Week 11: Numerical python and plotting

Contents

Important

First, `download_week11.py` and run the script in `VSCode`. You may need to confirm the download in your browser.

The script should end with `Successfully completed!`. If you encounter an error, follow the instructions in the error message. If needed, you can proceed with the exercises and seek assistance from a TA later.

This week, we will learn about the NumPy library, which is a fundamental package for scientific computing in Python. In NumPy, you can work with multidimensional arrays (representing matrices and vectors), and it contains an extensive collection of mathematical functions to operate on these arrays. NumPy is the foundation for *many* other Python libraries, such as Pandas, SciPy, and Matplotlib, which are used for data analysis, scientific computing, and data visualization.

The first three exercises this week introduce some basic functionalities of NumPy. There are no tests for these exercises, but it is recommended to try them out to get familiar with NumPy. Check the documentation of NumPy for help and examples here.

You should only need to use *one* for-loop today (Exercise 11.7) If you need to use a for-loop anywhere else, try to find out how this can be done in NumPy without a for-loop.

Exercise 11.1: Warm-up with NumPy

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Before diving into the exercises, let's start with some warm-up exercises to familiarize yourself with NumPy. To begin, import NumPy into your Python script using the common alias `np`:

```
import numpy as np
```

You can index NumPy arrays in *all the same ways* you can index lists or lists of lists!

That is, you can use square brackets to access elements, you can do slicing `[start:end:step]` to access a range of elements, negative indices can be used to access elements from the end of the array, and you can use multiple indices to access elements in nested lists. Review the content on lists if you need a refresher.

Now, try the following things: (check the documentation of NumPy for help and examples)

1. Create an array with the elements `[7, 6, 8]` (use `np.array()`).
2. Create an array with the elements `[0. 0. 0. 0. 0. 0]` (use `np.zeros()`).

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4. Create an array with the elements `[0, 1, 2, 3, 4, 5]` (use `np.arange()`).
5. **Create an array with the elements `[0, 1, 2, 3, 7, 6, 8]` (use `np.concatenate()` on the arrays from 4. and 1.).**
   - Print the first element of the array
   - Print the last element of the array
   - Print the first three elements of the array
   - Print the first, third, and fifth element of the array
   - Change the second element of the array to 5
6. **Create a 2D array with the elements `[[0, 1, 2], [3, 4, 5]]` (use the method `.reshape()` on the array from 4.).**
   - Print the size and shape of the array (use the attribute `.shape`)
   - Modify the array so that it has the shape (3, 2) (this time assign to the attribute `.shape`)

Hint

Exercise 11.2: Warm-up with NumPy 2D arrays

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Now let's work with indexing of n-dimensional NumPy arrays. If you run into problems, please consult NumPy Indexing Basics

For 2D array `x`, `x[0]` retrieves the first row of the array, while `x[0][0]` or `x[0, 0]` acceses the first element in the first row. Note that if our array was instead stored as a list of lists, we could only use `x[0][0]` to access the first element in the first row. To access a specific column in a 2D array, you can use the syntax `x[:, 0]` to access the first column. Here each of these indices can *also* take a slice. For example `x[0:2, 0]` will return the first two elements of the first column.

1. **Create a 2D array with the elements `[[7, 8, 9], [10, 11, 12]]`.**
   - Print the first row
   - Print the second column
   - Print the element in the third column and first row
   - Print the second and third column (use slicing)
   - Compute the sum of the entire array (use the method `.sum()`)
   - Compute the sum across the columns (use the method `.sum(0)`)
   - Compute the sum across the rows (use the method `.sum(1)`)

Exercise 11.3: Logical Indexing

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Using NumPy, it is possible to compare two arrays element-wise, resulting in an array with boolean (`True` or `False`) values. This array of booleans can then be used for indexing and to extract an array containing the elements from the original array for which the index is `True`.

```
>>> a = np.array([1, 2, 3, 7])
>>> b = np.array([2, 3, 1, 4])
>>> a > b
array([False, False,  True,  True])
>>> a[a > b]
array([3, 7])
```

Create the following arrays:

```
v1 = np.array([4, 2, 1, 2, 5])
v2 = np.array([-1, 4, 5, -3, 6])
```

Use logical indexing to obtain an array containing:

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1. The elements of `v1` that are less than 3. (`[2, 1, 2]`)
2. The elements of `v2` that are negative. (`[-1, -3]`)
3. The elements of `v2` that are greater than 0. (`[4, 5, 6]`)
4. The elements of `v1` that are greater than the corresponding element in v2. (`[4, 2]`)
5. The elements of `v2` that are not equal to 5. (`[-1, 4, -3, 6]`)
6. Think about how you would solve exercises 1-5 without using vectorization (i.e., NumPy).

Exercise 11.4: Array Operations and Modification

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Create the arrays:

```
v1 = np.array([1, 2, 3, 4, 5])
v2 = np.array([3, 4, 5, 6, 7])
v3 = np.array([1, 1, 1, 1])
```

Calculate the following:

1. Element-wise addition of `v1` and `v2`.
2. Element-wise multiplication of `v1` and `v2`.
3. The $\sin$ function applied to each element in `v1` (use `np.sin()`)
4. The sum of all elements in `v1` (use `np.sum()` or the method `.sum()`).
5. The length of `v3`, which is 4 (use the method `.shape`)

Consider the array `v = np.array([4, 7, -2, 9, 3, -6, -4, 1])`.

Modify the array `v` in the following ways:

1. Set all negative values to zero (find indices that satisfy the < 0 condition, and reassign them to zero).
2. Set all values that are less than the average to zeros (use `np.average()` or `np.mean()`).
3. Multiply all positive values by two.
4. Raise all values to the power of 2, but keep their original sign.

Exercise 11.5: Revisiting the List Exercises from Week 5

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NumPy arrays are on the surface similar to lists, but for certain tasks, NumPy arrays can solve the problem in much fewer lines of code and faster. Revisit some exercises from Week 5 to see how they can be solved with NumPy.

You can assume that the input(s) to the functions are 1D-NumPy arrays. With NumPy, you should be able to solve these exercises in one line without any for-loops.

1. Calculate the average of an array (Exercise 5.2).
2. Conditional maximum: Get the largest number smaller than a given number (Exercise 5.3).
3. Add two arrays together (Exercise 5.7).
4. Count how often a multiple of a specific number occurs in an array (similar to Exercise 5.8).
5. Return a sub-array of the original array, which only contains multiples of a number (similar to Exercise 5.9).

Fill in all the functions in the file `cp/ex11/list_exercises_numpy.py` and run the tests to check if your functions are correct.

Tip

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Exercise 11.6: Indexing Images

Exercise 11.6: Indexing Images

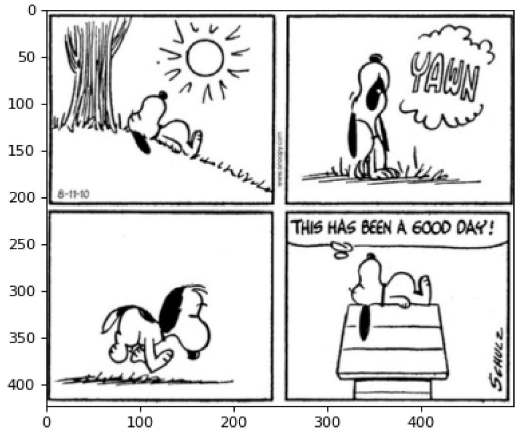
Now that you are familiar with the basic functionality of NumPy, let's do something a bit more practical. Let's look at some images!

Images can be represented as 2D arrays (or 3D arrays when looking at colored images), where each element in the array represents a pixel in the image, and the value of the element represents the intensity of the pixel. Let's start by loading an image (saved as a NumPy array) and looking at it:

```
import numpy as np
import matplotlib.pyplot as plt

img = np.load('cp/ex11/files/comic.npy') # Load image
plt.imshow(img, cmap='gray') # Display image
plt.show()
```

(Source code, png, hires.png, pdf)



Once we have looked at the image, we have identified that our interest lies solely in a specific portion of the image (perhaps only the first panel of the comic). Let's create a function that takes the image as input and produces a new image containing only the desired part.

For this task, we need to extract a part of the original image. This can be achieved by performing slicing of the original image.

Write a function `extract_subimage()` that accepts the image as input and returns a new image containing only a part of the original. Your function should take the image, the upper left corner of the sub-image,

> and a size (rows × columns) as input, and it should return a new image containing the pixels from the starting point to the starting point + size. Assume a 2D array as input, and that all pixels in the sub-image are within the image.

For example if we want only the first panel of the comic, we can call the function like this:

```
img = np.load('cp/ex11/files/comic.npy')
subimage = extract_subimage(img, (0, 0), (210, 250))
plt.imshow(subimage, cmap='gray')
plt.show()
```

(Source code, png, hires.png, pdf)

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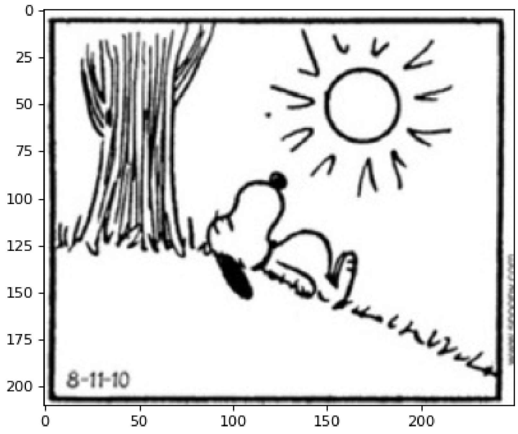

Add your function to the file `cp/ex11/extract_subimage.py` to run the tests.

cp.ex11.extract_subimage.extract_subimage(*image, start_point, size*)

Extract a subimage from an image.

Parameters:

- **image** (`ndarray`) – Image to extract from.
- **start_point** (`tuple`) – Coordinates of the top left corner of the subimage.
- **size** (`tuple`) – Size of the subimage.

Return type:

`ndarray`

Returns:

Subimage.

Exercise 11.7: Bacteria: Growth

Exercise 11.7: Bacteria: Growth

Let's take a look at the experiment data from Exercise 8 again and analyze the data using NumPy. We will start by looking at which time-point the threshold was exceeded (like in Exercise 8.9) and plot the time-points in a histogram. This time, we want to know the time-point of each experiment and not the average time-point of all experiments.

Start by loading the data from the files into a 2D array. Each row in the array should contain the data from one experiment. You can read a file directly to an array using the function `np.loadtxt()`. Write a function `load_data()`, that returns a 2D array containing all the experiments.

Tip

Remember that you can loop over the files like this:

```
for i in range(160):
    filename = f'cp/ex08/files/experiments/experiment_{i:03}.csv'
    data[i] = np.loadtxt(filename, delimiter=',')
```

This will be the only time today you need to use a for-loop.

Remember to preallocate your numpy array before the loop.

Once you have loaded the data, we want to find the time-point when the threshold was exceeded for each experiment. Write a function `threshold_exceeded()`, that takes the data as input and returns a 1D array containing the time-point when the threshold was exceeded for each experiment.

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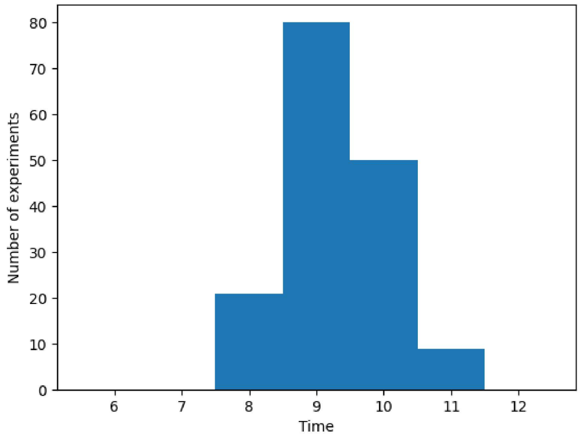
Tip

Plot a histogram of when a certain threshold was exceeded. You can use the function `plt.hist()` to plot a histogram. Try if you can get a histogram that looks like this:



Histogram of when the threshold was reached for each experiment.

Help for plotting

Add your functions to the file `cp/ex11/bacterial_growth.py` and run the tests to check if your functions are correct.

`cp.ex11.bacterial_growth.load_data()`

Load data from 160 files into one array. Files are located in cp/ex11/files/experiments.

Return type:

`ndarray`

Returns:

The data from the files in one array.

`cp.ex11.bacterial_growth.threshold_exceeded(data, threshold)`

Return the index at which the threshold is exceeded for each experiment.

Parameters:

- **data** (`ndarray`) – The data to search.
- **threshold** (`float`) – The threshold to compare against.

Return type:

`ndarray`

Returns:

The index at which the threshold is exceeded for each row.

Exercise 11.8: Bacteria - Average growth curve

Exercise 11.8: Bacteria - Average growth curve

Calculate the mean and standard deviation for each time point (i.e., each column).

Implement the functions `get_mean()` and `get_std()` in the file `cp/ex11/bacterial_growth.py` to run the tests.

Plot the mean and std. Try to make a plot that looks like this:

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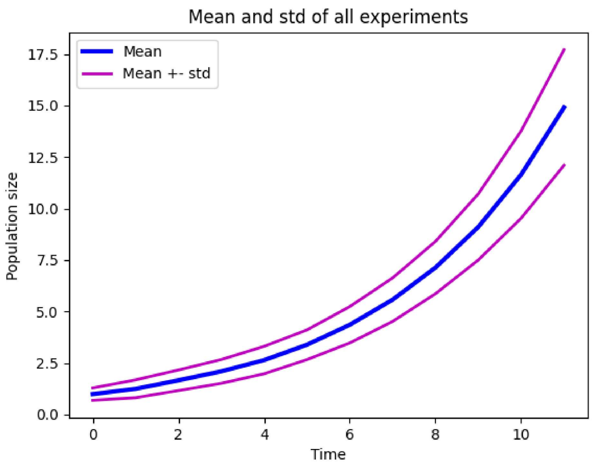

Mean growth curve with standard deviation.

Help for plotting

`cp.ex11.bacterial_growth.get_mean(data)`

Calculate the mean of the data.

Parameters:
data (`ndarray`) – The data to calculate the mean of.

Return type:
`ndarray`

Returns:
The mean of the data for each time-point.

`cp.ex11.bacterial_growth.get_std(data)`

Calculate the standard deviation of the data.

Parameters:
data (`ndarray`) – The data to calculate the standard deviation of.

Return type:
`ndarray`

Returns:
The standard deviation of the data for each time-point.

Exercise 11.9 Bacteria - Outliers

Continuing with the bacteria data, we will now look for outliers. An outlier is a data point that stands out significantly from the rest of the data.

Here we will identify outliers, by looking at the bacteria count at the last time-step across all experiments.

An experiment is considered an outlier if its final bacteria count, is more than two standard deviations from the mean of all experiments' final counts. You can use the function `get_mean()` and `get_std()` from the previous exercise to calculate the mean and standard deviation.

Therefore, you should write a function that examines `data` and returns a numpy array with the experiment index (the number in the filename) of the outlier experiments.

The function should be able to handle `data` of any size, that is any number of experiments and any number of time-steps.

You can use `np.where` to convert from a boolean array to an array of indices.

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cp.ex11.outliers.outliers(*data*)

Return the outliers of a dataset.

Parameters:
data (`ndarray`) – The data to search.

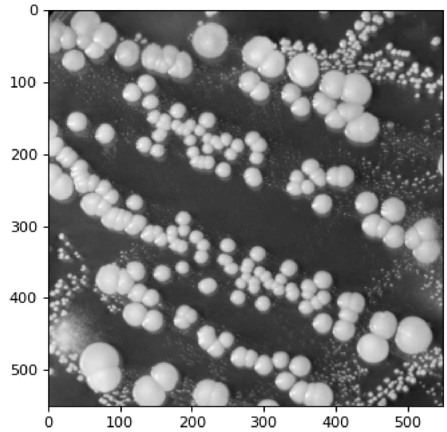
Return type:
`ndarray`

Returns:
The outliers of the data.

Exercise 11.10 Image Area

Here is an image of the bacteria, located in `cp/ex11/files/bacteria.npy` We want to calculate how much of the image is covered by bacteria. We consider only pixels with a value over 100 to be bacteria.

(`Source code`, `png`, `hires.png`, `pdf`)



Hint

Add your function to the file `cp/ex11/bacterial_area.py` to be able to test and hand-in your solution.

cp.ex11.bacterial_area.bacterial_area(*npy_path*)

Calculate the fraction of the image where pixel intensities are greater than 100.

Parameters: :type npy_path: `str` :param npy_path: Path to the image data file in NumPy format. :rtype: `float` :return: The fraction of area in an image where there are bacteria.