bring your laptop to lectures and tutorials. Thursdays 15:10-17:00.
- **Lab/tutorials:** cover the problem sets (past-future). Might ask you to show/present your answers at some point. Starting on week 2.
- **Assessment**:
  - 8 group problem sets: 40%.
  - 1 individual take-home exam: 60%.
- **Office hours** (Juan): Fridays 16:00 to 17:00. Location: Office 2.11, School of Economics.

Problem Sets

- The problem sets should be completed in groups of 3 members.
- **Deadline:** Tuesday 2:00 pm.
- **Submission platform**: Each group must submit the answers of each problem set using Learn. It is a group submission.
- Submission of the problem set must consist of a SINGLE DOCUMENT containing all the answers and the code for all the exercises. The document must be called: PSX_groupY.
- **Accepted formats**: *.ipynb*, *.pdf*.
- If your problem set is not in a notebook, we ask you to UPLOAD THE SCRIPT (*.py*). We might check if your code runs and delivers the outcome you show us.
- Late assignment policy
- **Marking Criteria available in the course outline on Learn**

Problem Sets

Table 1: Problem Set Grades Spring 2025

Statistics (All Groups)	PS1	PS2	PS3	PS4
Mean	65	72	70.2	74.2
Max	73	79	72	78.4
Min	50	63	67	69.76
Sd	8.2	5.1	1.8	3.1

Final Exam

Individual take-home exam of 2-3 days.

Should expect a set of exercises that cover most of the material seen in class.

We will provide you more information about the final project as the course advances.

Final Exam Statistics 24/25

Figure 1: Statistics

Statistic	Value
Minimum	34.50
Median	70.00
Maximum	83.50
Mean	68.16
Std	10.31
Number of Exams	46

Why Economists Program?

Why economists program?

" *The era of closed-form solutions for their own sake should be over. Newer generations get similar intuitions from computer-generated examples than from functional expressions*",
Jose-Victor Rios-Rull (2008).

Why economists program? Quantitative economics

- Economic models can be complicated $\rightarrow$ no closed-form (explicit) solution.
- More freedom of research $\rightarrow$ not subject to "simple" models with closed-form solutions and strong assumptions.
- Even if we can describe the qualitative results of theories, quantitative methods allow us to QUANTIFY THEORIES and QUANTIFY POLICIES.

Quantitative economics: not only how but how much

- **Standard approach**: theory$\rightarrow$ test mechanism/policy in reduced form with the data.

- **Quantitative approach**: theory $\rightarrow$ quantify mechanism/policy on the data.
  1. How much mechanism can account for data trends and facts?
  2. How much policy intervention would affect society outcomes? Changes in GDP, inequality, welfare?

Programming used across all economic fields

- **Micro**: solve structural models for a better understanding of micro-mechanisms and a more completed policy evaluation. Also study of networks, dynamic games, etc.
- **Macro**: solution and estimation of dynamic equilibrium models, policy evaluation and forecast. In macro one cannot run experiments. Quantified models allow us to run counterfactuals on environment changes or policy changes (welfare analysis).
- **Applied**: process large data sets with non-standard economic information: satellite pictures, weather data, historical data, text-mining, big-data, etc. Machine learning tools, non-standard estimators, simulation-based estimators, and other econometric tools.
- **Others Fields**: dynamic models of international trade, spatial models, economic consequences of climate change and environmental policies, asset pricing models, etc.

Example: Programming in Macroeconomics

Household maximisation problem, time-separable life time utility subject to her budget constraint:

$$\max_{\{c_t\}_{t=0}^{\infty}} \sum_{t=0}^{\infty} \beta^t E \underbrace{[\ln(C_t)]}_{Utility\ \ Function} \tag{1}$$

$$\text{s.t.} \quad \underbrace{K_{t+1} + C_t = Y_t + (1-\delta)K_t}_{Budget\ \ Constraint} \tag{2}$$

where now

$$Y_t = z_t K_t^{\alpha} \tag{3}$$

$$\log(z_t) = \rho \log(z_{t-1}) + \sigma \epsilon_t \tag{4}$$

$$\epsilon_t \sim N(0,1). \tag{5}$$

where C, K, Y denote consumption, capital and output. δ and z identify the capital depreciation rate and the aggregate shock.

