Python Foundation for Spatial Analysis (Full Course Material)

A gentle introduction to Python programming with a focus on spatial data.

Ujaval Gandhi

    - The `requests` module
    - Calculating Distance using OpenRouteService API
    - API Rate Limiting
        - The `time` module
    - Exercise
- Reading Files
    - Exercise
- Reading CSV Files
    - Using `enumerate()` function
    - Using `with` statement
    - Filtering rows
    - Calculating distance
    - Writing files
    - Exercise
- Working with Pandas
    - Reading Files
    - Filtering Data
    - Performing calculations
    - Exercise
- Working with Geopandas
    - Reading Spatial Data
    - Filtering Data
    - Working with Projections
    - Performing Spatial joins
    - Group Statistics
    - Exercise
- Creating Spatial Data
    - Reading Tab-Delimited Files
    - Filtering Data
    - Creating Geometries
    - Writing Files
    - Exercise
- Introduction to NumPy
    - Arrays
    - Array Operations
    - Exercise
- Working with RasterIO
    - Reading Raster Data
    - Merging Datasets
    - Writing Raster Data
    - Exercise
- Writing Standalone Python Scripts
    - Get a Text Editor
    - Writing a Script
    - Executing a Script
        - Windows
        - Mac and Linux
- What next?
    - Do a Project


SpatialThoughts

Introduction

This class covers Python from the very basics. Suitable for GIS practitioners with no programming background or python knowledge. The course will introduce participants to basic programming concepts, libraries for spatial analysis, geospatial APIs and techniques for building spatial data processing pipelines.

Learn more about my views on why and how to learn Python in this Introductory Presentation (https://docs.google.com/presentation/d/125LV0qR47S_OGaZZr5Zv-7lbWfdZ5pNo3iFm6IOX7uI/edit?usp=sharing).

Get the Data Package

The code examples in this class use a variety of datasets. All the required datasets and Jupyter notebooks are supplied to you in the `python_foundation.zip` file. Unzip this file to a directory - preferably to the `<home folder>/Downloads/python_foundation/` folder.

Not enrolled in our instructor-led class but want to work through the material on your own? Get free access to the data package (https://docs.google.com/forms/d/e/1FAIpQLSeSrQH38dutYRLLy4kOxw_ltpKG_jKkB4aSZc0dRjHhbma0ow/viewform)

Installation and Setting up the Environment

There are many ways to install Python on your system. Many operating systems comes with a Python distribution built-in too. If you use software such as QGIS - it comes with its own version of Python. Working on Python projects typically require installing third-party packages (i.e. tools). As these packages have different dependencies - they often cause conflicts and errors due to different versions of Python on your system.

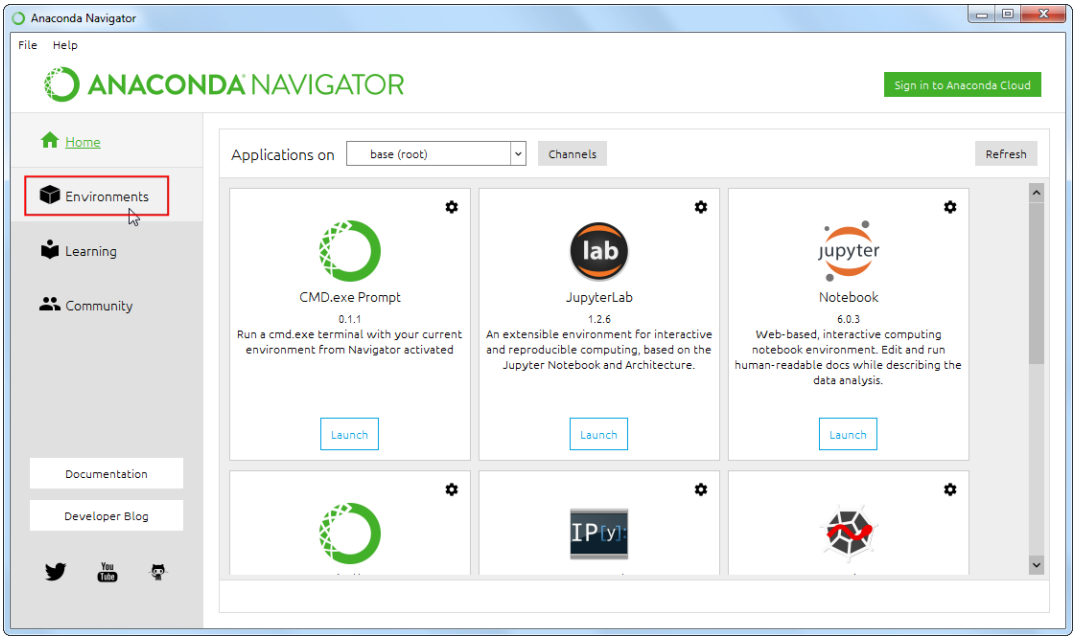
An easy and reliable way to get a Python installation on your system is via Anaconda (https://www.anaconda.com/). For this course, we will use the Anaconda3 Individual Edition to install Python and required spatial analysis packages.

> Many Python tool names have references to the reptile world. The default Python package manager is called Pip (https://pypi.org/project/pip/) which references the process of hatching eggs. Interestingly, the naming of the Python language itself had nothing to do with reptiles (https://en.wikipedia.org/wiki/Guido_van_Rossum#Python).

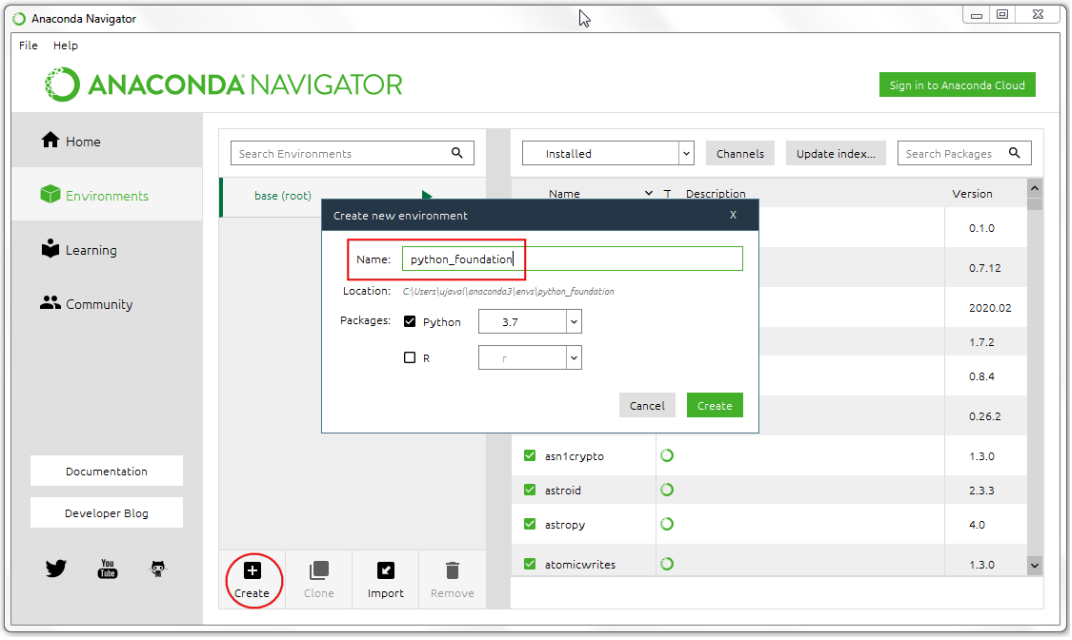
1. Download the Anaconda Installer (https://www.anaconda.com/products/individual) for Python 3.7 (or a higher version) for your operating system. Once downloaded, double click the installer and install it into the default suggested directory. Select an install for *Just Me* and **use default settings**. *Note: If your username has spaces, or non-English characters, it causes problems. In that case, you can install it to a path such as* `C:\anaconda` .

2. Once installed, launch the *Anaconda Navigator* program. It is a good practice to create a new *environment* for each of your Python projects. An environment is a space where you will install required packages. Many packages may contain conflicting requirements which could prevent them all being installed into a single environment. Having a separate environment isolates your project from such problems. Click on the *Environments* tab.

> Linux users can open a terminal and type `anaconda-navigator` to launch the program.

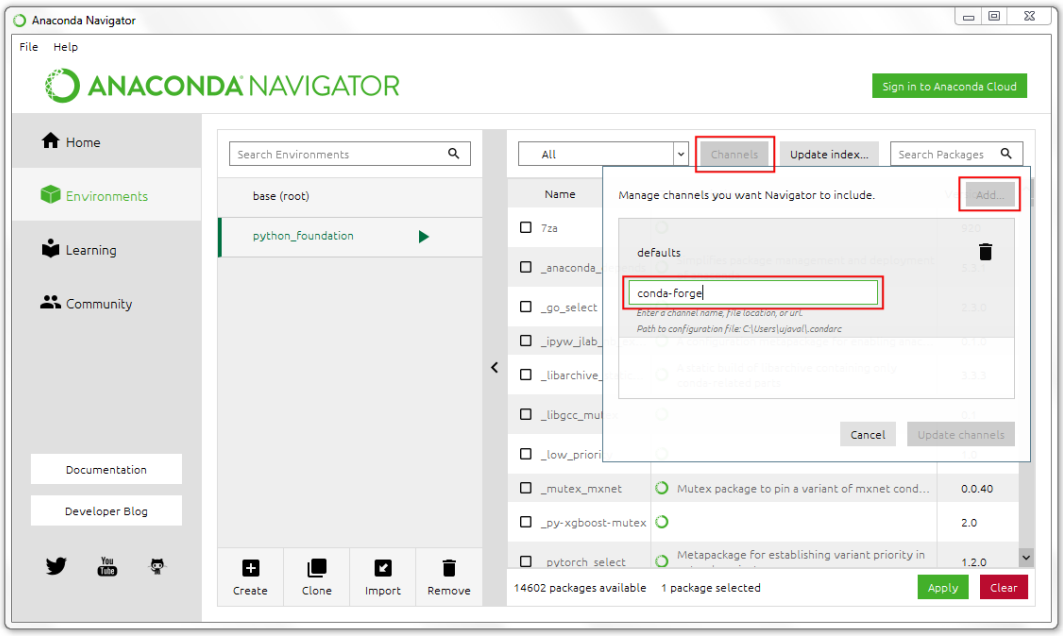


3. Click the *+ Create* button and name the environment as `python_foundation` . Click *Create*.

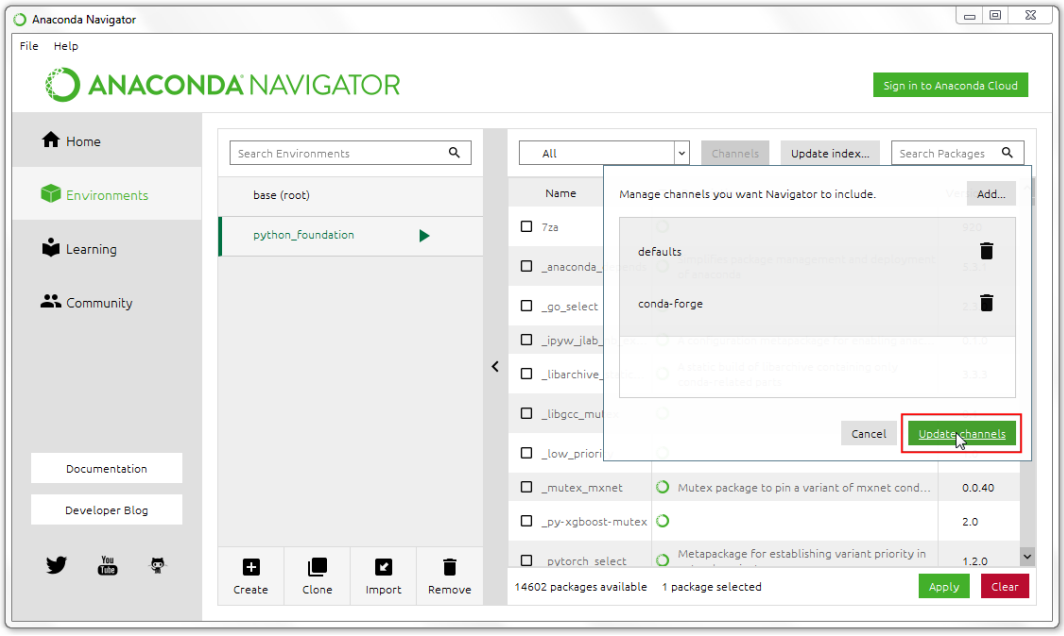


4. Once created, click the *Channels* button. A channel is a repository where packages are hosted. The default channel is good for most purposes. But some packages we require for this class are not available in the default channel, so we need to add another channel. In the *Manage channels* dialog, click *Add* and enter `conda-forge`. Press *Enter*.

