Programming for ML and Data Science

Preliminaries

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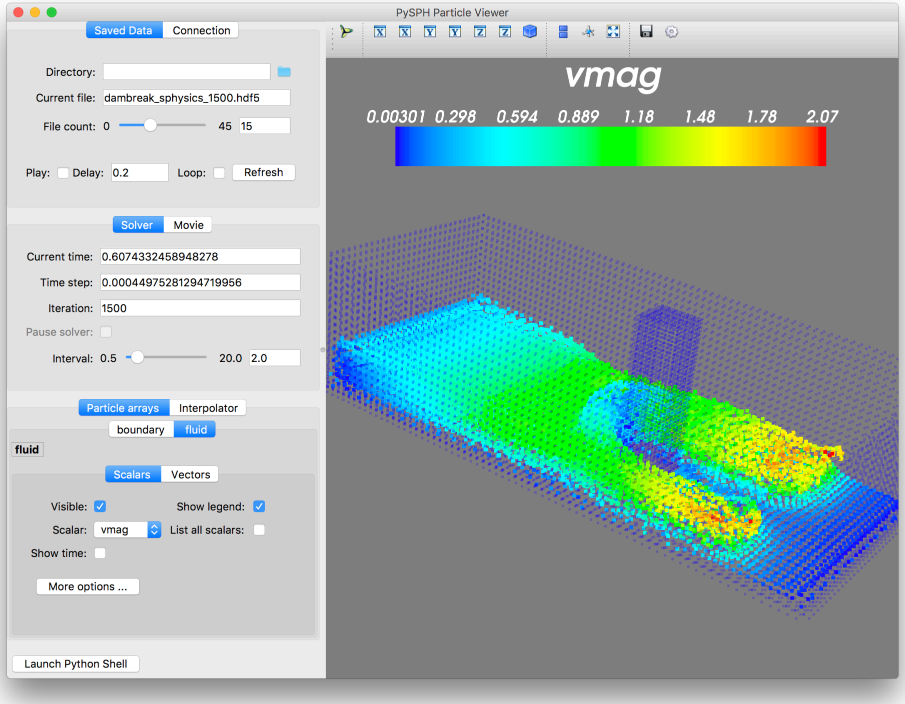
About Prabhu

- Professor of Aerospace Engineering
- Work broadly in computational science
  - Numerical simulation of fluids
  - High perf. and parallel computing
  - Scientific data visualization
- Open source contributor
  - Mayavi (2001): 3D visualization
  - PySPH (2012) and many others
- Programming Python since 1998
- Nominated PSF fellow since 2010



Directory:
Current file: dambreak_sphysics_1500.hdf5
File count: 0 45 15
Play: □ Delay: 0.2 Loop: □

Current time: 0.6074332458948278
Time step: 0.00044975281294719956
Iteration: 1500
Pause solver: □
Interval: 0.5 20.0 2.0

Visible: ☑ Show legend: ☑
Scalar: vmag List all scalars: □
Show time: □

General information

- Schedule: Thu. 7:30pm to 9pm and Sat. 9:30am to 11:00am.
- Prof. Vinay Kulkarni and Prof. Prabhu Ramachandran

TAs

- Brijesh Kumar
- Abhishek Choudhary
- Ashutosh Kumar Singh
- Dibyajyoti Baidya
- Mayank Bajaj
- Neha Vinod Shahu
- Russel Abreo
- Onkar Gayakwad (from GL)

Structure of course

- 2 x 1.5 hour lectures per week
- 1 hour tutorial session
- 24 lectures and 12 tutorials
- Plenty of hands-on material and exercises

Evaluation

- Quiz: 5 x 2 Marks
- Mid term test: 20 Marks
- Project: 20 Marks
- End semester examination: 50 marks

Getting the best out of the course

- Programming requires doing
- Not enough to read
- Type, execute the code, change it, and run it
- Experiment
- Do the homework
- Attend the tutorial classes
- Complete periodic take-home exercises

Expectations

- Expect you to give your best
- Stop us if you have questions
- Keep questions focussed on the content
- Also ask TAs questions

What we do not teach

- Too much theory
  - Focus of other the other courses
- No specific end-user applications
  - Focus on tools of the trade

Learning outcomes

- At the end of the course you will
  - Be able to use Python for ML/DS
  - Get a broad overview of applied ML/DS
  - Create ML models and evaluate them

Course syllabus

- Introduction to Python and Jupyter
- Data visualization and plotting with Python
- Overview of programming concepts
- Statistical plotting and computation
- Probabilistic programming
- Processing images and text
- Exploratory data analysis with pandas

Course syllabus

- High level overview of ML
- Regression, Classification, Clustering
- Data science life cycle
- Feature engineering for text, image, audio, and video
- Data engineering
- Big data and cloud resources

Course outline: part 1

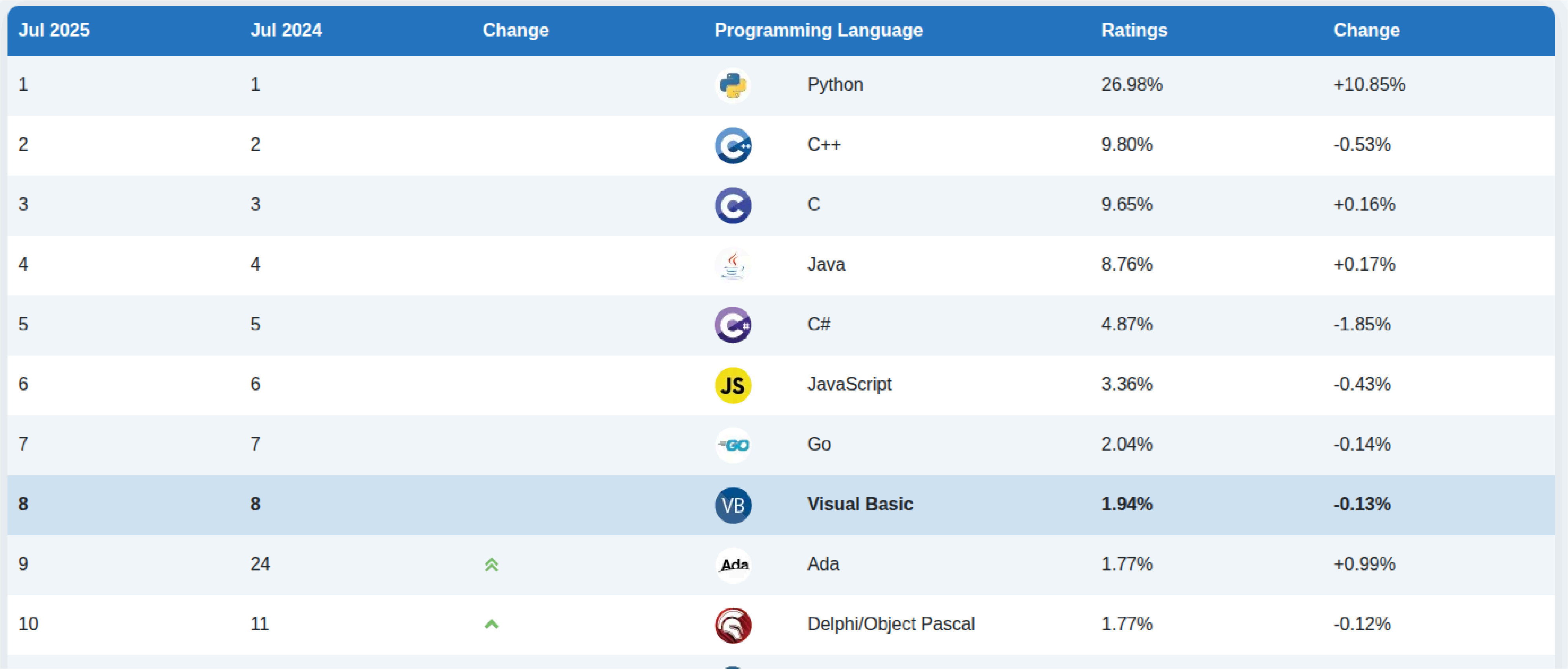
- **Week 1: Introduction to Python Programming**
  - Jupyter notebooks, and plotting with matplotlib, using numpy arrays
  - More Python and plotting: data structures, loops, conditionals, writing functions
  - Local installation, writing and running Python scripts
- **Week 2: Python for statistical analysis**
  - Review of Python core concepts
  - Python for statistics using numpy and matplotlib
  - Loading and visualizing data
  - Introduction to probabilistic programming with numpy and scipy
- **Week 3: Python for statistics data processing**
  - Probabilistic programming with numpy and scipy
  - Elementary image processing with numpy
  - Interactive widgets

Course outline

- **Week 4: Advanced numpy and text processing**
  - Advanced numpy: special indexing, broadcasting, masked indexing
  - Text processing with Python, input and output
  - Applications with other Python data structures
- **Week 5: Exploratory data analysis**
  - Introduction to pandas for data analysis
  - Reading, processing, and plotting data using pandas
  - Basic regression using numpy, statsmodels, and scikit-learn
- **Week 6: Regression and classification**
  - Linear and polynomial regression
  - Logistic regression, decision trees and random forests
  - Classification metrics: confusion matrix, ROC, AUC etc.

So why Python?

- Most popular language for ML
- #1 on TIOBE rankings

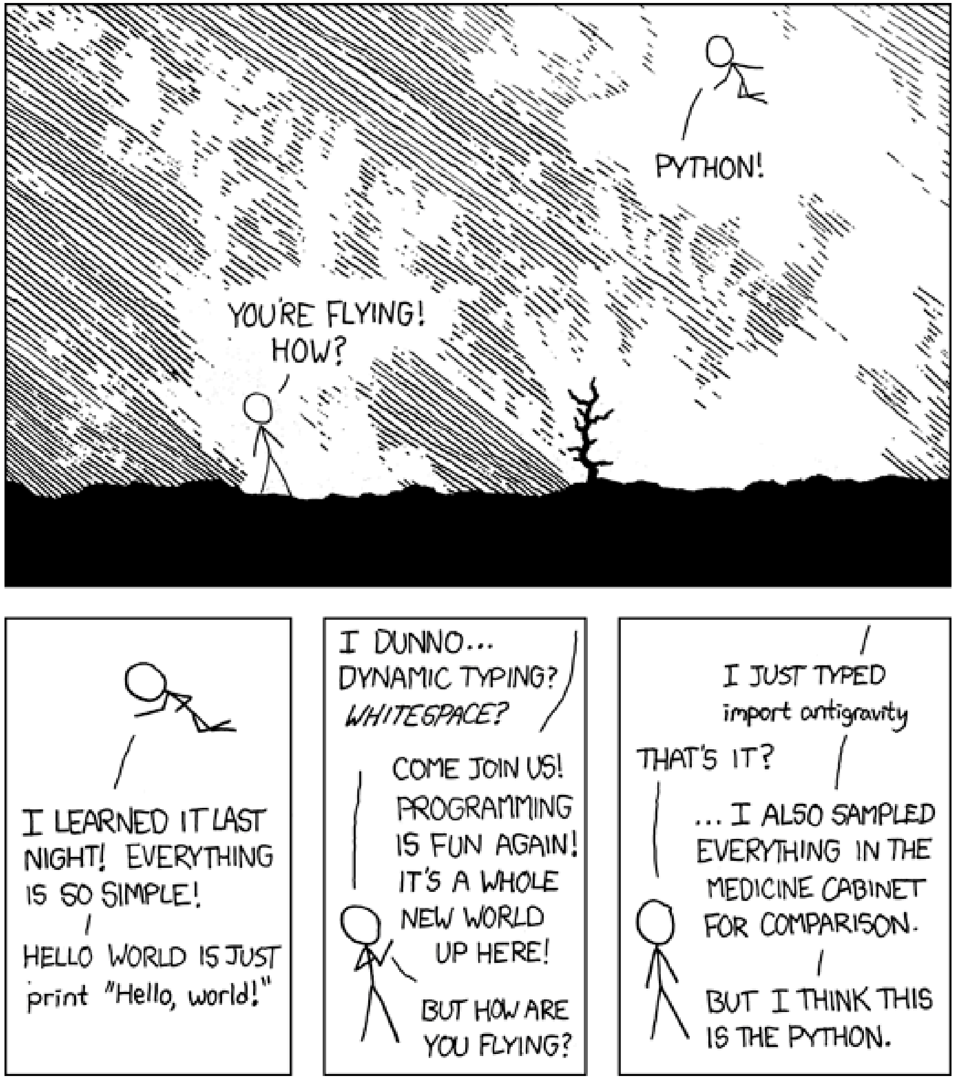


Jul 2025	Jul 2024	Change	Programming Language		Ratings	Change
1	1			Python	26.98%	+10.85%
2	2			C++	9.80%	-0.53%
3	3			C	9.65%	+0.16%
4	4			Java	8.76%	+0.17%
5	5			C#	4.87%	-1.85%
6	6		JS	JavaScript	3.36%	-0.43%
7	7		GO	Go	2.04%	-0.14%
8	**8**		VB	**Visual Basic**	**1.94%**	**-0.13%**
9	24	⇈	Ada	Ada	1.77%	+0.99%
10	11	↑		Delphi/Object Pascal	1.77%	-0.12%

So why Python?

- Easy to learn, read, and write
- Powerful libraries
- Strong and welcoming community

Python gives you superpowers


PYTHON!
YOU'RE FLYING! HOW?
I LEARNED IT LAST NIGHT! EVERYTHING IS SO SIMPLE!
HELLO WORLD IS JUST print "Hello, world!"
I DUNNO... DYNAMIC TYPING? WHITESPACE?
COME JOIN US! PROGRAMMING IS FUN AGAIN! IT'S A WHOLE NEW WORLD UP HERE!
BUT HOW ARE YOU FLYING?
I JUST TYPED import antigravity
THAT'S IT?