Wages are higher

Programming and quantitative economics skills are highly valued in the labor market

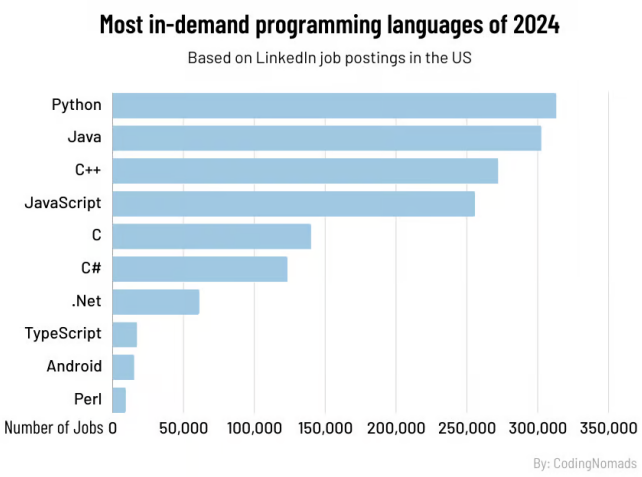


Figure 2: Linkedin job postings across programming languages. Source: Coding Nomads.

Some examples: Quantitative Economics

- Macroeconomics and inequality.
  Castañeda, A., Diaz-Gimenez, J., & Rios-Rull, J. V., (2003). Accounting for the US earnings and wealth inequality. Journal of Political Economy.
- Quantify welfare effects in macroeconomics
  Krueger, D., Mitman, K., & Perri, F. (2016). On the distribution of the welfare losses of large recessions. National Bureau of Economic Research.
- Quantify the aggregate effects of policies (in development)
  Kaboski, J. P., & Townsend, R. M. (2011). A structural evaluation of a large-scale quasi-experimental microfinance initiative. Econometrica.
- Quantify the welfare effects of policies (in education)
  Mullins, J. (2020). A structural meta-analysis of welfare reform experiments and their impacts on children. University of Minnesota, Minneapolis and Saint Paul, MN.

Survey

www.menti.com

Password: 1908 4847

Learning Programming

The importance of theory in programming

This is not just a course on learning a program. Theory will be important.

- Economic theory and mathematics will be very relevant for this course. Need to first understand the problem and theory to be able to write the code.
- We will focus on numerical analysis which requires us a well understanding of mathematics.

The three steps of numerical analysis

1. Mathematical model $\rightarrow$ create an algorithm
2. Algorithm [1] $\rightarrow$ write the code
3. Code $\rightarrow$ present your results

[1] Algorithm: A set of finite rules or instructions to be followed in calculations or other problem-solving operations. It can be understood as a cooking receipt but for a computational problem: ingredients (inputs), steps to execute one by one, new dish (output).

How do we program?

We never get right the code the first time. Is my problem in understanding the exercise? The mathematics behind the algorithm? Or in how to translate the algorithm into code?

1. Check lecture notes and the theory behind the exercise.
2. Write down in a paper what you want the code to do or the outcome to reproduce.
3. Sketch the code (pseudo-code) in a paper.
4. Bring the problem to the computer: write the code. More on this, next slides.
5. Present the outcome. Print function, plots, tables, etc

Writing code

- We all forget the correct syntax. Learning to write code is about learning how to properly use your past codes, code from others, and online resources. We never program from scratch.
  - **Google will be your best friend for this course.** We work with Python: Very popular open-software program. Great documentation with a huge community behind it. Julia is also open-software.
  - Stackoveflow: Almost all code doubts that you might have, are already asked (and answered) here.
- **Clear and understandable code.** Make use of comments to document what you do. Keep the code clean and tidy. Readability beats cleverness.
- **Comprehensive testing.** As you work on your code, test it. Use of print command, check the data type and format, use debugging tools.

Good coding practices

Figure 3: Coding is fun!

Good coding practices

- Keep your code simple, tidy, and easy to read: Readability $>$ Cleverness.
- Break complex problems in small taskes: Divide and Conquer.
- Make frequent use of functions.
- Don't use magic numbers. No numbers scattered around: assign them in a constant.
- Don't Repeat Yourself principles.
- Be lazy, automate: First think and plan-ahead to avoid you overwriting.
- Organize your time efficiently. Breaks are necessary when coding.

Getting help

Steps to follow when you are stuck on the code

1. Look in lecture notes, our codes, your past codes, and online documentation.
2. Search: Google + Stackoverflow.
3. Talk about it in your group.
4. Help each other. Except on the final problem set.
5. We won't answer emails about code troubles like "why is my code not working?".