> Learn more about conda-forge (https://conda-forge.org/docs/user/introduction.html)

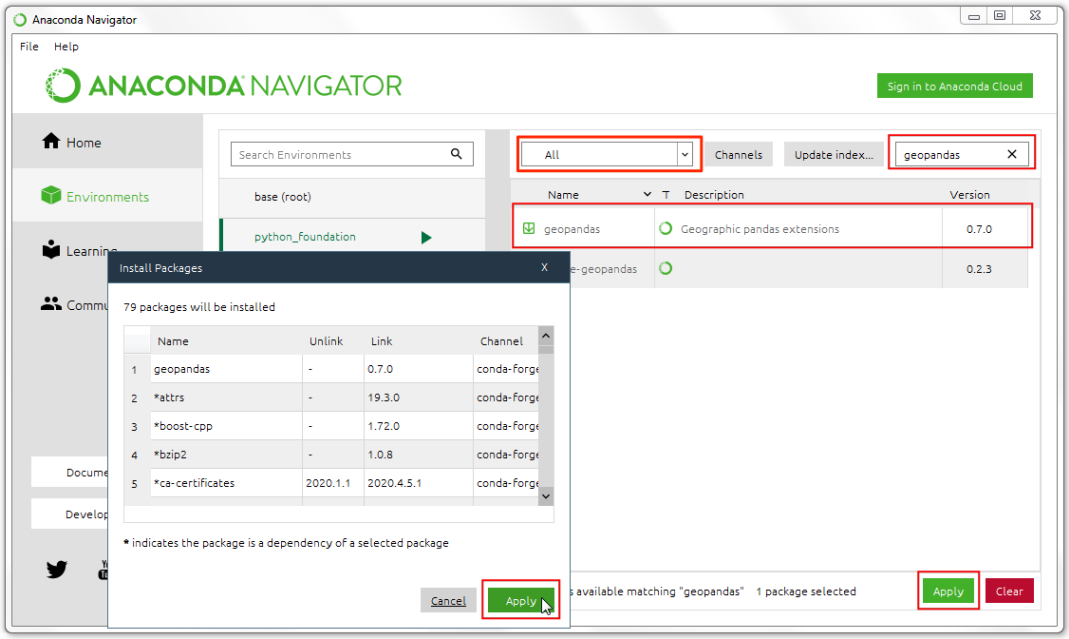


5. Click the *Update Channels* button.



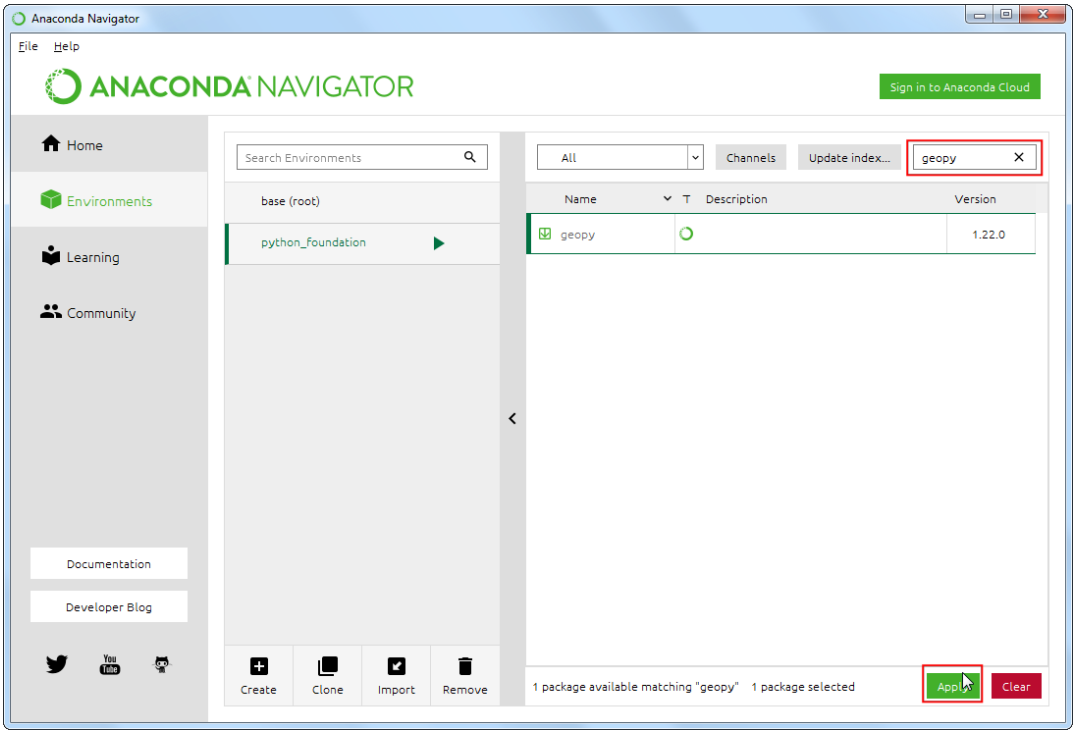
6. Once the update is done, search for the package `geopandas`. This is a package that allows you to work with vector geospatial data in Python. Select the check-box next to the first result and click *Apply* to install the package with all its dependencies.

> If you do not see any results, make sure you have selected *All* in the dropdown selector next to *Channels* instead of *Installed*.

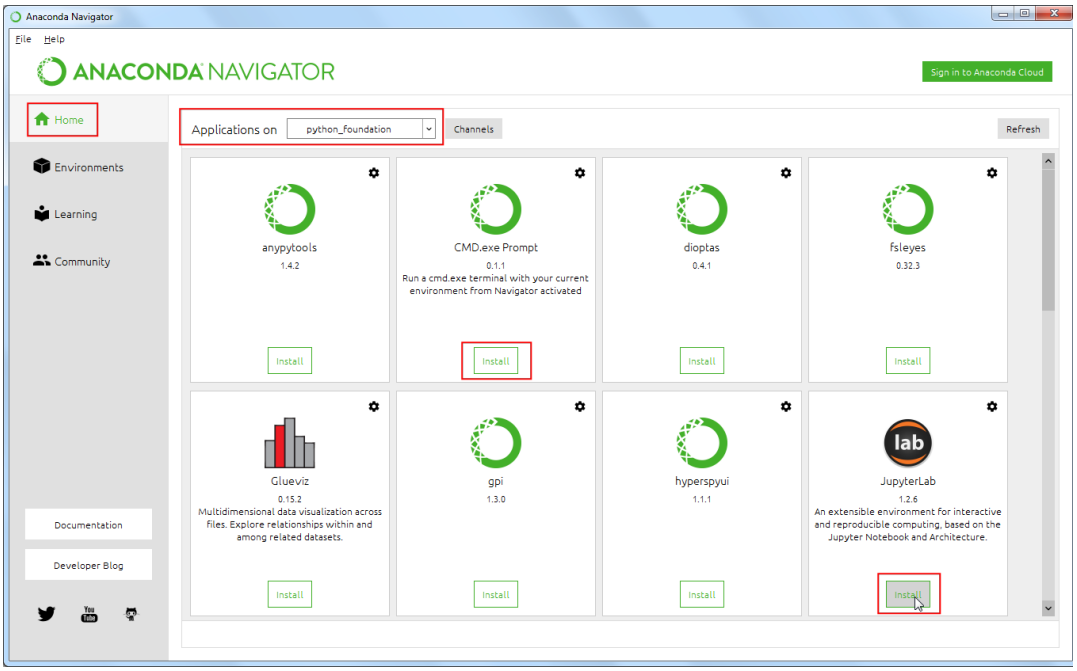


7. Similarly, search and install the following packages

- `geopy`
- `rasterio`
- `matplotlib`

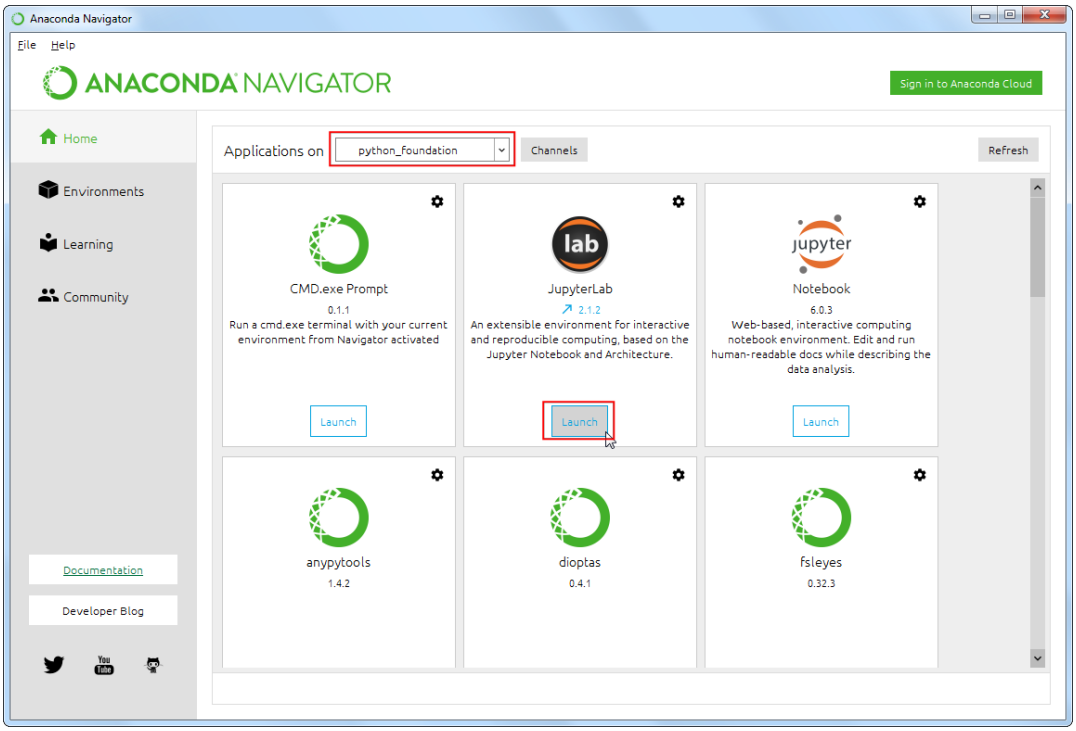


8. Switch to the *Home* tab. Ensure that you have the *python_foundation* environment selected. We will now install some programs which allow us to write and execute Python scripts. From the home screen, install the `JupyterLab` application. Windows users may optionally install the `CMD.exe prompt` application.

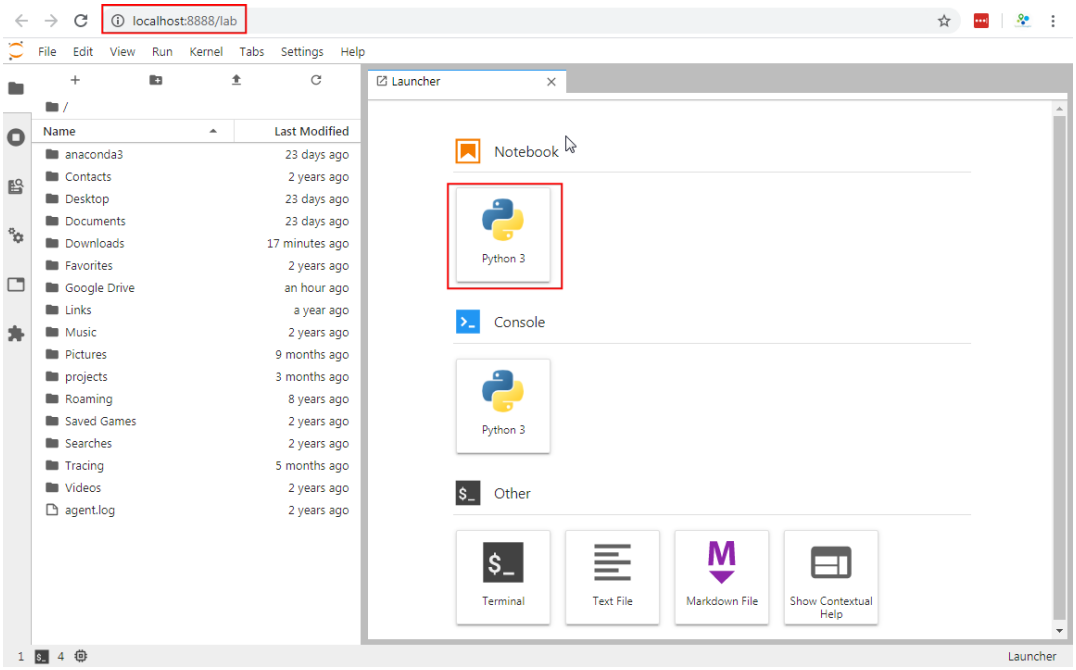


9. After the installation completes, click *Launch* button for the *JupyterLab* application. JupyterLab is a web application that allows you to write, document and run Python code. It allow you to interactively run small bits of code and see the results. It also support a variety of output formats such as charts or maps - making it an ideal platform for data science projects. The name Jupyter comes from the 3 primary programming languages it supports - Julia, Python and R. We will be using Jupyter notebooks for all exercises in this course.

Linux users can open a terminal and first switch to the correct environment using the command `conda activate python_foundation`. After that, JupyterLab can be opened using the `jupyter-lab` command.

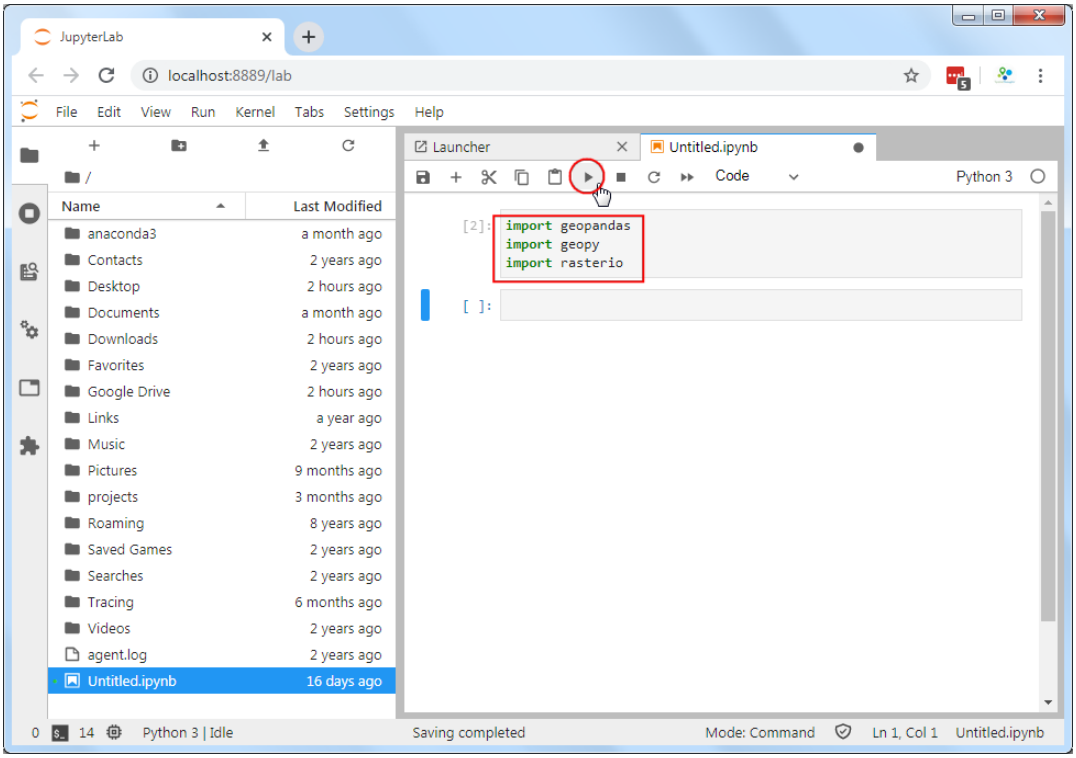


10. A new browser tab will open with an instance of JupterLab. Click the *Python 3* button under *Notebooks*.



11. Enter the following statements in the first cell and click the *Run* button. **If nothing happens - it means your installation was successful!**. If you get an *ImportError*, repeat the installation steps carefully again.

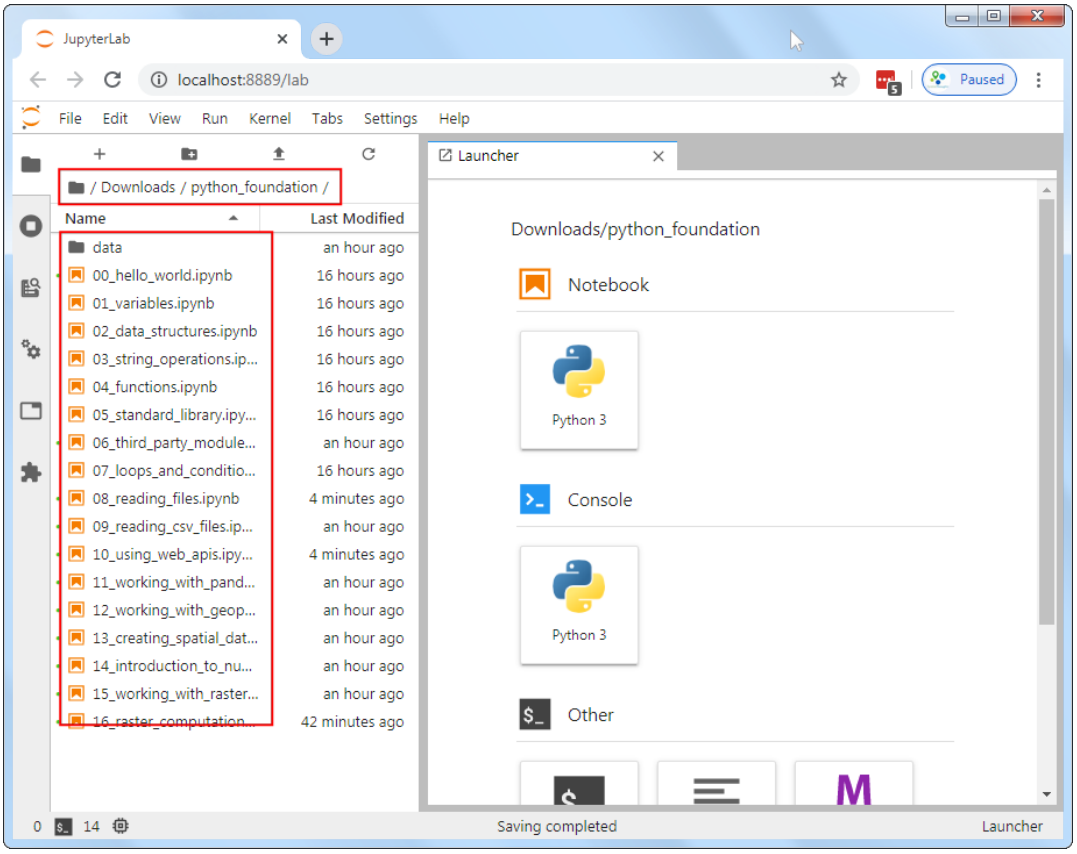
```
import geopandas
import geopy
import rasterio
```



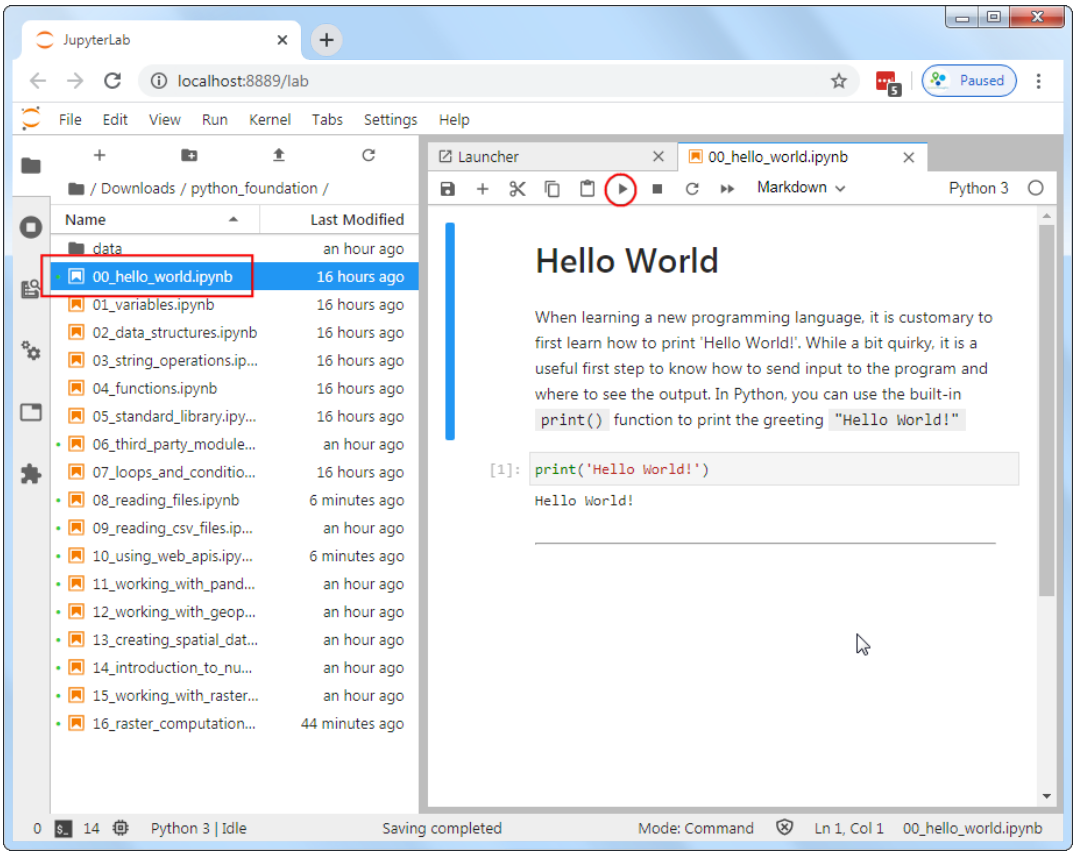
Using Jupyter Notebooks

Your class data package contain multiple Jupyter notebooks containing code and exercises for this class.

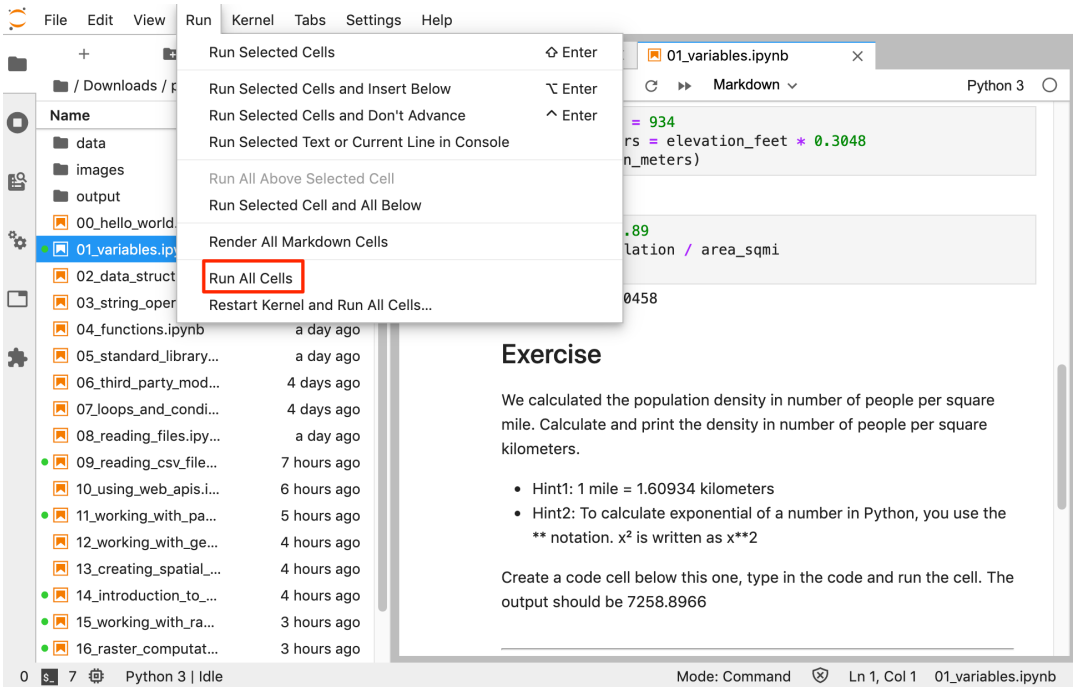
1. Launch the *Anaconda Navigator* program. Ensure that you have the *python_foundation* environment selected. click *Launch* button for the *JupyterLab* application. It will open your Web Browser and load the application in a new tab. From the left-hand panel, navigate to the directory where you extracted the data package.



2. Jupyter notebooks have a `.ipynb` extensions. Double-click on a notebook file to open it. Code in the notebook is executed cell-by-cell. You can select a cell and click the *Run* button to execute the code and see the output.



3. At the end of each notebook, you will find an exercise. Before adding a new cell and attempting to complete the exercise, make sure you go to **Run → Run All Cells** to execute all the code in the notebook. Doing this will ensure all the required variables are avalable to you to use in the exervise.



Open the notebook named `00_hello_world.ipynb` .

Hello World

When learning a new programming language, it is customary to first learn how to print 'Hello World!'. While a bit quirky, it is a useful first step to know how to send input to the program and where to see the output. In Python, you can use the built-in `print()` function to print the greeting `"Hello World!"`

```
print('Hello World!')
```

Open the notebook named `01_variables.ipynb`.

Variables

Strings

A string is a sequence of letters, numbers, and punctuation marks - or commonly known as **text**

In Python you can create a string by typing letters between single or double quotation marks.

```
city = 'San Fransico'
state = 'California'
print(city, state)
```

```
print(city + state)
```

```
print(city + ',' + state)
```

Numbers

Python can handle several types of numbers, but the two most common are:

- **int**, which represents integer values like 100, and
- **float**, which represents numbers that have a fraction part, like 0.5

```
population = 881549
latitude = 37.7739
longitude = -121.5687
```

```
print(type(population))
```

```
print(type(latitude))
```

```
elevation_feet = 934
elevation_meters = elevation_feet * 0.3048
print(elevation_meters)
```

```
area_sqmi = 46.89
density = population / area_sqmi
print(density)
```

Exercise

We have a variable named `distance_km` below with the value `4135` - indicating the straight-line distance between San Francisco and New York in Kilometers. Create another variable called `distance_mi` and store the distance value in miles.

- Hint1: 1 mile = 1.60934 kilometers

Add the code in the cell below and run it. The output should be 2569.37

```
distance_km = 4135
# Remove this line and add code here
```

Open the notebook named `02_data_structures.ipynb` .

Data Structures

Tuples

A *tuple* is a sequence of objects. It can have any number of objects inside. In Python tuples are written with round brackets **()**.

```
latitude = 37.7739
longitude = -121.5687
coordinates = (latitude, longitude)
print(coordinates)
```

You can access each item by its position, i.e. *index*. In programming, the counting starts from 0. So the first item has an index of 0, the second item an index of 1 and so now. The index has to be put inside square brackets **[]**.

```
y = coordinates[0]
x = coordinates[1]
print(x, y)
```

Lists

A **list** is similar to a tuple - but with a key difference. With tuples, once created, they cannot be changed, i.e. they are immutable. But lists are mutable. You can add, delete or change elements within a list. In Python, lists are written with square brackets **[]**

```
cities = ['San Francisco', 'Los Angeles', 'New York', 'Atlanta']
print(cities)
```

You can access the elements from a list using index the same way as tuples.

```
print(cities[0])
```

You can call `len()` function with any Python object and it will calculates the size of the object.

```
print(len(cities))
```

We can add items to the list using the `append()` method

```
cities.append('Boston')
print(cities)
```

As lists are *mutable*, you will see that the size of the list has now changed

```
print(len(cities))
```

Another useful method for lists is `sort()` - which can sort the elements in a list.

```
cities.sort()
print(cities)
```

The default sorting is in *ascending* order. If we wanted to sort the list in a *decending* order, we can call the function with `reverse=True`

```
cities.sort(reverse=True)
print(cities)
```

Sets

Sets are like lists, but with some interesting properties. Mainly that they contain only unique values. It also allows for *set operations* - such as *intersection*, *union* and *difference*. In practice, the sets are typically created from lists.

```
capitals = ['Sacramento', 'Boston', 'Austin', 'Atlanta']
capitals_set = set(capitals)
cities_set = set(cities)

capital_cities = capitals_set.intersection(cities_set)
print(capital_cities)
```

Sets are also useful in finding unique elements in a list. Let's merge the two lists using the `extend()` method. The resulting list will have duplicate elements. Creating a set from the list removes the duplicate elements.

```
cities.extend(capitals)
print(cities)
print(set(cities))
```

Dictionaries

In Python dictionaries are written with curly brackets **{}**. Dictionaries have *keys* and *values*. With lists, we can access each element by its index. But a dictionary makes it easy to access the element by name. Keys and values are separated by a colon **:**.

```
data = {'city': 'San Francisco', 'population': 881549, 'coordinates': (-122.4194, 37.774
        9) }
print(data)
```

You can access an item of a dictionary by referring to its key name, inside square brackets.

```
print(data['city'])
```

Exercise

From the dictionary below, how do you access the latitude and longitude values? print the latitude and longitude of new york city by extracting it from the dictionary below.

```
nyc_data = {'city': 'New York', 'population': 8175133, 'coordinates': (40.661, -73.944)
         }
```

Open the notebook named `03_string_operations.ipynb` .

String Operations

```
city = 'San Francisco'
print(len(city))
```

```
print(city.split())
```

```
print(city.upper())
```

```
city[0]
```

```
city[-1]
```

```
city[0:3]
```

```
city[4:]
```

Escaping characters

Certain characters are special since they are by Python language itself. For example, the quote character **'** is used to define a string. What do you do if your string contains a quote character?

In Python strings, the backslash \ is a special character, also called the **escape** character. Prefixing any character with a backslash makes it an ordinary character. (Hint: Prefixing a backslash with a backshalsh makes it ordinary too!)

It is also used for representing certain whitespace characters, \n is a newline, \t is a tab etc.

Remove the # from the cell below and run it.

```
# my_string = 'It's a beautiful day!'
```

We can fix the error by espacing the single quote within the string.

```
my_string = 'It\'s a beautiful day!'
print(my_string)
```

Alternatively, you can also use double-quotes if your string contains a single-quote.

```
my_string = "It's a beautiful day!"
```

What if our string contains both single and double quotes?

We can use triple-quotes! Enclosing the string in triple quotes ensures both single and double quotes are treated correctly.

```
latitude = '''37° 46' 26.2992 N'''
longitude = '''122° 25' 52.6692" W'''
print(latitude, longitude)
```

Backslashes pose another problem when dealing with Windows paths

```
#path = 'C:\Users\ujaval'
#print(path)
```

Prefixing a string with **r** makes is a *Raw string*. Which doesn't interpret backslash as a special character

```
path = r'C:\Users\ujaval'
print(path)
```

Printing Strings

Modern way of creating strings from variables is using the `format()` method

```
city = 'San Fransico'
population = 881549
output = 'Population of {} is {}.'.format(city, population)
print(output)
```

You can also use the format method to control the precision of the numbers

```
latitude = 37.7749
longitude = -122.4194

coordinates = '{:.2f},{:.2f}'.format(latitude, longitude)
print(coordinates)
```

Exercise

Use the string slicing to extract and print the degrees, minutes and second parts of the string below. The output should be as follows

```
37
46
26.2992
```

```
latitude = '''37° 46' 26.2992"'''
```

Open the notebook named `04_loops_and_conditionals.ipynb`.

Loops and Conditionals

For Loops

A for loop is used for iterating over a sequence. The sequence can be a list, a tuple, a dictionary, a set, or a string.

```
cities = ['San Francisco', 'Los Angeles', 'New York', 'Atlanta']

for city in cities:
    print(city)
```

To iterate over a dictionary, you can call the `items()` method on it which returns a tuple of key and value for each item.

```
data = {'city': 'San Francisco', 'population': 881549, 'coordinates': (-122.4194, 37.774
        9) }

for x, y in data.items():
    print(x, y)
```

The built-in `range()` function allows you to create sequence of numbers that you can iterate over

```
for x in range(5):
    print(x)
```

The range function can also take a start and an end number

```
for x in range(1, 10, 2):
    print(x)
```

Conditionals

Python supports logical conditions such as equals, not equals, greater than etc. These conditions can be used in several ways, most commonly in *if statements* and loops.

An *if statement* is written by using the `if` keyword.

Note: A very common error that programmers make is to use = to evaluate a *equals to* condition. The = in Python means assignment, not equals to. Always ensure that you use the == for an equals to condition.

```
for city in cities:
    if city == 'Atlanta':
        print(city)
```

You can use `else` keywords along with `if` to match elements that do not meet the condition

```
for city in cities:
    if city == 'Atlanta':
        print(city)
    else:
        print('This is not Atlanta')
```

Python relies on indentation (whitespace at the beginning of a line) to define scope in the for loop and if statements. So make sure your code is properly indented.

You can evaluate a series of conditions using the `elif` keyword.

Multiple criteria can be combined using the `and` and `or` keywords.

```
cities_population = {
    'San Francisco': 881549,
    'Los Angeles': 3792621,
    'New York': 8175133,
    'Atlanta':498044
}

for city, population in cities_population.items():
    if population < 1000000:
        print('{} is a small city'.format(city))
    elif population > 1000000 and population < 5000000:
        print('{} is a big city'.format(city))
    else:
        print('{} is a mega city'.format(city))
```

Control Statements

A for-loop iterates over each item in the sequence. Sometimes is desirable to stop the execution, or skip certain parts of the for-loops. Python has special statements, `break` , `continue` and `pass` .

A `break` statement will stop the loop and exit out of it

```
for city in cities:
    print(city)
    if city == 'Los Angeles':
        print('I found Los Angeles')
        break
```

A `continue` statement will skip the remaining part of the loop and go to the next iteration

```
for city in cities:
    if city == 'Los Angeles':
        continue
    print(city)
```

A `pass` statement doesn't do anything. It is useful when some code is required to complete the syntax, but you do not want any code to execute. It is typically used as a placeholder when a function is not complete.

```
for city in cities:
    if city == 'Los Angeles':
        pass
    else:
        print(city)
```

Exercise

The Fizz Buzz challenge.

Write a program that prints the numbers from 1 to 100 and for multiples of 3 print **Fizz** instead of the number and for the multiples of 5 print **Buzz**. If it is divisible by both, print **FizzBuzz**.

So the output should be something like below

```
1, 2, Fizz, 4, Buzz, Fizz, 7, 8, Fizz, Buzz, 11, Fizz, 13, 14, FizzBuzz, ...
```

Breaking down the problem further, we need to create for-loop with following conditions

- If the number is a multiple of both 3 and 5 (i.e. 15), print FizzBuzz
- If the number is multiple of 3, print Fizz
- If the number is multiple of 5, print Buzz
- Otherwise print the number

Hint: See the code cell below. Use the modulus operator **%** to check if a number is divisible by another. `10 % 5` equals 0, meaning it is divisible by 5.

```
for x in range(1, 10):
    if x%2 == 0:
        print('{} is divisible by 2'.format(x))
    else:
        print('{} is not divisible by 2'.format(x))
```

Open the notebook named `05_functions.ipynb`.