... I ALSO SAMPLED EVERYTHING IN THE MEDICINE CABINET FOR COMPARISON.
BUT I THINK THIS IS THE PYTHON.

[1]

Poll: How well do you know Python?

- How much Python programming do you know?

a. None

b. A little bit (novice)

c. Moderate

d. Proficient

Poll: Did you take the online course?

- The one on https://yaksh.fossee.in ?

a. Yes

b. No

Why learn programming today?

- Why not just use GPT/Gemini/whatever?

- How can you tell if the code is correct?
- Must understand what is going on
- Solid understanding of programming model

Our approach

- Learn by doing
- High level introduction to Python
- Immersion in the tools

Important

Expect you to type along and do

Python, `python`, Python

- Language
- Interpreter
  - **CPython**: `python`
  - Jython: Python on the JVM
- Distribution
  - Official CPython, ActiveState Python
  - miniforge, Python(x,y) etc.
  - Anaconda, miniconda

Python interpreter

- Interactive usage

```
$ python
Python 3.11.11 | packaged by conda-forge | ... [GCC 13.3.0] on linux
Type "help", "copyright", "credits" or "license" for more information.
>>>
```

- Executing Python code (Python scripts)

```
$ python hello.py
Hello world!
$
```

Python standard library

- Builtin additional functionality
    - Through Python modules
- “Batteries included”

Other community packages

- Many other open source packages
- We will use many of them
- `jupyter`, `numpy`, `scipy`
- `matplotlib`, `sklearn`, `pytorch`, `tensorflow`, etc.
- Community maintained
- Often provided in a “distribution”: conda-forge etc.