Programming language: Python

Python

- Python is a **general-purpose** programming language conceived in 1989 by Dutch programmer *Guido van Rossum*.
- **Free** and **open-source** language.
- Python has experienced rapid adoption in the last decades and now it is one of the most **popular** programming languages. See The Economist article.
- Used by the scientific community, CIA, Google, Spotify, Pixar, etc.

Figure 4: Guido van Rossum

Pros of Python

- Most **trending** coding language: great documentation with a huge community behind. Many developers, collaborators, and ample learning sources.

- **Versatile language**. Python is a **general-purpose language** used for: communications, web development, multimedia, **scientific computing, data science,** machine learning, etc.

- Free and open-source language.
  - Open-source: you can access all the primitive code from any routine, function, or package. And modify the code to your taste.
  - Nice IDEs available. Can set up your own **beautiful display**, not like Stata...

- Elegant syntax and elegant desing: much easier to learn than other programming languages (C, C++, Java, etc.).

Cons of Python

- Some of the pros of Python might be a con.
  - We might prefer non-general-purpose program (as Matlab, Stata) if our work is just centered in a specific "field".
  - Commercial languages (Matlab, Stata) offer better support than free open-source languages.
- **Execution time is** relatively **slow**. Alternatives: cloud computing, parallelization, other programs as Julia.

Python features

- Python is a high-level language suitable for rapid development. It has a relatively **small core language** supported by **many libraries**. Main libraries we will use are
  - NumPy: fundamental library for scientific computing.
  - PanDas: fundamental library for data manipulation and data analysis.
  - SciPy: fundamental library for numerical analysis: optimization, integration, interpolation, etc. Written in low-languages (Fortran, C, and C+) enjoying the speed of compiled code.
  - Matplotlib: main library for plots and visual representation.
- Python supports **multiple programming styles** (procedural, object-oriented, and functional. Yet, it is mainly design for Object-Oriented Programming.
- it is **interpreted** rather than compiled. Execution time is low.

Python is based on Object Oriented Programming

Python is based on OOP but also supports procedural, and functional programming. Matlab, Stata are procedural-based. Julia also has multiple programming styles but is better suited for a procedural approach.

- **The procedural paradigm:** Program has a state that contain values of its variables. Functions are called to act on these data, data are passed back via function calls.

- **The OOP paradigm: data** and **functions** are **bundled together** into **objects**
  - In the OOP functions are usually called methods.
  - In Python the data and methods of an object are referred to as attributes. Depending on the class of object (like float, array, string, dataframe, etc) the object will have different methods.

Example: Procedural vs OOP

Since Python supports both procedural and OOP we can use both approaches. Note that many functions will also be a method and viceversa.

Example

Compute the mean of an array $A = \begin{bmatrix} 1 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$

```
# Import NumPy library to work with matrices/arrays.
import numpy as np
A = np.array([[0,1,0],[0,1,1]])  #create the 2-D array---i.e. matrix
# Procedural approach. We call np.mean function to act on A data.
 np.mean(A)
 0.5
# OOP approach. We call the array-method mean to act on the array-object A.
 A.mean()
 0.5
```

Object Oriented Programming

Object Oriented Programming OOP is useful as for the same reason abstraction is: for recognizing and exploiting common structure.

In Python everything in memory is treated as an object. This includes not just lists, strings, numbers, but also datasets, functions, etc.

An object is
a collection of data and instructions held in computer memory that consists of:

- a type,
- some content,
- a unique identity,
- methods.

Infrastructure

Infrastructure

Python is a programming language. Now we need to download the "programs"—the Integrated Development Environments (IDE)—to use the language.

- for Python:
  - The **Anaconda** distribution.
  - IDE (code editor): **Visual Studio Code, Spyder, etc**.
  - Notebooks in **Jupyter Notebooks or Google Colab**.
  - Anaconda Installation Installation guide

Anaconda

Installing **Anaconda**:

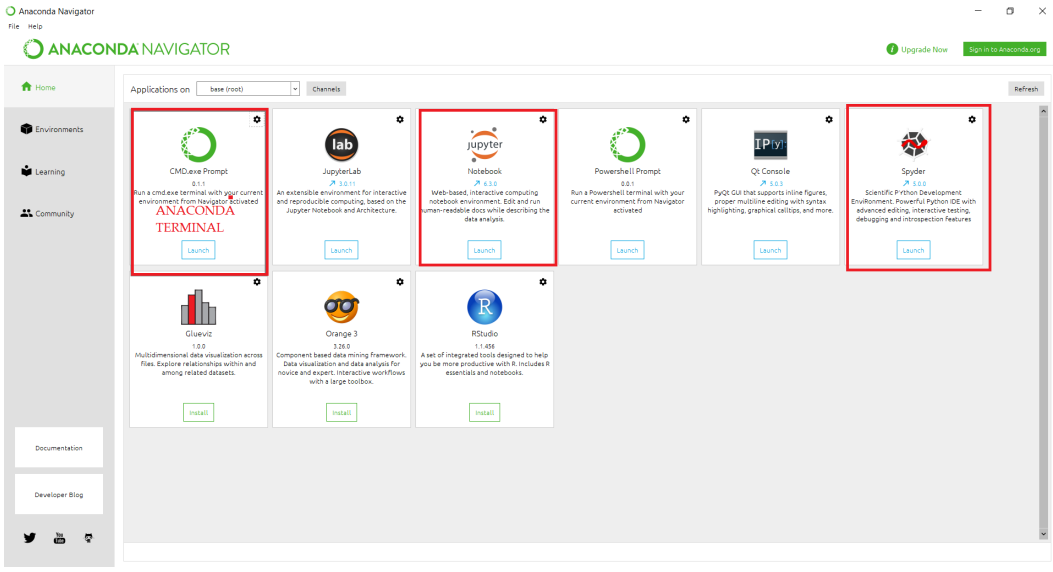
1. Download Anaconda Individual Edition Python 3.9 from Anaconda website.
2. Run the installer (default settings are fine)

With Anaconda we already download our main Python IDE, **Spyder**, the useful **Jupyter Notebooks**, and the IDE+notebooks in **VS editor**.

Anaconda's terminal *CMD Prompt*.

- To open a program type the name of the program in the terminal: `spyder` `jupyter notebook`
- To update a program: `conda update spyder`
- To install a package—Example: installing the quantecon package. `conda install -c conda-forge quantecon`

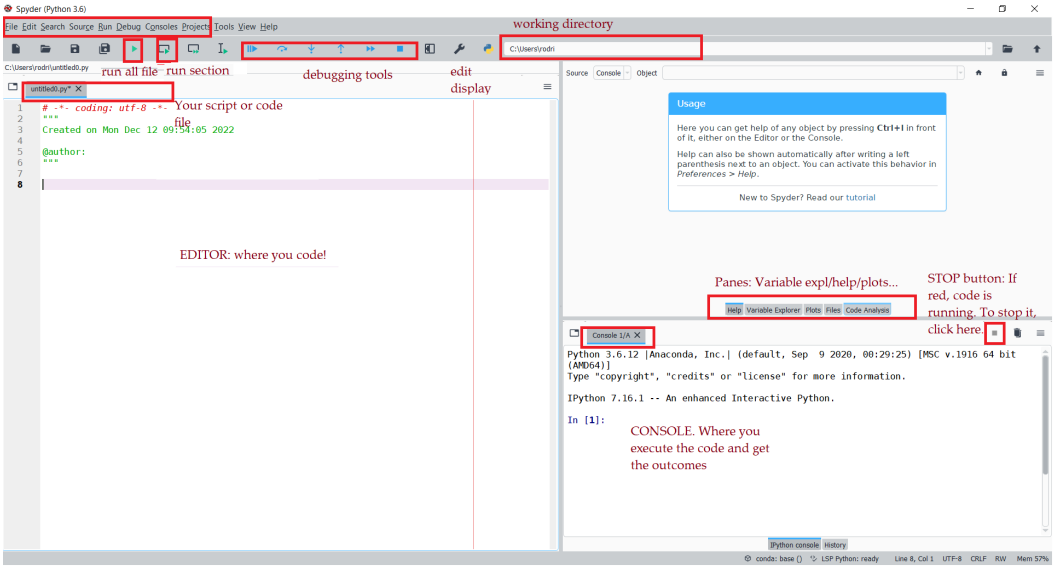
Anaconda desktop



Spyder

- Integrated Development Environment (IDE) for Python.
- *Spyder is a free and open source scientific environment written in Python, for Python, and designed by and for scientists, engineers and data analysts.*
- Quick-start tutorial.
- Intro Videos.

