

Programming for Essential Digital Skills, Part 2

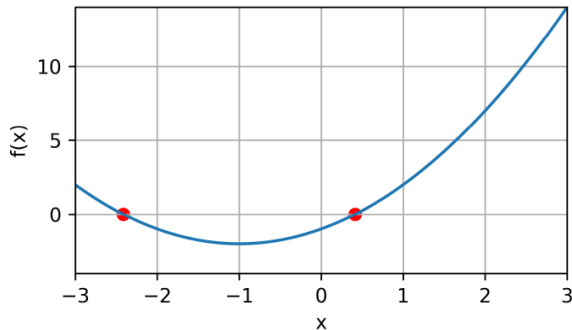
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Chapter 8 - Mathematics and plotting

Root finding

Consider $f(x) = x^2 + 2x - 1$. A **root** x of the function f is a point that satisfies $f(x) = 0$.



SciPy: Scientific Computing with Python

Subpackages

SciPy is organized into subpackages covering different scientific computing domains. These are summarized in the following table:

Subpackage	Description
<code>cluster</code>	Clustering algorithms
<code>constants</code>	Physical and mathematical constants
<code>fft</code>	Discrete Fourier transforms
<code>fftpack</code>	Fast Fourier Transform routines (legacy)
<code>integrate</code>	Integration and ordinary differential equation solvers
<code>interpolate</code>	Interpolation and smoothing splines
<code>io</code>	Input and Output
<code>linalg</code>	Linear algebra
<code>ndimage</code>	N-dimensional image processing
<code>odr</code>	Orthogonal distance regression
<code>optimize</code>	Optimization and root-finding routines

Solving the equation $f(x) = 0$ using `fsolve()`

Solving the equation $f(x) = 0$ using `fsolve()`

```
import scipy.optimize as optimize

def f(x):
    return x**2 + 2*x - 1

guess = 3
f_zero = optimize.fsolve(f,guess)[0]

print("A root of the function f is given by", f_zero)
```

A root of the function f is given by 0.41421356237309503

Solving the equation $f(x) = 3$

Suppose we want to solve $f(x) = 3$. How to do this with root finding?

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- If we define $g(x) = f(x) - 3$, then $g(x) = 0$ if and only if $f(x) = 3$.

Solving the equation $f(x) = 3$

Suppose we want to solve $f(x) = 3$. How to do this with root finding?

- If we define $g(x) = f(x) - 3$, then $g(x) = 0$ if and only if $f(x) = 3$.

```
def g(x):  
    return f(x) - 3  
  
guess = 4  
f_zero = optimize.fsolve(g,guess)[0]  
  
print("A number x satisfying f(x) = 3, is given by", f_zero)
```

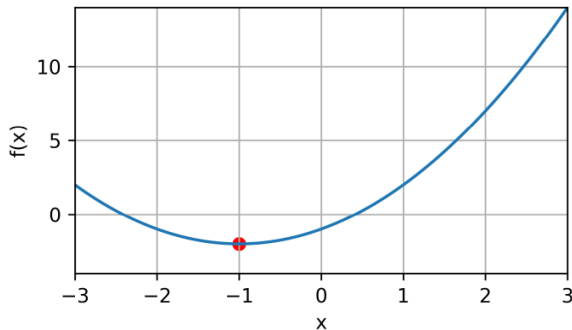
A number x satisfying $f(x) = 3$, is given by 1.2360679774998171

Solving the equation $f(x) = c$

```
def solve_eq(f,c,guess):  
    # This function returns the solution to  $f(x) = c$  using  
    # fsolve() on the function  $g(x) = f(x) - c$   
  
    def g(x):  
        return f(x) - c  
  
    x = optimize.fsolve(g,guess)[0]  
    return x
```

Minimizing a function f

Consider $f(x) = x^2 + 2x - 1$. **Minimum of f** is a point x for which $f(x)$ is smallest.



Computing a minimum of f using `fmin()`

```
import scipy.optimize as optimize
```

```
def f(x):  
    return x**2 + 2*x - 1
```

```
guess = 1  
minimum = optimize.fmin(f,guess)
```

Optimization terminated successfully.

Current function value: -2.000000

Iterations: 19

Function evaluations: 38

```
print('The minimum of the function f is attained at x = ', minimum)
```

The minimum of the function f is attained at $x = [-1.]$

Computing a minimum of f using `fmin()`

```
import scipy.optimize as optimize

def f(x):
    return x**2 + 2*x - 1

guess = 1
minimum = optimize.fmin(f,guess,disp=False)[0]

print('The minimum of the function f is attained at x = ', minimum)
```

The minimum of the function f is attained at x = -1.00000000000000018

Computing a minimum of f using `fmin()`

```
import scipy.optimize as optimize

def f(x):
    return x**2 + 2*x - 1

guess = 1
minimum = optimize.fmin(f,guess,disp=False)[0]

print('The minimum of the function f is attained at x = ', minimum)
```

The minimum of the function f is attained at $x = -1.00000000000000018$

Note: `fmin()` might return a “local” minimum, which is not the true minimum of the function (Classroom Exercise 1).

Matplotlib: Data visualization

Matplotlib is a package that can be used for data visualization

- For this we use the `matplotlib.pyplot` (sub)package ...
- ... which we usually import under the name `plt`

How are functions plotted in Python?

- 1 Create a vector of x -values, e.g.,

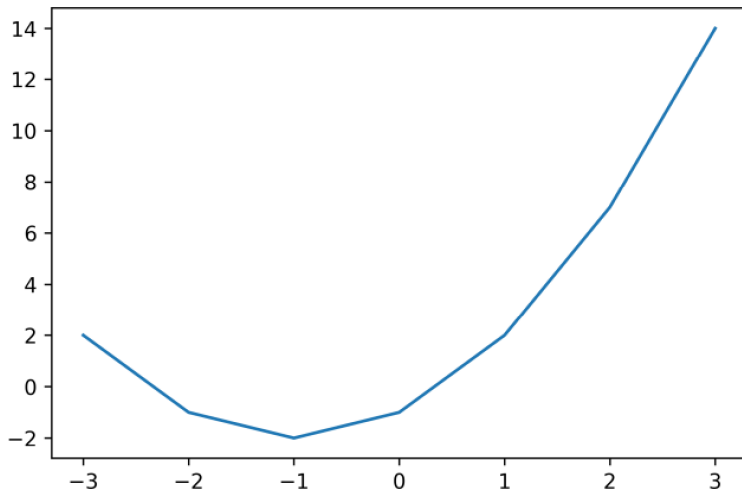
$$x = [-3, -2, -1, 0, 1, 2, 3].$$

- 2 Compute the function values

$$[f(-3), f(-2), f(-1), f(0), f(1), f(2), f(3)] = [2, -1, -2, -1, 2, 7, 14].$$

- 3 Draw the points $(x_i, f(x_i))$ and connect them with line segments.

Resulting Python plot



Plotting a “smooth” line

Increase the number of points in x to get a smoother line using `np.linspace()`.

- Command `np.linspace(a,b,k)` plots k evenly spaced points in interval $[a, b]$.

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- Command `np.linspace(a,b,k)` plots k evenly spaced points in interval $[a, b]$.

```
import numpy as np
```

```
a = 0
```

```
b = 1
```

```
k = 11
```

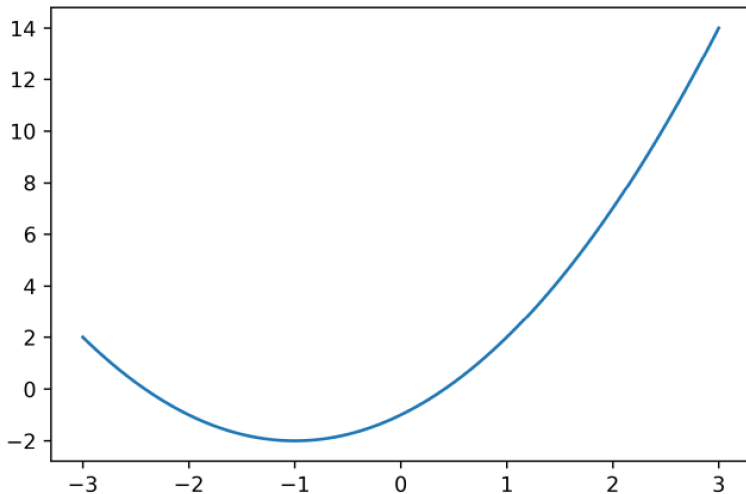
```
x = np.linspace(a,b,k)
```

```
print(x)
```

```
[0.  0.1 0.2 0.3 0.4 0.5 0.6 0.7 0.8 0.9 1. ]
```

Resulting “smoothed” Python plot

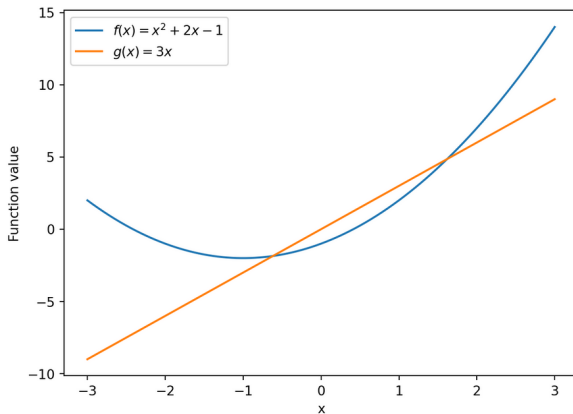
Using `x = np.linspace(-3,3,600)`



Adding legend to plot

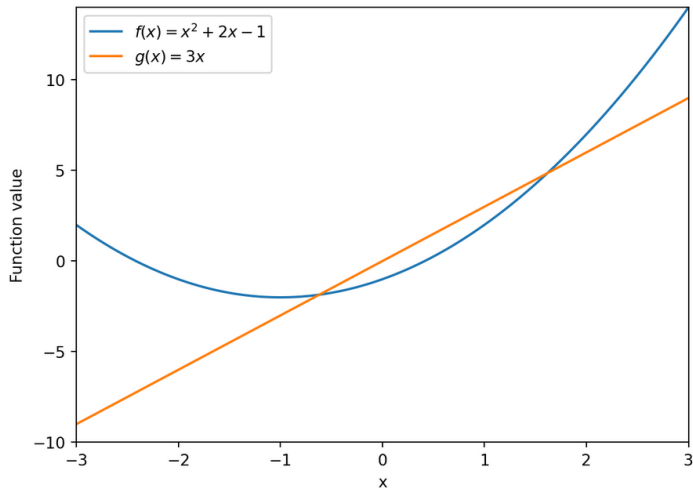
Use label-argument in `plt.plot()` in combination with `plt.legend()` at the end ...

- ... and `plt.xlabel('x')` and `plt.ylabel('Function value')` for axis labels.



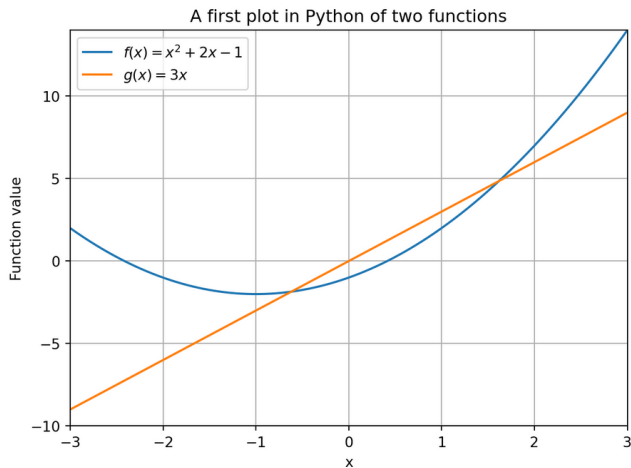
Fixing axes ranges

Use `plt.xlim(-3,3)` and `plt.ylim(-10,14)` to fix range of horizontal/vertical axis, resp.



Adding title and grid

- Use `plt.title('A first plot of two functions')` to add title
- Use `plt.grid()` to add grid.

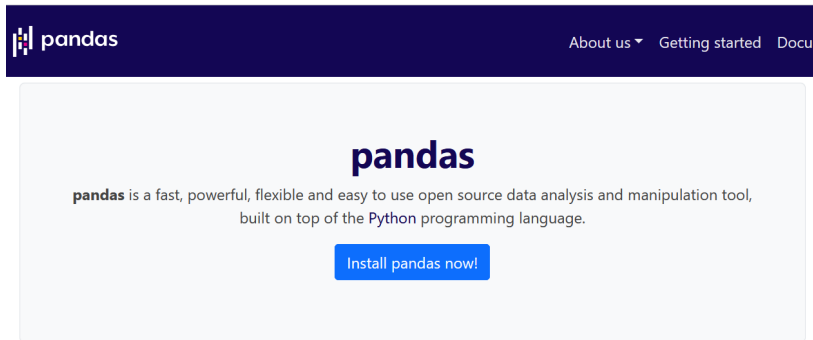


Classroom Exercise 1

Consider the function $f(x) = \frac{9}{10}x^4 - 3x^3 - \frac{7}{2}x^2 + 12x + 3$.

- Plot this function with horizontal axis range $[-6, 6]$, and vertical axis range $[-15, 15]$.
- Find four roots of this function with `fsolve()` by trying out different initial guesses.
- Find a minimum of this function with `fmin()` by using initial guesses -1 and 2 . Are both solutions actual minima of the function?

Chapter 9 - Data handling with Pandas



Import the package under alias `pd`

```
import pandas as pd
```

Input data

Data can come from many sources. We look at two possibilities:

- Python dictionary (data contained in Python script)
- Matrix, i.e., list of lists (data contained in Python script)
- Comma-separated values (CSV) file (data loaded into Python from another file)

Data in dictionary

```
# Dictionary with data
dataset = {
    'name' : ["Aiden", "Bella", "Carlos", "Dalia", "Elena", "Farhan"],
    'height (cm)' : [185, 155, 190, 185, 160, 170],
    'weight (kg)' : [80, 60, 100, 85, 62, 75],
    'age (years)' : [23, 23, 23, 21, 19, 25],
    'dietary preference' : ['Veggie', 'