

Lecture VII - NumPy and Pandas for Scientific Computing

Programming with Python

Dr. Tobias Vlček

Quick Recap of the last Lecture

Modules

- Modules are `.py` files containing Python code
- They are used to organize and reuse code
- They can define functions, classes, and variables
- Can be imported into other scripts

...

Tip

We can import entire modules or individual functions, classes or variables.

Standard Libraries

- Python includes many built-in modules like:
 - `random` provides functions for random numbers
 - `os` allows interaction with the operating system
 - `csv` is used for reading and writing CSV files
 - `re` is used for working with regular expressions

Packages

- Packages are collections of modules
- Often available from the Python Package Index (PyPI)
- Install using `pip install <package_name>`
- Virtual environments help manage dependencies

...

Tip

Virtual environments are not that important for you right now, as they are mostly used if you work on several projects with different dependencies at once.

NumPy Module

What is NumPy?

- **NumPy** is a package for scientific computing in Python
- Provides large, multi-dimensional arrays and matrices
- Wide range of functions to operate on these
- Python lists can be slow - Numpy arrays are much faster

...

Note

The name of the package comes from Numerical Python.

Why is NumPy so fast?

- Arrays are stored in a contiguous block of memory
- This allows for efficient memory access patterns
- Operations are implemented in the languages C and C++

...

Question: Have you heard of C and C++?

How to get started

1. Install NumPy using `pip install numpy`
2. In Thonny, Tools -> Manage Packages...
3. Import NumPy in a script using `import numpy as np`

...

```
import numpy as np
x = np.array([1, 2, 3, 4, 5]); type(x)
```

`numpy.ndarray`

...

Note

You don't have to use `as np`. But it is a common practice to do so.

Creating Arrays

- The backbone of Numpy is the so called ndarray
- Can be initialized from different data structures:

```
import numpy as np
```

```
array_from_list = np.array([1, 1, 1, 1])  
print(array_from_list)
```

```
[1 1 1 1]
```

```
import numpy as np
```

```
array_from_tuple = np.array((2, 2, 2, 2))  
print(array_from_tuple)
```

```
[2 2 2 2]
```

Heterogenous Data Types

- It is possible to store different data types in a ndarray

```
import numpy as np
```

```
array_different_types = np.array(["s", 2, 2.0, "i"])  
print(array_different_types)
```

```
['s' '2' '2.0' 'i']
```

```
...
```

Note

But it is mostly not recommended, as it can lead to performance issues. If possible, try to **keep the types homogenous**.

Prefilled Arrays

Improve performance by **allocating memory upfront**

- `np.zeros(shape)`: to create an array of zeros
- `np.random.rand(shape)`: array of random values
- `np.arange(start, stop, step)`: evenly spaced
- `np.linspace(start, stop, num)`: evenly spaced

```
...
```

Note

The shape refers to the size of the array. It can have one or multiple dimensions.

Dimensions

- The shape is specified as tuple in these arrays
- (2) or 2 creates a 1-dimensional array (vector)
- (2,2) creates a 2-dimensional array (matrix)
- (2,2,2) 3-dimensional array (3rd order tensor)
- (2,2,2,2) 4-dimensional array (4th order tensor)
- ...

Computations

- We can apply operations to the entire array at once
- This is much faster than applying them element-wise

...

```
import numpy as np
x = np.array([1, 2, 3, 4, 5])
x + 1
```

```
array([2, 3, 4, 5, 6])
```

Arrays in Action

Task: Practice working with Numpy:

```
# TODO: Create a 3-dimensional tensor with filled with zeros
# Choose the shape of the tensor, but it should have 200 elements
# Add the number 5 to all values of the tensor

# Your code here
assert sum(tensor) == 1000

# TODO: Print the shape of the tensor using the method shape()
# TODO: Print the dtype of the tensor using the method dtype()
# TODO: Print the size of the tensor using the method size()
```

Indexing and Slicing

- Accessing and slicing ndarray works as before
- Higher dimension element access with multiple indices

...

Question: What do you expect will be printed?

```
import numpy as np
x = np.random.randint(0, 10, size=(3, 3))
print(x); print("----")
print(x[0:2,0:2])
```

```
[[5 2 4]
 [9 8 8]]
```

```
[0 5 4]]
---
[[5 2]
 [9 8]]
```

Data Types

- Numpy provides data types as characters
- i: integer
- b: boolean
- f: float
- S: string
- U: unicode

```
...
```

```
string_array = np.array(["Hello", "World"]); string_array.dtype
dtype('<U5')
```

Enforcing Data Types

- We can also **provide** the type when creating arrays

```
...
```

```
x = np.array([1, 2, 3, 4, 5], dtype = 'f'); print(x.dtype)
```

```
float32
```

```
...
```

- Or we can **change** them for existing arrays

```
x = np.array([1, 2, 3, 4, 5], dtype = 'f'); print(x.astype('i').dtype)
```

```
int32
```

```
...
```

Note

Note, how the types are specified as `int32` and `float32`.