Spyder desktop



Spyder desktop

Toolbar. quickly access some of the most common commands in Spyder, such as run, save and debug files.

Panels.

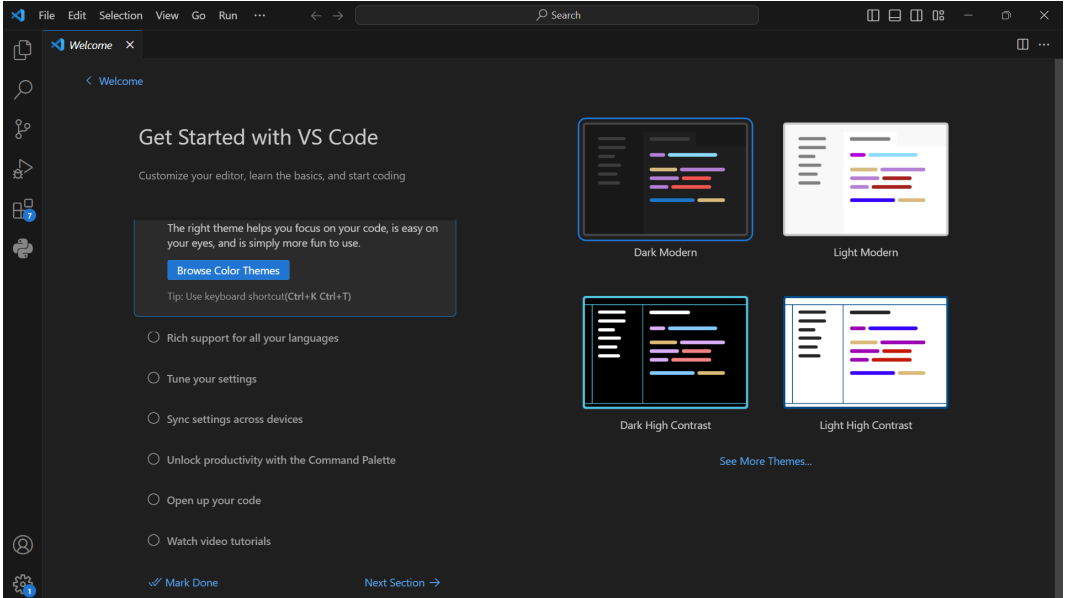
- **Editor:** create, open, and edit script files—where you code. Editor tutorial for a detail explanation, key components, shortcuts and personalizing features.
- **I-python Console:** execute commands and interact with data inside IPython interpreters—where the code is executed. Tutorial
- **Variable explorer:** allows you to interactively browse and manage the objects generated running your code. Where your outcomes get stored.
- **Help:** display documentation for the objects you are using in the Editor or the IPython console.
- **Other panes**: Plots/History/Files/Code analysis.

Spyder does not work? Troubles? check Spyder basic first aid.

Spyder shortcuts

- F9: run selected lines.
- Ctrl+enter: Execute cell.
- Ctrl+F: search
- Ctrl+R: search and replace.
- Ctrl+S: save.
- Ctrl+T: new console.
- Ctrl+I: help
- Ctrl+Z: undo.
- Arrow-up: In console to get the code previously executed.