Summary: Python ecosystem

- Python Language
- Python interpreters
  - **CPython**: `python`
  - Jython: Python on the JVM
- Python standard library
- Community packages
- Python distributions

Programming

ⓘ **A famous quote**[1]

Programs must be written for people to read, and only incidentally for machines to execute.

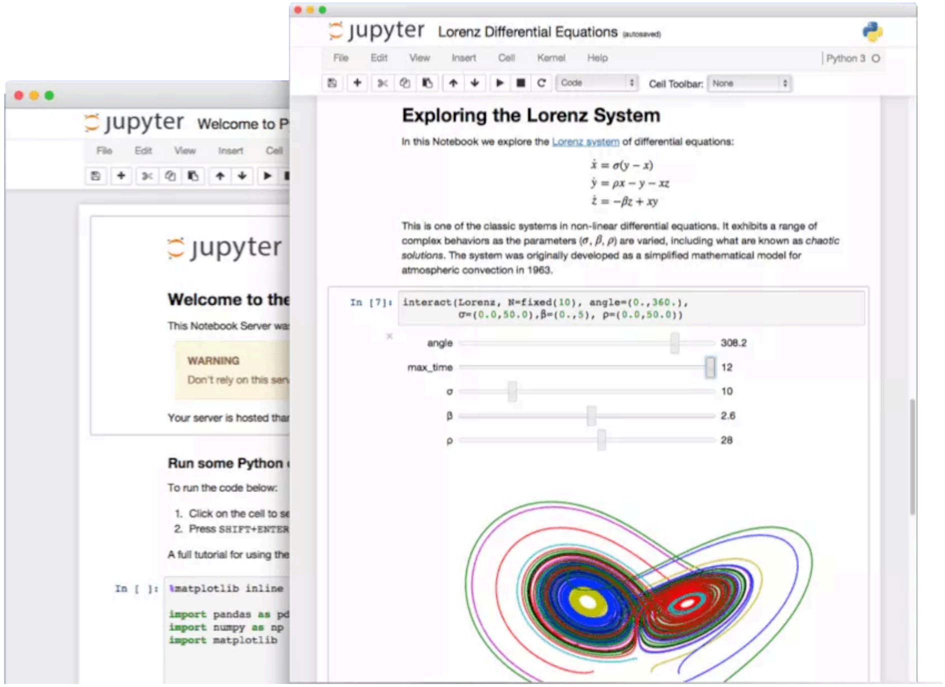
A mental model

- `python` interprets each statement
- Top to bottom
- Sequentially

> **Tip**
>
> If you find programming hard, perhaps you need to provide simpler instructions?

What is Jupyter?

- Powerful interface
- Combine code, text, math
- Interactive widgets


jupyter Welcome to P
File Edit View Insert Cell
jupyter
jupyter Lorenz Differential Equations (autosaved)
File Edit View Insert Cell Kernel Help
Python 3
Code
Cell Toolbar: None

Welcome to the

This Notebook Server wa

WARNING

Don't rely on this ser

Your server is hosted tha

Run some Python

To run the code below:

1. Click on the cell to se
2. Press SHIFT+ENTER

A full tutorial for using the

```
In [ ]: %matplotlib inline

        import pandas as pd
        import numpy as np
        import matplotlib
```

Exploring the Lorenz System

In this Notebook we explore the Lorenz system of differential equations:

$$\dot{x} = \sigma(y - x)$$
$$\dot{y} = \rho x - y - xz$$
$$\dot{z} = -\beta z + xy$$

This is one of the classic systems in non-linear differential equations. It exhibits a range of complex behaviors as the parameters (σ, β, ρ) are varied, including what are known as *chaotic solutions*. The system was originally developed as a simplified mathematical model for atmospheric convection in 1963.

```
In [7]: interact(Lorenz, N=fixed(10), angle=(0.,360.),
                 σ=(0.0,50.0),β=(0.,5), ρ=(0.0,50.0))
```