Functions

A function is a block of code that takes one or more *inputs*, does some processing on them and returns one or more *outputs*. The code within the function runs only when it is called.

A funtion is defined using the `def` keyword

```
def my_function():
    ....
    ....
    return something
```

Functions are useful because they allow us to capture the logic of our code and we can run it with differnt inputs without having to write the same code again and again.

```
def greet(name):
    return 'Hello ' + name

print(greet('World'))
```

Functions can take multiple arguments. Let's write a function to convert coordinates from degrees, minutes, seconds to decimal degrees. This conversion is needed quite often when working with data collected from GPS devices.

- 1 degree is equal to 60 minutes
- 1 minute is equal to 60 seconds (3600 seconds)

To calculate decimal degrees, we can use the formula below:

If degrees are positive:

```
Decimal Degrees = degrees + (minutes/60) + (seconds/3600)
```

If degrees are negative

```
Decimal Degrees = degrees - (minutes/60) - (seconds/3600)
```

```
def dms_to_decimal(degrees, minutes, seconds):
    if degrees < 0:
        result = degrees - minutes/60 - seconds/3600
    else:
        result = degrees + minutes/60 + seconds/3600
    return result
```

```
output = dms_to_decimal(10, 10, 10)
print(output)
```

Exercise

Given a coordinate string with value in degree, minutes and seconds, convert it to decimal degrees by calling the `dms_to_decimal` function.

```
def dms_to_decimal(degrees, minutes, seconds):
    if degrees < 0:
        result = degrees - minutes/60 - seconds/3600
    else:
        result = degrees + minutes/60 + seconds/3600
    return result

coordinate = '''37° 46' 26.2992"'''

# Add the code below to extract the parts from the coordinate string,
# call the function to convert to decimal degrees and print the result
```

```
# Hint: Converting strings to numbers
# When you extract the parts from the coordinate string, they are strings
# You will need to use the built-in int() / float() functions to
# convert them to numbers
x = '25'
print(x, type(x))
y = int(x)
print(y, type(y))
```

Open the notebook named `06_standard_library.ipynb` .

The Python Standard Library

Python comes with many built-in modules that offer ready-to-use solutions to common programming problems. To use these modules, you must use the `import` keyword. Once imported in your Python script, you can use the functions provided by the module in your script.

We will use the built-in `math` module that allows us to use advanced mathematical functions.

```
import math
```

You can also import specific functions or constants from the module like below

```
from math import pi
print(pi)
```

Calculating Distance

Given 2 points with their Latitude and Longitude coordinates, the Haversine Formula calculates the straight-line distance in meters, assuming that Earth is a sphere.

The formula is simple enough to be implemented in a spreadsheet too. If you are curious, see my post (https://spatialthoughts.com/2013/07/06/calculate-distance-spreadsheet/) about using this formula for calculating distances in a spreadsheet.

We can write a function that accepts a pair of origin and destination coordinates and computes the distance.

```
san_francisco = (37.7749, -122.4194)
new_york = (40.661, -73.944)
```

```
def haversine_distance(origin, destination):
  lat1, lon1 = origin
  lat2, lon2 = destination
  radius = 6371000
  dlat = math.radians(lat2-lat1)
  dlon = math.radians(lon2-lon1)
  a = math.sin(dlat/2) * math.sin(dlat/2) + math.cos(math.radians(lat1)) \
    * math.cos(math.radians(lat2)) * math.sin(dlon/2) * math.sin(dlon/2)
  c = 2 * math.atan2(math.sqrt(a), math.sqrt(1-a))
  distance = radius * c
  return distance
```

```
distance = haversine_distance(san_francisco, new_york)
print(distance/1000, 'km')
```

Discover Python Easter Eggs

Programmers love to hide secret jokes in their programs for gun. These are known as *Easter Eggs*. Python has an easter egg that you can see when you try to import the module named `this`. Try writing the command `import this` below.

```
import this
```

Let's try one more. Try importing the `antigravity` module.

Here's a complete list of easter eggs in Python (https://towardsdatascience.com/7-easter-eggs-in-python-7765dc15a203).

Exercise

Find the coordinates of 2 cities near you and calculate the distance between them by calling the `haversine_distance` function below.

```
def haversine_distance(origin, destination):
  lat1, lon1 = origin
  lat2, lon2 = destination
  radius = 6371000
  dlat = math.radians(lat2-lat1)
  dlon = math.radians(lon2-lon1)
  a = math.sin(dlat/2) * math.sin(dlat/2) + math.cos(math.radians(lat1)) \
    * math.cos(math.radians(lat2)) * math.sin(dlon/2) * math.sin(dlon/2)
  c = 2 * math.atan2(math.sqrt(a), math.sqrt(1-a))
  distance = radius * c
  return distance

# city1 = (lat1, lng1)
# city2 = (lat2, lng2)
# call the function and print the result
```

Open the notebook named `07_third_party_modules.ipynb`.

Third-party Modules

Python has a thriving ecosystem of third-party modules (i.e. libraries or packages) available for you to install. There are hundreds of thousands of such modules available for you to install and use.

Installing third-party libraries

Python comes with a package manager called `pip`. It can install all the packages listed at PyPI (Python Package Index) (https://pypi.org/). To install a package using pip, you need to run a command like following in a Terminal or CMD prompt.

```
pip install <package name>
```

For this course, we are using Anancoda platform - which comes with its own package manager called `conda`. You can use Anaconda Navigator to search and install packages. Or run the command like following in a Terminal or CMD Prompt.

```
conda install <package name>
```

See this comparison of pip and conda (https://www.anaconda.com/blog/understanding-conda-and-pip) to understand the differences.

Calculating Distance

We have already installed the `geopy` package in our environment. `geopy` comes with functions that have already implemented many distance calculation formulae.

- `distance.great_circle()`: Calculates the distance on a great circle using haversine formula
- `distance.geodesic()`: Calculates the distance using a chosen ellipsoid using vincenty's formula

```
from geopy import distance

san_francisco = (37.7749, -122.4194)
new_york = (40.661, -73.944)

straight_line_distance = distance.great_circle(san_francisco, new_york)
ellipsoid_distance = distance.geodesic(san_francisco, new_york, ellipsoid='WGS-84')

print(straight_line_distance, ellipsoid_distance)
```

Exercise

Repeat the distance calculation exercise from the previous module but perform the calculation using the geopy library.

```
from geopy import distance

# city1 = (lat1, lng1)
# city2 = (lat2, lng2)
# call the geopy distance function and print the great circle and ellipsoid distance
```

Open the notebook named `08_using_web_apis.ipynb`.

Using Web APIs

An API, or Application Program Interface, allows one program to *talk* to another program. Many websites or services provide an API so you can query for information in an automated way.

For mapping and spatial analysis, being able to use APIs is critical. For the longest time, Google Maps API was the most popular API on the web. APIs allow you to query web servers and get results without downloading data or running computation on your machine.

Common use cases for using APIs for spatial analysis are

- Getting directions / routing
- Route optimization
- Geocoding
- Downloading data
- Getting real-time weather data
- ...

The provide of such APIs have many ways to implement an API. There are standards such as REST, SOAP, GraphQL etc. *REST* is the most populat standard for web APIs, and for geospatial APIs. REST APIs are used over HTTP and thus called web APIs.

Understanding JSON and GeoJSON

JSON stands for **J**ava**S**cript **O**bject **N**otation. It is a format for storing and transporting data, and is the de-facto standard for data exchanged by APIs. GeoJSON is an extension of the JSON format that is commonly used to represent spatial data.

Python has a built-in `json` module that has methods for reading json data and converting it to Python objects, and vice-versa. In this example, we are using the `requests` module for querying the API which conveniently does the conversion for us. But it is useful to learn the basics of working with JSON in Python.

The GeoJSON data contains *features*, where each feature has some *properties* and a *geometry*.

```
geojson_string = '''
{
  "type": "FeatureCollection",
  "features": [
    {"type": "Feature",
      "properties": {"name": "San Francisco"},
      "geometry": {"type": "Point", "coordinates": [-121.5687, 37.7739]}
    }
  ]
}
'''
print(geojson_string)
```

To convert a JSON string to a Python object (i.e. parsing JSON), we can use the `json.loads()` method.

```
import json

data = json.loads(geojson_string)
print(type(data))
print(data)
```

Now that we have *parsed* the GeoJSON string and have a Python object, we can extract infromation from it. The data is stored in a *FeatureCollection* - which is a list of *features*. In our example, we have just 1 feature inside the feature collection, so we can access it by using index **0**.

```
city_data = data['features'][0]
print(city_data)
```

The feature representation is a dictionary, and individual items can be accesses using the *keys*

```
city_name = city_data['properties']['name']
city_coordinates = city_data['geometry']['coordinates']
print(city_name, city_coordinates)
```

The `requests` module

To query a server, we send a **GET** request with some parameters and the server sends a response back. The `requests` module allows you to send HTTP requests and parse the responses using Python.

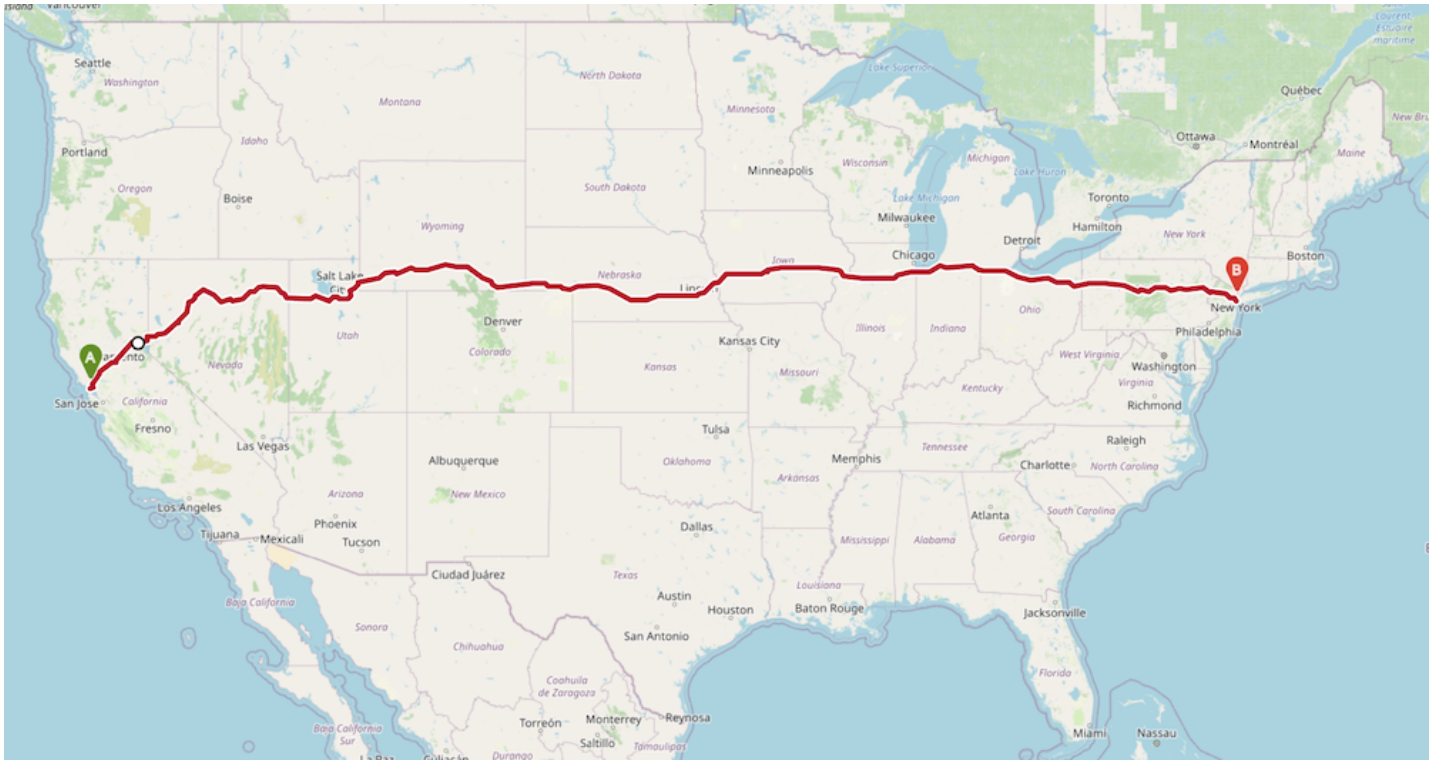
The response contains the data received from the server. It contains the HTTP *status_code* which tells us if the request was successful. HTTP code 200 stands for *Sucess OK*.

```
import requests

response = requests.get('https://www.spatialthoughts.com')

print(response.status_code)
```

Calculating Distance using OpenRouteService API



OpenRouteService (ORS) (https://openrouteservice.org/) provides a free API for routing, distance matrix, geocoding, route optimization etc. using OpenStreetMap data. We will learn how to use this API through Python and get real-world distance between cities.

Almost all APIs require you to sign-up and obtain a *key*. The *key* is used to identify you and enforce usage limits so that you do not overwhelm the servers. We will obtain a key from OpenRouteServie so we can use their API

Visit OpenRouteService Sign-up page (https://openrouteservice.org/dev/#/signup) and create an account. Once your account is activated, visit your Dashboard and request a token. Select *Free* as the Token type and enter `python_foundation` as the Token name. Click *CREATE TOKEN*. Once created, copy the long string displayed under Key and enter below.

```
ORS_API_KEY = '<replace this with your key>'
```

We will use the OpenRouteServices's Directions Service (https://openrouteservice.org/dev/#/api-docs/v2/directions/%7Bprofile%7D/get). This service returns the driving, biking or walking directions between the given origin and destination points.

```
import requests

san_francisco = (37.7749, -122.4194)
new_york = (40.661, -73.944)

parameters = {
    'api_key': ORS_API_KEY,
    'start' : '{},{}'.format(san_francisco[1], san_francisco[0]),
    'end' : '{},{}'.format(new_york[1], new_york[0])
}

response = requests.get(
    'https://api.openrouteservice.org/v2/directions/driving-car', params=parameters)

if response.status_code == 200:
    print('Request successful.')
    data = response.json()
else:
    print('Request failed.')
```

We can read the `response` in JSON format by calling `json()` method on it.

```
data = response.json()
```

The response is a GeoJSON object representing the driving direction between the 2 points. The object is a feature collection with just 1 feature. We can access it using the index **0**. The feature's property contains `summary` information which has the data we need.

```
summary = data['features'][0]['properties']['summary']
print(summary)
```

We can extract the `distance` and convert it to kilometers.

```
distance = summary['distance']
print(distance/1000)
```

You can compare this distance to the straight-line distance and see the difference.

API Rate Limiting

Many web APIs enforce *rate limiting* - allowing a limited number of requests over time. With computers it is easy to write a for loop, or have multiple programs send hundrends or thousands of queries per second. The server may not be configured to handle such volume. So the providers specify the limits on how many and how fast the queries can be sent.

OpenRouteService lists several API Restrictions (https://openrouteservice.org/plans/). The free plan allows for upto 40 direction requests/minute.

There are many libraries available to implement various strategies for rate limiting. But we can use the built-in `time` module to implement a very simple rate limiting method.

The `time` module

Python Standard Library has a `time` module that allows for time related operation. It contains a method `time.sleep()` which delays the execution of the program for the specified number of seconds.

```
import time
for x in range(10):
    print(x)
    time.sleep(1)
```

Exercise

Below cell contains a dictionary with 3 destination cities and their coordinates. Write a `for` loop to iterate over the `destination_cities` disctionary and call `get_driving_distance()` function to print real driving distance between San Fransico and each city. Rate limit your queries by adding `time.sleep(2)` between successive function calls.

```
import csv
import os
import requests
import time
ORS_API_KEY = '<replace this with your key>'

def get_driving_distance(source_coordinates, dest_coordinates):
    parameters = {
    'api_key': ORS_API_KEY,
    'start' : '{},{}'.format(source_coordinates[1], source_coordinates[0]),
    'end' : '{},{}'.format(dest_coordinates[1], dest_coordinates[0])
    }

    response = requests.get(
        'https://api.openrouteservice.org/v2/directions/driving-car', params=parameters)

    if response.status_code == 200:
        data = response.json()
        summary = data['features'][0]['properties']['summary']
        distance = summary['distance']
        return distance/1000
    else:
        print('Request failed.')
        return -9999

san_francisco = (37.7749, -122.4194)

destination_cities = {
    'Los Angeles': (34.0522, -118.2437),
    'Boston': (42.3601, -71.0589),
    'Atlanta': (33.7490, -84.3880)
}
```

Open the notebook named `09_reading_files.ipynb` .

Reading Files

Python provides built-in functions for reading and writing files.

To read a file, we must know the path of the file on the disk. Python has a module called `os` that has helper functions that helps dealing with the the operating system. Advantage of using the `os` module is that the code you write will work without change on any suppored operating systems.

```
import os
```

To open a file, we need to know the path to the file. We will now open and read the file `worldcitites.csv` located in your data package. In your data package the data folder is in the `data/` directory. We can construct the relative path to the file using the `os.path.join()` method.

```
data_pkg_path = 'data'
filename = 'worldcities.csv'
path = os.path.join(data_pkg_path, filename)
print(path)
```

To open the file, use the built-in `open()` function. We specify the *mode* as `r` which means read-only. If we wanted to change the file contents or write a new file, we would open it with `w` mode.

Our input file also contains Unicode characters, so we specify `UTF-8` as the encoding.

The open() function returns a file object. We can call the `readline()` method for reading the content of the file, one line at a time.

It is a good practice to always close the file when you are done with it. To close the file, we must call the `close()` method on the file object.

```
f = open(path, 'r', encoding='utf-8')
print(f.readline())
print(f.readline())
f.close()
```

Calling `readline()` for each line of the file is tedious. Ideally, we want to loop through all the lines in file. You can iterate through the file object like below.

We can loop through each line of the file and increase the `count` variable by 1 for each iteration of the loop. At the end, the count variable's value will be equal to the number of lines in the file.

```
f = open(path, 'r', encoding='utf-8')

count = 0
for line in f:
    count += 1
f.close()
print(count)
```

Exercise

Print first 5 lines of the file.

- Hint: Use break statement

```
import os
data_pkg_path = 'data'
filename = 'worldcities.csv'
path = os.path.join(data_pkg_path, filename)

# Add code to open the file and read first 5 lines
```

Open the notebook named `10_reading_csv_files.ipynb` .

Reading CSV Files

Comma-separated Values (CSV) are the most common text-based file format for sharing geospatial data. The structure of the file is 1 data record per line, with individual *columns* separated by a comma.

In general, the separator character is called a delimiter. Other popular delimiters include the tab (\t), colon (:) and semi-colon (;) characters.

Reading CSV file properly requires us to know which delimiter is being used, along with quote character to surround the field values that contain space of the delimiter character. Since reading delimited text file is a very common operation, and can be tricky to handle all the corner cases, Python comes with its own library called `csv` for easy reading and writing of CSV files. To use it, you just have to import it.

```
import csv
```

The preferred way to read CSV files is using the `DictReader()` method. Which directly reads each row and creates a dictionary from it - with column names as *key* and column values as *value*. Let's see how to read a file using the `csv.DictReader()` method.

```
import os
data_pkg_path = 'data'
filename = 'worldcities.csv'
path = os.path.join(data_pkg_path, filename)
```

```
f = open(path, 'r')
csv_reader = csv.DictReader(f, delimiter=',', quotechar='"')
print(csv_reader)
f.close()
```

Using `enumerate()` function

When iterating over an object, many times we need a counter. We saw in the previous example, how to use a variable like `count` and increase it with every iteration. There is an easy way to do this using the built-in `enumerate()` function.

```
cities = ['San Francisco', 'Los Angeles', 'New York', 'Atlanta']
for x in enumerate(cities):
    print(x)
```

We can use enumerate() on any iterable object and get a tuple with an index and the iterable value with each iteration. Let's use it to print the first 5 lines from the DictReader object.

```
f = open(path, 'r', encoding='utf-8')
csv_reader = csv.DictReader(f, delimiter=',', quotechar='"')
for index, row in enumerate(csv_reader):
    print(row)
    if index == 4:
        break
f.close()
```

Using `with` statement

The code for file handling requires we open a file, do something with the file object and then close the file. That is tedious and it is possible that you may forget to call `close()` on the file. If the code for processing encounters an error the file is not closed property, it may result in bugs - especially when writing files.

The preferred way to work with file objects is using the `with` statement. It results in simpler and cleaer code - which also ensures file objects are closed properly in case of errors.

As you see below, we open the file and use the file object `f` in a `with` statement. Python takes care of closing the file when the execution of code within the statement is complete.

```
with open(path, 'r', encoding='utf-8') as f:
    csv_reader = csv.DictReader(f)
```

Filtering rows

We can use conditional statement while iterating over the rows, to select and process rows that meet certain criterial. Let's count how many cities from a particular country are present in the file.

Replace the `home_country` variable with your home country below.

```
home_country = 'India'
num_cities = 0

with open(path, 'r', encoding='utf-8') as f:
    csv_reader = csv.DictReader(f)

    for row in csv_reader:
        if row['country'] == home_country:
            num_cities += 1

print(num_cities)
```

Calculating distance

Let's apply the skills we have learnt so far to solve a complete problem. We want to read the `worldcities.csv` file, find all cities within a home country, calculate the distance to each cities from a home city and write the results to a new CSV file.

First we find the coordinates of the out selected `home_city` from the file. Replace the `home_city` below with your hometown or a large city within your country. Note that we are using the `city_ascii` field for city name comparison, so make sure the `home_city` variable contains the ASCII version of the city name.

```
home_city = 'Bengaluru'

home_city_coordinates = ()

with open(path, 'r', encoding='utf-8') as f:
    csv_reader = csv.DictReader(f)
    for row in csv_reader:
        if row['city_ascii'] == home_city:
            lat = row['lat']
            lng = row['lng']
            home_city_coordinates = (lat, lng)
            break

print(home_city_coordinates)
```

Now we can loop through the file, find a city in the chosen home country and call the `geopy.distance.geodesic()` function to calculate the distance. In the code below, we are just computing first 5 matches.

```
from geopy import distance

counter = 0
with open(path, 'r', encoding='utf-8') as f:
    csv_reader = csv.DictReader(f)
    for row in csv_reader:
        if (row['country'] == home_country and
            row['city_ascii'] != home_city):
            city_coordinates = (row['lat'], row['lng'])
            city_distance = distance.geodesic(
                city_coordinates, home_city_coordinates).km
            print(row['city_ascii'], city_distance)
            counter += 1

        if counter == 5:
            break
```

Writing files

Instead of printing the results, let's write the results to a new file. Similar to csv.DictReader(), there is a companion `csv.DictWriter()` method to write files. We create a `csv_writer` object and then write rows to it using the `writerow()` method.

First we create an `output` folder to save the results. We can first check if the folder exists and if it doesn't exist, we can create it.

```
output_dir = 'output'
if not os.path.exists(output_dir):
    os.mkdir(output_dir)
```

```
output_filename = 'cities_distance.csv'
output_path = os.path.join(output_dir, output_filename)

with open(output_path, mode='w', encoding='utf-8') as output_file:
    fieldnames = ['city', 'distance_from_home']
    csv_writer = csv.DictWriter(output_file, fieldnames=fieldnames)
    csv_writer.writeheader()

    # Now we read the input file, calculate distance and
    # write a row to the output
    with open(path, 'r', encoding='utf-8') as f:
        csv_reader = csv.DictReader(f)
        for row in csv_reader:
            if (row['country'] == home_country and
                row['city_ascii'] != home_city):
                city_coordinates = (row['lat'], row['lng'])
                city_distance = distance.geodesic(
                    city_coordinates, home_city_coordinates).km
                csv_writer.writerow(
                    {'city': row['city_ascii'],
                     'distance_from_home': city_distance}
                )
```

Below is the complete code for our task of reading a file, filtering it, calculating distance and writing the results to a file.

```
import csv
import os
from geopy import distance

data_pkg_path = 'data'
input_filename = 'worldcities.csv'
input_path = os.path.join(data_pkg_path, input_filename)
output_filename = 'cities_distance.csv'
output_dir = 'output'
output_path = os.path.join(output_dir, output_filename)

home_city = 'Bengaluru'
home_country = 'India'

with open(input_path, 'r', encoding='utf-8') as input_file:
    csv_reader = csv.DictReader(input_file)
    for row in csv_reader:
        if row['city_ascii'] == home_city:
            home_city_coordinates = (row['lat'], row['lng'])
            break

with open(output_path, mode='w') as output_file:
    fieldnames = ['city', 'distance_from_home']
    csv_writer = csv.DictWriter(output_file, fieldnames=fieldnames)
    csv_writer.writeheader()

    with open(input_path, 'r', encoding='utf-8') as input_file:
        csv_reader = csv.DictReader(input_file)
        for row in csv_reader:
            if (row['country'] == home_country and
                row['city_ascii'] != home_city):
                city_coordinates = (row['lat'], row['lng'])
                city_distance = distance.geodesic(
                    city_coordinates, home_city_coordinates).km
                csv_writer.writerow(
                    {'city': row['city_ascii'],
                     'distance_from_home': city_distance}
                )

print('Successfully written output file at {}'.format(output_path))
```

Exercise

Replace the `home_city` and `home_country` variables with your own home city and home country and create a CSV file containing distance from your home city to every other city in your country.

Open the notebook named `11_working_with_pandas.ipynb`.

Working with Pandas

Pandas is a powerful library for working with data. Pandas provides fast and easy functions for reading data from files, and analyzing it.

Pandas is based on another library called `numpy` - which is widely used in scientific computing. Pandas extends `numpy` and provides new data types such as **Index**, **Series** and **DataFrames**.

Pandas implementation is very fast and efficient - so compared to other methods of data processing - using `pandas` results is simpler code and quick processing. We will now re-implement our code for reading a file and computing distance using Pandas.

By convention, `pandas` is commonly imported as `pd`

```
import pandas as pd
```

Reading Files

```
import os
data_pkg_path = 'data'
filename = 'worldcities.csv'
path = os.path.join(data_pkg_path, filename)
```

A **DataFrame** is the most used Pandas object. You can think of a DataFrame being equivalent to a Spreadsheet or an Attribute Table of a GIS layer.

Pandas provide easy methods to directly read files into a DataFrame. You can use methods such as `read_csv()`, `read_excel()`, `read_hdf()` and so forth to read a variety of formats. Here we will read the `worldcitites.csv` file using `read_csv()` method.

```
df = pd.read_csv(path)
```

Once the file is read and a DataFrame object is created, we can inspect it using the `head()` method.

```
print(df.head())
```

There is also a `info()` method that shows basic information about the dataframe, such as number of rows/columns and data types of each column.

```
print(df.info())
```

Filtering Data

Pandas have many ways of selecting and filtered data from a dataframe. We will now see how to use the Boolean Filtering (https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#boolean-indexing) to filter the dataframe to rows that match a condition.

```
home_country = 'India'
filtered = df[df['country'] == home_country]
print(filtered)
```

Filtered dataframe is a just view of the original data and we cannot make changes to it. We can save the filtered view to a new dataframe using the `copy()` method.

```
country_df = df[df['country'] == home_country].copy()
```

To locate a particular row or column from a dataframe, Pandas providea `loc[]` and `iloc[]` methods - that allows you to *locate* particular slices of data. Learn about different indexing methods (https://pandas.pydata.org/pandas-docs/stable/user_guide/indexing.html#different-choices-for-indexing) in Pandas. Here we can use `iloc[]` to find the row matching the `home_city` name. Since `iloc[]` uses index, the *0* here refers to the first row.

```
home_city = 'Bengaluru'
filtered = country_df[country_df['city_ascii'] == home_city]
print(filtered.iloc[0])
```

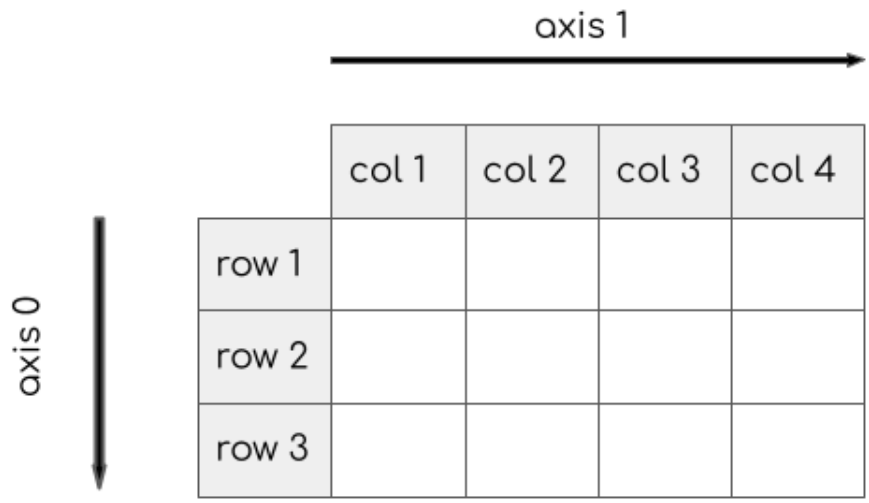
Now that we have filtered down the data to a single row, we can select individual column values using column names.

```
home_city_coordinates = (filtered.iloc[0]['lat'], filtered.iloc[0]['lng'])
print(home_city_coordinates)
```

Performing calculations

Let's learn how to do calculations on a dataframe. We can iterate over each row and perform some calculations. But pandas provide a much more efficient way. You can use the `apply()` method to run a function on each row. This is fast and makes it easy to complex computations on large datasets.

The `apply()` function takes 2 arguments. A function to apply, and the axis along which to apply it. `axis=0` means it will be applied to columns and `axis=1` means it will apply to rows.




```
from geopy import distance

def calculate_distance(row):
    city_coordinates = (row['lat'], row['lng'])
    return distance.geodesic(city_coordinates, home_city_coordinates).km

result = country_df.apply(calculate_distance, axis=1)
print(result)
```

We can add these results to the dataframe by simply assigning the result to a new column.

```
country_df['distance'] = result
print(country_df)
```

We are done with our analysis and ready to save the results. We can further filter the results to only certain columns.

```
filtered = country_df[['city_ascii','distance']]
print(filtered)
```

Let's rename the `city_ascii` column to give it a more readable name.

```
filtered = filtered.rename(columns = {'city_ascii': 'city'})
print(filtered)
```

Now that we have added filtered the original data and computed the distance for all cities, we can save the resulting dataframe to a file. Similar to read methods, Pandas have several write methods, such as `to_csv()`, `to_excel()` etc.

Here we will use the `to_csv()` method to write a CSV file. Pandas assigns an index column (unique integer values) to a dataframe by default. We specify `index=False` so that this index is not added to our output.

```
output_filename = 'cities_distance_pandas.csv'
output_dir = 'output'
output_path = os.path.join(output_dir, output_filename)
filtered.to_csv(output_path, index=False)
print('Successfully written output file at {}'.format(output_path))
```

Exercise

You will notice that the output file contains a row with the `home_city` as well. Modify the `filtered` dataframe to remove this row and write it to a file.

Hint: Use the Boolean filtering method we learnt earlier to select rows that do not match the `home_city` .

Working with Geopandas

GeoPandas extends the Pandas library to enable spatial operations. It provides new data types such as **GeoDataFrame** and **GeoSeries** which are subclasses of Pandas **DataFrame** and **Series** and enables efficient vector data processing in Python.

GeoPandas make use of many other widely used spatial libraries - but it provides an interface similar to Pandas that make it intuitive to use it with spatial analysis. GeoPandas is built on top of the following libraries that allow it to be spatially aware.

- Shapely (https://shapely.readthedocs.io/en/latest/manual.html) for geometric operations (i.e. buffer, intersections etc.)
- PyProj (https://pyproj4.github.io/pyproj/stable/index.html) for working with projections
- Fiona (https://pypi.org/project/Fiona/) for file input and output, which itself is based on the widely used GDAL/OGR (https://gdal.org/) library

We will carry out a geoprocessing task that shows various features of this library and show how to do geo data processing in Python. The task is to take a roads data layer from OpenStreetMap and compute the total length of National Highways for each district in a state. The problem is described in detail in my Advanced QGIS (https://courses.spatialthoughts.com/advanced-qgis.html#exercise-find-the-length-of-national-highways-in-a-state) course and show the steps needed to perform this analysis in QGIS. We will replicate this example in Python.

By convention, `geopandas` is commonly imported as `gpd`

```
import geopandas as gpd
```

Reading Spatial Data

```
import os
data_pkg_path = 'data'
filename = 'karnataka.gpkg'
path = os.path.join(data_pkg_path, filename)
```

GeoPandas has a `read_file()` method that is able to open a wide variety of vector datasets, including zip files. Here we will open the GeoPackage `karnataka.gpkg` and read a layer called `karnataka_major_roads` . The result of the read method is a **GeoDataFrame**.

```
roads_gdf = gpd.read_file(path, layer='karnataka_major_roads')
print(roads_gdf.info())
```

A GeoDataFrame contains a special column called *geometry*. All spatial operations on the GeoDataFrame are applied to the geomety column. The geometry column can be accessed using the `geometry` attribute.

```
print(roads_gdf.geometry)
```

Filtering Data

One can use the standard Pandas filtering methods to select a subset of the GeoDataFrame. In addition, GeoPandas also provide way to subset the data based on a bounding box with the `cx[]` indexer (https://geopandas.readthedocs.io/en/latest/indexing.html).

For our analysis, we need to apply a filter to extract only the road segments where the `ref` attribute starts with **'NH'** - indicating a national highway. We can apply boolean filtering using Panda's `str.match()` method with a regular expression.

```
filtered = roads_gdf[roads_gdf['ref'].str.match('^NH') == True]
print(filtered.head())
```

Working with Projections

Dealing with projetions is a key aspect of working with spatial data. GeoPandas uses the `pyproj` library to assign and manage projections. Each GeoDataFrame as a `crs` attribute that contains the projection info. Our source dataset is in EPSG:4326 WGS84 CRS.

```
print(filtered.crs)
```

Since our task is to compute line lengths, we need to use a Projected CRS. We can use the `to_crs()` method to reproject the GeoDataFrame.

```
roads_reprojected = filtered.to_crs('EPSG:32643')
print(roads_reprojected.crs)
```

Now that the layer has been reprojected, we can calculate the length of each geometry using the `length` attribute. The result would be in meters. We can add the line lengths in a new column named `length` .

```
roads_reprojected['length'] = roads_reprojected['geometry'].length
```

We can apply statistical operations on a DataFrame columns. Here we can compute the total length of national highways in the state by calling the `sum()` method.

```
total_length = roads_reprojected['length'].sum()
print('Total length of national highways in the state is {} KM'.format(total_length/1000
        ))
```

Performing Spatial joins

There are two ways to combine datasets in geopandas – table joins and spatial joins. For our task, we need information about which district each road segments belongs to. This can be achived using another spatial layer for the districts and doing a spatial join to transfer the attributes of the district layer to the matching road segment.

The `karnataka.gpkg` contains a layer called `karnataka_districts` with the district boundaries and names.

```
districts_gdf = gpd.read_file(path, layer='karnataka_districts')
print(districts_gdf.head())
```

Before joining this layer to the roads, we must reproject it to match the CRS of the roads layer.

```
districts_reprojected = districts_gdf.to_crs('EPSG:32643')
```

A spatial join is performed using the `sjoin()` method. It takes 2 core arguments.

- `op` : The spatial predicate to decdie which objects to join. Options are *intersects*, *within* and *contains*.
- `how` : The type of join to perform. Options are *left*, *right* and *inner*.

For our task, we can do a *left* join and add attributes of the district that *intersect* the road.

```
joined = gpd.sjoin(roads_reprojected, districts_reprojected, how='left', op='intersects'
        )
print(joined.head())
```

Group Statistics

The resulting geodataframe now has the matching column from the intersecting district feature. We can now sum the length of the roads and group them by districts. This type of *Group Statistics* is performed using Panda's `group_by()` method.

```
results = joined.groupby('DISTRICT')['length'].sum()/1000
print(results)
```

The result of the `group_by()` method is a Pandas *Series*. It can be saved to a CSV file using the `to_csv()` method.

```
output_filename = 'national_highways_by_districts.csv'
output_dir = 'output'
output_path = os.path.join(output_dir, output_filename)
results.to_csv(output_path)
print('Successfully written output file at {}'.format(output_path))
```

Exercise

Before writing the output to the file, round the distance numbers to a whole number.

Open the notebook named `13_creating_spatial_data.ipynb`.

Creating Spatial Data

A common operation in spatial analysis is to take non-spatial data, such as CSV files, and creating a spatial dataset from it using coordinate information contained in the file. GeoPandas provides a convenient way to take data from a delimited-text file, create geometry and write the results as a spatial dataset.

We will read a tab-delimited file of places, filter it to a feature class, create a GeoDataFrame and export it as a GeoPackage file.

```
import os
import pandas as pd
import geopandas as gpd
```

```
data_pkg_path = 'data/geonames/'
filename = 'US.txt'
path = os.path.join(data_pkg_path, filename)
```

Reading Tab-Delimited Files

The source data comes from GeoNames (https://en.wikipedia.org/wiki/GeoNames) - a free and open database of geographic names of the world. It is a huge database containing millions of records per country. The data is distributed as country-level text files in a tab-delimited format. The files do not contain a header row with column names, so we need to specify them when reading the data. The data format is described in detail on the Data Export (https://www.geonames.org/export/) page.

We specify the separator as **\t** (tab) as an argument to the `read_csv()` method. Note that the file for USA has more than 2M records.

```
column_names = [
    'geonameid', 'name', 'asciiname', 'alternatenames',
    'latitude', 'longitude', 'feature class', 'feature code',
    'country code', 'cc2', 'admin1 code', 'admin2 code',
    'admin3 code', 'admin4 code', 'population', 'elevation',
    'dem', 'timezone', 'modification date'
]

df = pd.read_csv(path, sep='\t', names=column_names)
print(df.info())
```

Filtering Data

The input data as a column `feature_class` categorizing the place into 9 feature classes (https://www.geonames.org/export/codes.html). We can select all rows with the value `T` with the category *mountain,hill,rock...*

```
mountains = df[df['feature class']=='T']
print(mountains.head()[['name', 'latitude', 'longitude', 'dem','feature class']])
```

Creating Geometries

GeoPandas has a conveinent function `points_from_xy()` that creates a Geometry column from X and Y coordinates. We can then take a Pandas dataframe and create a GeoDataFrame by specifying a CRS and the geometry column.

```
geometry = gpd.points_from_xy(mountains.longitude, mountains.latitude)
gdf = gpd.GeoDataFrame(mountains, crs='EPSG:4326', geometry=geometry)
print(gdf.info())
```

Writing Files

We can write the resulting GeoDataFrame to any of the supported vector data format. Here we are writing it as a new GeoPackage file.

You can open the resulting geopackage in a GIS and view the data.

```
output_dir = 'output'
output_filename = 'mountains.gpkg'
output_path = os.path.join(output_dir, output_filename)

gdf.to_file(driver='GPKG', filename=output_path, encoding='utf-8')
print('Successfully written output file at {}'.format(output_path))
```

Exercise

The data package contains multiple geonames text files from different countries in the `geonames/` folder. Write code to read all the files, merge them and extract the mountain features to a single geopackage.

- Hint1: Use the `os.listdir()` method to get all files in a directory.
- Hint2: Use the Pandas method `concat()` to merge multiple dataframes.

```
import os
import pandas as pd
import geopandas as gpd

data_pkg_path = 'data/geonames/'
files = os.listdir(data_pkg_path)

filepaths = []
for file in files:
    filepaths.append(os.path.join(data_pkg_path, file))
print(filepaths)

# Iterate over the files, read them using pandas and create a list of dataframes.
# You can then use pd.concat() function to merge them
```

Open the notebook named `14_introduction_to_numpy.ipynb`.

Introduction to NumPy

NumPy (Numerical Python) is an important Python library for scientific computation. Libraries such as Pandas and GeoPandas are built on top of NumPy.

It provides a fast and efficient ways to work with *Arrays*. In the domain of spatial data analysis, it plays a critical role in working with Raster data - such as satellite imagery, aerial photos, elevation data etc. Since the underlying structure of raster data is a 2D array for each band - learning NumPy is critical in processing raster data using Python.

By convention, `numpy` is commonly imported as `np`

```
import numpy as np
```

Arrays

The array object in NumPy is called `ndarray`. It provides a lot of supporting functions that make working with arrays fast and easy. Arrays may seem like Python Lists, but `ndarray` is upto 50x faster in mathematical operations. You can create an array using the `array()` method. As you can see, the rsulting object is of type `numpy.ndarray`

```
a = np.array([1, 2, 3, 4])
print(type(a))
```

Arrays can have any *dimensions*. We can create a 2D array like below. `ndarray` objects have the property `ndim` that stores the number of array dimensions. You can also check the array size using the `shape` property.

```
b = np.array([[1, 2, 4], [3, 4, 5]])
print(b)
print(b.ndim)
print(b.shape)
```

You can access elements of arrays like Python lists using `[]` notation.

```
print(b[0])
```

```
print(b[0][2])
```

Array Operations

Mathematical operations on numpy arrays are easy and fast. NumPy as many built-in functions for common operations.

```
print(np.sum(b))
```

You can also use the functions operations on arrays.

```
c = np.array([[2, 2, 2], [2, 2, 2]])
print(np.divide(b, c))
```

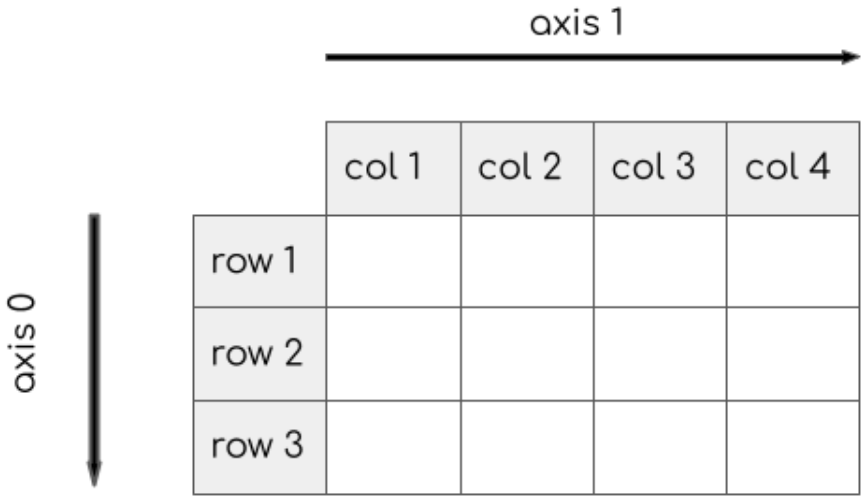
If the objects are numpy objects, you can use the Python operators as well

```
print(b/c)
```

You can also combine array and scalar objects. The scalar operation is applied to each item in the array.

```
print(b)
print(b*2)
print(b/2)
```

An important concept in NumPy is the *Array Axes*. Similar to the `pandas` library, In a 2D array, Axis 0 is the direction of rows and Axis 1 is the direction of columns. The diagram below show the directions.



Let's see how we can apply a function on a specific axis. Here when we apply `sum` function on axis-0 of a 2D array, it gives us a 1D-array with values summed across rows.

```
print(b)
row_sum = b.sum(axis=0)
print(row_sum)
```

Exercise

Sum the array `b` along Axis-1. What do you think will be the result?

```
import numpy as np

b = np.array([[1, 2, 4], [3, 4, 5]])
print(b)
```

Open the notebook named `15_working_with_rasterio.ipynb`.

Working with RasterIO

RasterIO (https://rasterio.readthedocs.io/en/latest/) is a modern library to work with geospatial data in a gridded format. It excels at providing an easy way to read/write raster data and access individual bands and pixels as `numpy` arrays.

RasterIO is built on top of the popular GDAL (Geospatial Data Abstraction Library) (https://gdal.org/). GDAL is written in C++ so the Python API provided by GDAL is not very intuitive for Python users. RaserIO aims to make it easy for Python users to use the underlying GDAL library in an intuitive way.

In this section, we will take 4 individual SRTM tiles around the Mt. Everest region and merge them to a single GeoTiff using RasterIO.

```
import rasterio
```

```
import os
data_pkg_path = 'data'
srtm_dir = 'srtm'
filename = 'N28E087.hgt'
path = os.path.join(data_pkg_path, srtm_dir, filename)
```

Reading Raster Data

RasterIO can read any raster format supported by the GDAL library. We can call the `open()` method with the file path of the raster. The resulting dataset behaves much like Python's File object.

```
dataset = rasterio.open(path)
```

You can check information about the raster using the `meta` attribute.

An important property is the dataset *transform*. The transform contains the pixel resolution of the dataset and the row and column coordinates of the upper left corner of the dataset.

```
metadata = dataset.meta
metadata
```

To read the pixel values, we need to call the `read()` method by passing it a band's index number. Following the GDAL convention, bands are indexed from 1. Since our dataset contain just 1-band, we can read it as follows.

```
band1 = dataset.read(1)
print(band1)
```

Finally, when we are done with the dataset, we must close it. It is especially important when writing a dataset.

```
dataset.close()
```

Merging Datasets

Let's see how we can read the 4 individual tiles and mosaic them together. RasterIO provides multiple sub-modules for various raster operations. We can use the `rasterio.merge` module to carry out this operation.

We first find all the individual files in the directory using the `os.listdir()` function.

```
srtm_path = os.path.join(data_pkg_path, 'srtm')
all_files = os.listdir(srtm_path)
print(all_files)
```

The rasterio.merge module has a `merge()` method that takes a list of *datasets* and returns the merged dataset. So we create an empty list, open each of the files and append it to the list.

```
dataset_list = []
for file in all_files:
    path = os.path.join(srtm_path, file)
    dataset_list.append(rasterio.open(path))
print(dataset_list)
```

We can pass on the list of tile dataset to the merge method, which will return us the merged data and a new *transform* which contains the updated extent of the merged raster.

```
from rasterio import merge
merged_result = merge.merge(dataset_list)
print(merged_result)
```

We save the data and the transform to separate variables.

```
merged_data = merged_result[0]
merged_transform = merged_result[1]
```

Verify that the resulting array shape the sum of individual rasters

```
print(merged_data.shape)
```

Writing Raster Data

Similar to regular Python files, to create a new file, we can open the output file in the *write* mode. RasterIO provides a `write()` method that we can use to write individual bands.

```
output_filename = 'merged.tif'
output_dir = 'output'
output_path = os.path.join(output_dir, output_filename)
```

We need to specify many metadata parameters to initialize the output dataset. Some of these parameter values can be directly copied from the input files, such as `crs`, `dtype`, `nodata` etc., while others can be obtained from the merged dataset, such as `height` and `width`.

Remember to call the `close()` method which will finalize the file and write the data to disk.

```
new_dataset = rasterio.open(output_path, 'w',
                            driver='GTiff',
                            height=merged_data.shape[1],
                            width=merged_data.shape[2],
                            count=1,
                            nodata=-32768.0,
                            dtype=merged_data.dtype,
                            crs='+proj=latlong',
                            transform=merged_transform)
new_dataset.write(merged_data)
new_dataset.close()
print('Successfully written output file at {}'.format(output_path))
```

Exercise

The merged array represents elevation values. The extent of the tiles cover Mt. Everest. Read the resulting raster and find the maximum elevation value contained in it.

```
import rasterio
import os
import numpy as np

output_filename = 'merged.tif'
output_dir = 'output'
output_path = os.path.join(output_dir, output_filename)

# Read the output file as a NumPy array and find the maximum value
```