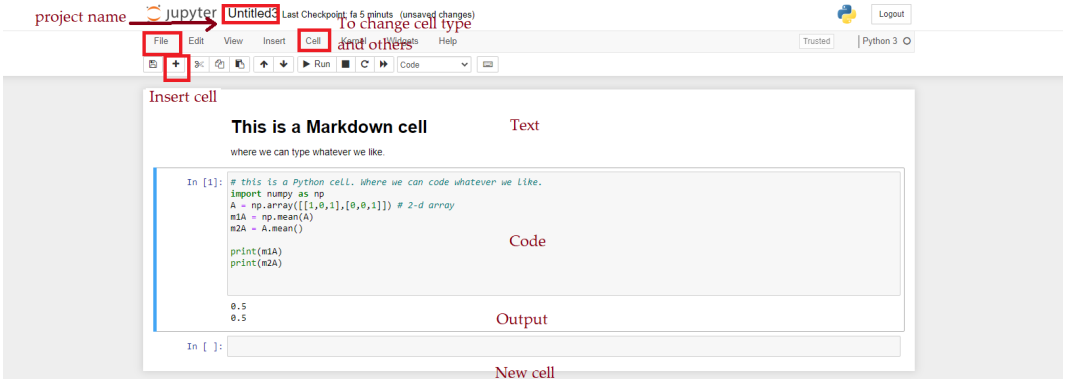
Visual Studio Code



Jupyter Notebooks

- Notebooks are very useful to present your code in results. We recommend you to work on the problem sets on Spyder and then submit the code+answers in a Jupyter notebook (nice and efficient).
- Tutorial
- Starting Jupyter notebook:
  1. Open Anaconda Navigator and launch Jupyter Notebook by mouse click. Using terminal: Open anacond prompt (windows) or Terminal (Mac). Write Jupyter notebook and hit enter.
  2. - Once launched: select your working directory folder. Click on *New*, click on *Python 3*. You have just created an empty Jupyter notebook!

Jupyter Notebooks desktop



Notebooks

Notebooks consists of two types of cells:

- Code cells with Python code
- Markdown cells with text. Short markdown tutorial

When inside a cell you are in edit mode, when not you are in command mode. To change the cell type your are, go to *Cell* – C*ell type* and select *code* or *Markdown*.

Jupyter notebooks short-cuts

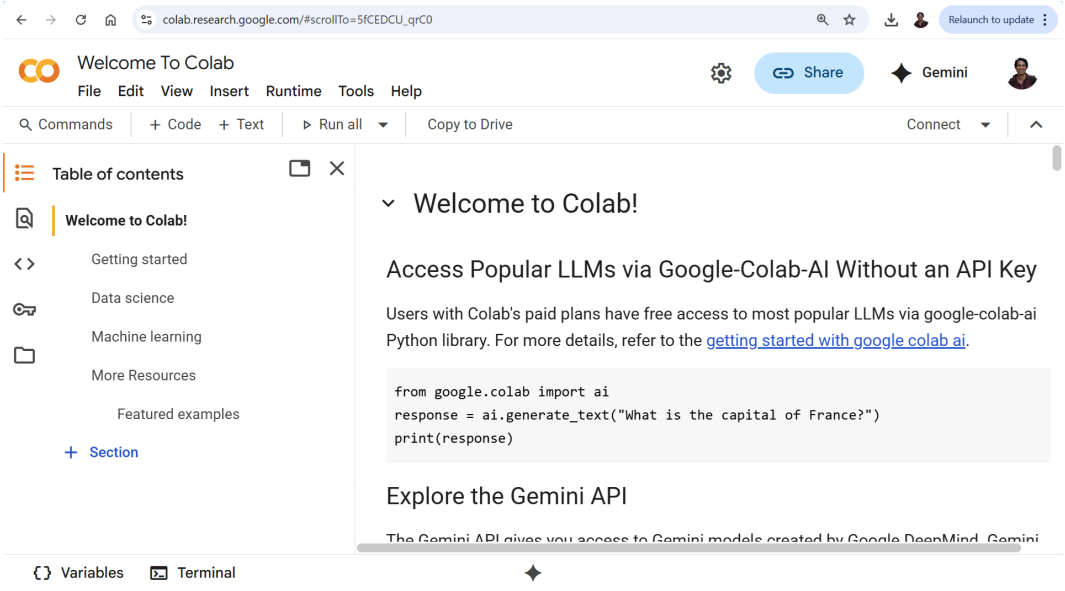
- Run cell: Ctrl+Enter.
- Enter edit mode: Enter.
- Enter command mode: Ctrl+M

Jupyter notebooks

Notebooks are the nicest and more efficient way to present your exercises. We expect you to submit the homework in notebooks.

- Save and output format of notebooks: You can save your current notebook (*.ipynb*) using save as or the download option. You can submit your problem set as a *.ipynb*.
- You can also directly download your notebook to a pdf. File-download as–pdf. For that, you need to first install a **Pandoc** and **Miktex** through CMD Prompt.
- Files in *ipynb*, can be directly opened in Github (and in general in browsers). *.ipynb*. You can also print the notebook and presented and submit it in *.pdf*. We recommend you to submit your homeworks in these formats.

Google Colab: allows you to write and execute Python in your browser



Your To-Dos

- Download Anaconda. Open Jupyter Notebooks, VSCode or Spider. Check and run *code_example_1.py*.
- Form your group for the problem sets (3 members) and register in the Econ-10115 - PNME - PS Groups
- Work on the problem set 0 and upload it in your group's repository (whatever you manage to do).
- Use the Python Refresher if you need.