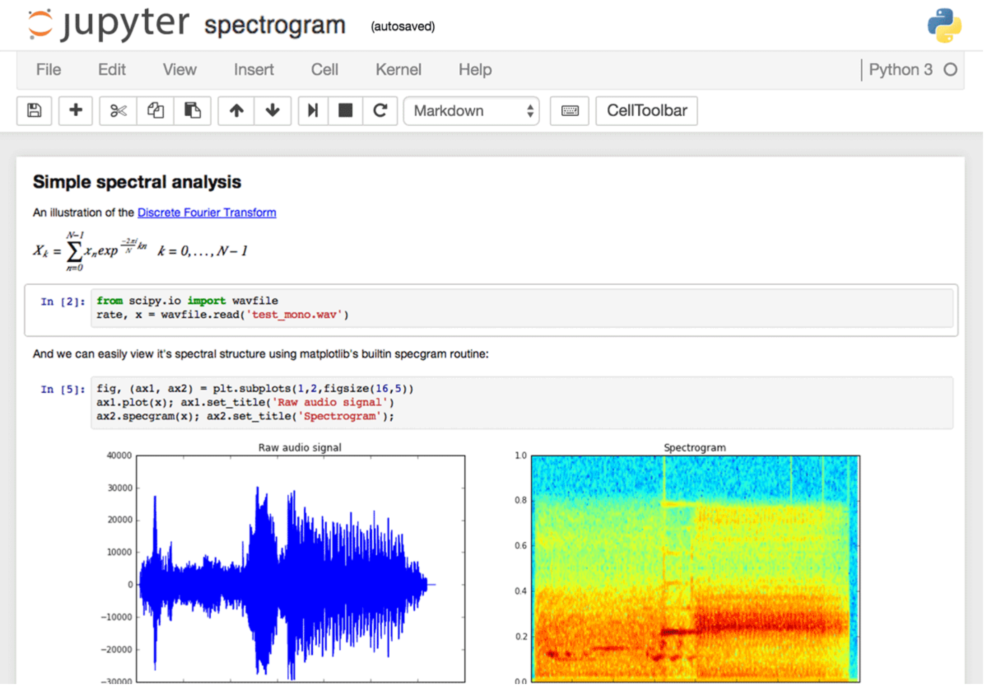
angle 308.2

max_time 12

σ 10

β 2.6

ρ 28



Simple spectral analysis

An illustration of the Discrete Fourier Transform

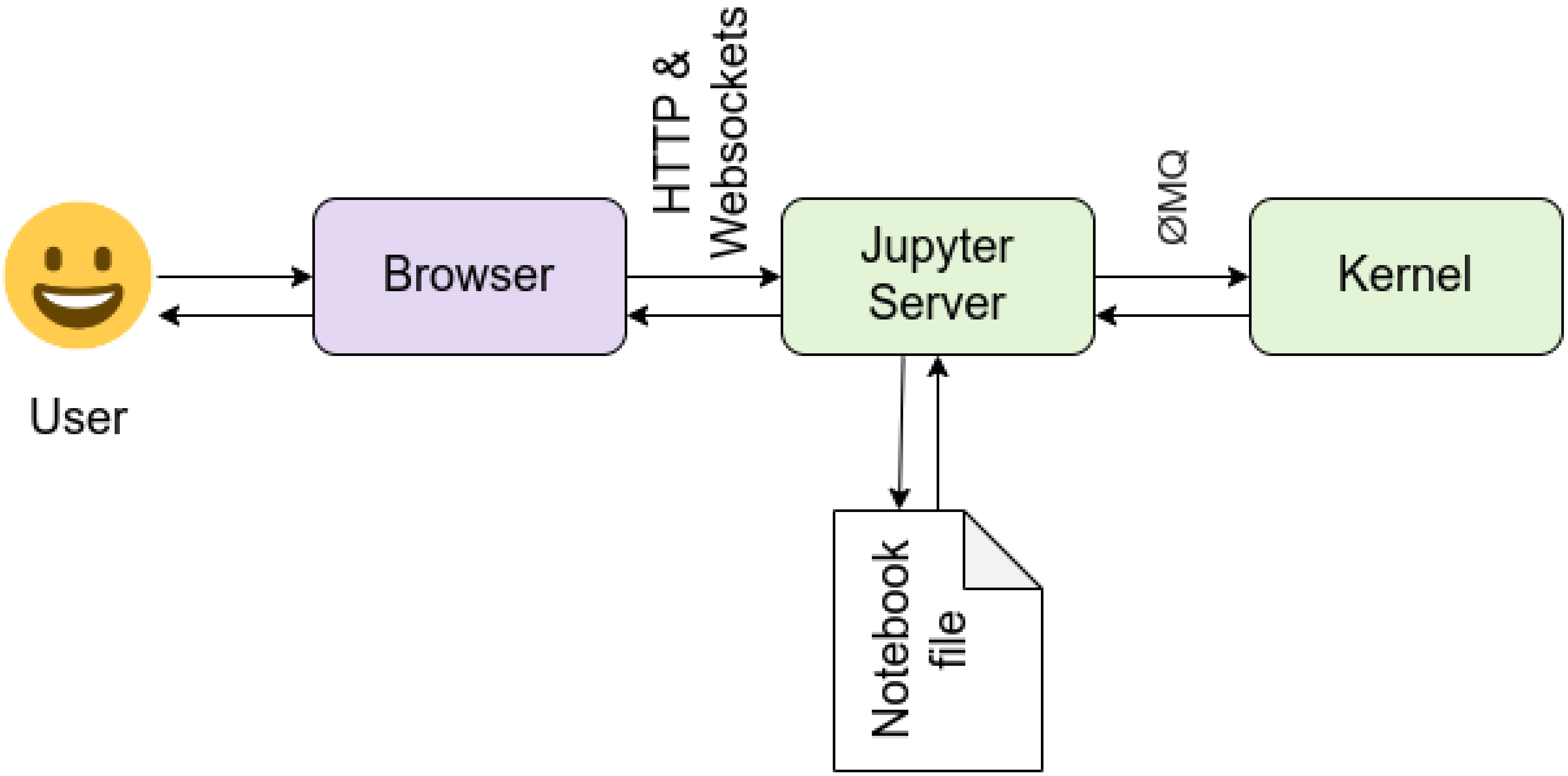
$$X_k = \sum_{n=0}^{N-1} x_n \exp^{\frac{-2\pi i}{N}kn} \quad k = 0, \ldots, N-1$$

```
In [2]: from scipy.io import wavfile
        rate, x = wavfile.read('test_mono.wav')
```

And we can easily view it's spectral structure using matplotlib's builtin specgram routine:

```
In [5]: fig, (ax1, ax2) = plt.subplots(1,2,figsize(16,5))
        ax1.plot(x); ax1.set_title('Raw audio signal')
        ax2.specgram(x); ax2.set_title('Spectrogram');
```

How does it work?



How does it work?

- Kernels manage execution and communication
- Supports 40 different languages
- Python, Julia, R, Scala, Java, Octave, Scheme, Cling …

- Notebook is an interface that talks to the kernel

Alternatives

- Jupyterlite: on your browser
- Google colab: on their servers
- Alternatives: Marimo

Some reference texts

- Python data science handbook
- Learning Data Science
- Veridical Data Science
- Computational and Inferential thinking

Before we start

- Get comfortable with
  1. Keyboard!
  2. Code editor
- Practice
- https://zty.pe
- Try to clear wave 10

Questions?

Poll: What OS do you use?

What OS do you use on your programming environment for this course? No phone/tablet.

a. Windows

b. MacOS

c. Linux

d. Other

Let us dive in!

- Visit here: prabhuramachandran.github.io/pml
- Provides a live environment
  - Tested on recent Firefox or Chrome
  - Don’t use a private window
- Will have the class slides/notebooks etc.
- Avoid editing files in `slides`, `tutorials`