Sidenote: Bits

Question: Do you have an idea what 32 stands for?

```
...
```

- It's the number of bits used to represent a number
 - `int16` is a 16-bit integer
 - `float32` is a 32-bit floating point number
 - `int64` is a 64-bit integer
 - `float128` is a 128-bit floating point number

Why do Bits Matter?

- They matter, because they can affect:
 - the performance of your code
 - the precision of your results

...

- That's why numbers can have a limited precision!
 - An `int8` has to be in the range of -128 to 127
 - An `int16` has to be in the range of -32768 to 32767

...

Question: Size difference between `int16` and `int64`?

Joining Arrays

- You can use concatenate two **join arrays**
- With `axis` you can specify the dimension
- In 2-dimensions `hstack()` and `vstack()` are easier

...

Question: What do you expect will be printed?

```
import numpy as np
ones = np.array((1,1,1,1))
twos = np.array((1,1,1,1)) *2
print(np.vstack((ones,twos))); print(np.hstack((ones,twos)))
```

```
[[1 1 1 1]
 [2 2 2 2]]
[1 1 1 1 2 2 2 2]
```

Common Methods

- `sort()`: sort the array from low to high
- `reshape()`: reshape the array into a new shape
- `flatten()`: flatten the array into a 1D array
- `squeeze()`: squeeze the array to remove 1D entries
- `transpose()`: transpose the array

...

Tip

Try experiment with these methods, they can make your work much easier.

Speed Differences in Action

Task: Complete the following task to practice with Numpy:

```
# TODO: Create a 2-dimensional matrix with filled with ones of size 1000 x 1000.
# Afterward, flatten the matrix to a vector and loop over the vector.
# In each loop iteration, add a random number between 1 and 10000.
# TODO: Now, do the same with a list of the same size and fill it with random numbers.
# Then, sort the list as you have done with the Numpy vector before.
# You can use the `time` module to compare the runtime of both approaches.
import time
start = time.time()
# Your code here
end = time.time()
print(end - start) # time in seconds
```

9.059906005859375e-06

Pandas Module

What is Pandas?

- Pandas is a data manipulation and analysis library
- It provides data structures like **DataFrames and Series**
- Tools for data cleaning, analysis, and visualization
- It can also be used to work with Excel files!

How to install Pandas

- In the last lecture, we have installed it with `pip install pandas` or with Thonny
- Now, import the package `import pandas as pd`

...

Note

You can also use a different abbreviation, but `pd` is the most common one.

Creating DataFrames

- DataFrames behave quite similar to Numpy arrays
- But they have row and column labels

...

```
import pandas as pd
df = pd.DataFrame({ # DataFrame is created from a dictionary
    "Name": ["Tobias", "Robin", "Nils", "Nikolai"],
    "Kids": [2, 1, 0, 0],
    "City": ["Oststeinbek", "Oststeinbek", "Hamburg", "Lübeck"],
    "Salary": [3000, 3200, 4000, 2500]}); print(df)
```

	Name	Kids	City	Salary
0	Tobias	2	Oststeinbek	3000
1	Robin	1	Oststeinbek	3200
2	Nils	0	Hamburg	4000
3	Nikolai	0	Lübeck	2500

Reading from CSV Files

```
df = pd.read_csv("employees.csv") # Reads the CSV file
print(df)
```

	Name	Age	Department	Position	Salary
0	Alice	30	HR	Manager	50000
1	Bob	25	IT	Developer	60000
2	Charlie	28	Finance	Analyst	55000
3	David	35	Marketing	Executive	52000
4	Eve	32	Sales	Representative	48000
5	Frank	29	IT	Developer	61000
6	Grace	31	HR	Assistant	45000
7	Hank	27	Finance	Analyst	53000
8	Ivy	33	Marketing	Manager	58000
9	Jack	26	Sales	Representative	47000
10	Kara	34	IT	Developer	62000
11	Leo	30	HR	Manager	51000
12	Mona	28	Finance	Analyst	54000
13	Nina	35	Marketing	Executive	53000
14	Oscar	32	Sales	Representative	49000
15	Paul	29	IT	Developer	63000
16	Quinn	31	HR	Assistant	46000
17	Rita	27	Finance	Analyst	52000
18	Sam	33	Marketing	Manager	59000
19	Tina	26	Sales	Representative	48000
20	Uma	34	IT	Developer	64000
21	Vince	30	HR	Manager	52000
22	Walt	28	Finance	Analyst	55000
23	Xena	35	Marketing	Executive	54000
24	Yara	32	Sales	Representative	50000
25	Zane	29	IT	Developer	65000
26	Anna	31	HR	Assistant	47000
27	Ben	27	Finance	Analyst	53000
28	Cathy	33	Marketing	Manager	60000
29	Dylan	26	Sales	Representative	49000
30	Ella	34	IT	Developer	66000
31	Finn	30	HR	Manager	53000
32	Gina	28	Finance	Analyst	56000
33	Hugo	35	Marketing	Executive	55000
34	Iris	32	Sales	Representative	51000
35	Jake	29	IT	Developer	67000
36	Kyla	31	HR	Assistant	48000
37	Liam	27	Finance	Analyst	54000
38	Mia	33	Marketing	Manager	61000
39	Noah	26	Sales	Representative	50000
40	Olive	34	IT	Developer	68000
41	Pete	30	HR	Manager	54000
42	Quincy	28	Finance	Analyst	57000
43	Rose	35	Marketing	Executive	56000
44	Steve	32	Sales	Representative	52000
45	Tara	29	IT	Developer	69000
46	Umar	31	HR	Assistant	49000

47	Vera	27	Finance	Analyst	55000
48	Will	33	Marketing	Manager	62000
49	Zara	26	Sales	Representative	51000

Basic Operations

- Use the `df.head()` method to display the first 5 rows
- Use the `df.tail()` method to display the last 5 rows

...

```
df = pd.read_csv("employees.csv")
print(df.tail())
```

	Name	Age	Department	Position	Salary
45	Tara	29	IT	Developer	69000
46	Umar	31	HR	Assistant	49000
47	Vera	27	Finance	Analyst	55000
48	Will	33	Marketing	Manager	62000
49	Zara	26	Sales	Representative	51000

Information about the DataFrame

- Use `df.info()` to display information about a DataFrame

...

```
df = pd.read_csv("employees.csv")
print(df.info())
```

```
<class 'pandas.core.frame.DataFrame'>
RangeIndex: 50 entries, 0 to 49
Data columns (total 5 columns):
#   Column      Non-Null Count  Dtype
---  -
0   Name        50 non-null    object
1   Age         50 non-null    int64
2   Department  50 non-null    object
3   Position    50 non-null    object
4   Salary      50 non-null    int64
dtypes: int64(2), object(3)
memory usage: 2.1+ KB
None
```

Statistics about a DataFrame

- Use `df.describe()` to display summary statistics
- Use the `df.index` **attribute** to access the **index**

...

```
df = pd.read_csv("employees.csv")
print(df.describe())
```

	Age	Salary
count	50.000000	50.000000
mean	30.320000	54980.000000
std	2.958488	6175.957333
min	25.000000	45000.000000
25%	28.000000	50250.000000
50%	30.000000	54000.000000
75%	33.000000	59750.000000
max	35.000000	69000.000000

Filtering DataFrames

- Use `df['column_name']` to access a column
- Use the `df[df['column'] > value]` method to filter

...

```
df = pd.read_csv("employees.csv")
df_high_salary = df[df['Salary'] >= 67000]
print(df_high_salary)
print(df_high_salary.iloc[2]["Name"]) #Access the third row and the "Name" column
print(df_high_salary.loc[40]["Name"]) #Access the label 40 and the "Name" column
```

	Name	Age	Department	Position	Salary
35	Jake	29	IT	Developer	67000
40	Olive	34	IT	Developer	68000
45	Tara	29	IT	Developer	69000

Tara
Olive

Filtering in Action

Task: Complete the following task:

```
# TODO: Load the employees.csv located in the git repository into a DataFrame
# First, filter the DataFrame for employees with a manager position
# Then, print the average salary of the remaining employees
# Finally, print the name of the employee with the lowest salary
```

...

Note

Note, that we can use the `mean()` method on the `Salary` column, as it is a numeric column. In addition, we can use the `min()` method on the `Salary` column to find the lowest salary.

Grouping DataFrames

Grouping

- Grouping is a powerful feature of Pandas
- Groups data by one or more columns
- And then perform operations
- Syntax is `df.groupby('column').method()`

```
...
df = pd.read_csv("employees.csv")
df = df.drop(columns=["Name", "Department"])
df.groupby(['Position']).mean() # Mean per position
```

	Age	Salary
Position		
Analyst	27.5	54400.0
Assistant	31.0	47000.0
Developer	30.6	64500.0
Executive	35.0	54000.0
Manager	31.5	56000.0
Representative	29.0	49500.0

Grouping by Multiple Columns

- Group by multiple columns `['column1', 'column2']`
- You can use lists or tuples to specify multiple columns

```
...
df = pd.read_csv("employees.csv")
df = df.drop(columns=["Name"])
# Max per position and department
df.groupby(['Position', "Department"]).max()
```

Position	Department
Analyst	Finance
Assistant	HR
Developer	IT
Executive	Marketing

Position	Department
Manager	HR
Representative	Marketing
	Sales

Grouping with Aggregations

- As seen, we can use aggregation functions:
 - `sum()`: sum of the values
 - `mean()`: mean of the values
 - `max()`: maximum of the values
 - `min()`: minimum of the values
 - `count()`: count of the values

Melting DataFrames

- Use `pd.melt()` to transform from wide to long

...

```
df = pd.read_csv("employees.csv").drop(columns=["Name"])
df = pd.melt(df, id_vars=['Position'])
print(df.head()); print(df.tail())
```

```

      Position variable value
0      Manager      Age    30
1  Developer      Age    25
2    Analyst      Age    28
3  Executive      Age    35
4 Representative  Age    32
      Position variable value
145  Developer  Salary  69000
146  Assistant  Salary  49000
147    Analyst  Salary  55000
148    Manager  Salary  62000
149 Representative  Salary  51000
```

Pandas in Action

Task: Complete the following task:

```
# TODO: Load the employees.csv again into a DataFrame
# First, group by the "Position" column and count the employees per position
# Then, group by the "Department" column and calculate the sum of all other columns per
→ department
df = pd.read_csv("employees.csv")
# Your code here
```

...

Note

Do you notice any irregularities while calculating the sum per department?

Concatenating DataFrames

- `pd.concat()` to concatenate along shared columns

```
df1 = pd.DataFrame({"A": [1, 2, 3], "B": [4, 5, 6]})
df2 = pd.DataFrame({"A": [7, 8, 9], "B": [10, 11, 12]})
df = pd.concat([df1, df2])
print(df)
```

	A	B
0	1	4
1	2	5
2	3	6
0	7	10
1	8	11
2	9	12

Joining DataFrames

- Use `pd.join()` to join DataFrames along columns
- Joining is done on the index by default!

```
df1 = pd.DataFrame({"A": [1, 2, 3], "B": [4, 5, 6]}, index=['x', 'y', 'z'])
df2 = pd.DataFrame({"C": [7, 8, 9], "D": [10, 11, 12]}, index=['z', 'y', 'w'])
df = df1.join(df2)
print(df)
```

	A	B	C	D
x	1	4	NaN	NaN
y	2	5	8.0	11.0
z	3	6	7.0	10.0

Merging DataFrames on Columns

- `pd.merge(df_name, on='column', how='type')`
- merge DataFrames along shared columns
- `how` specifies the type of merge
 - `inner`: rows with matching keys in both DataFrames
 - `outer`: rows from both are kept, missing values are filled
 - `left`: rows from the left are kept, missing values are filled
 - `right`: rows from right are kept, missing values are filled

Outer Merge

```
df3 = pd.DataFrame({"A": [1, 2, 3], "B": [4, 5, 6]})
df4 = pd.DataFrame({"A": [2, 3, 4], "C": [7, 8, 9]})
df_merged = df3.merge(df4, on="A", how="outer")
print(df_merged)
```

	A	B	C
0	1	4.0	NaN
1	2	5.0	7.0
2	3	6.0	8.0
3	4	NaN	9.0

Working with Excel Files

Working with Excel Files

Reading Excel Files

- Read using the `pd.read_excel(file_path)` function
- Write using the `df.to_excel(file_path)` method

...

```
import pandas as pd
df = pd.read_csv("employees.csv")
df.to_excel("employees.xlsx", index=False)
```

...

Note

Note, that you likely need to install the `openpyxl` package to be able to write Excel files, as it handles the file format.

Advanced Excel file handling

```
df = pd.read_excel("employees.xlsx")

# Writes to the Employees sheet and does not include row indices
df.to_excel("employees.xlsx", sheet_name="Employees", index=False)

# Reads from the Employees sheet
df = pd.read_excel("employees.xlsx", sheet_name="Employees")
```

...

Note

And that's it for today's lecture!

You now have the basic knowledge to start working with scientific computing. Don't worry that we haven't applied Excel files yet, we will do so in the upcoming tutorial.

Literature

Interesting Books

- Downey, A. B. (2024). Think Python: How to think like a computer scientist (Third edition). O'Reilly. [Link to free online version](#)
- Elter, S. (2021). Schrödinger programmiert Python: Das etwas andere Fachbuch (1. Auflage). Rheinwerk Verlag.

...

For more interesting literature to learn more about Python, take a look at the [literature list](#) of this course.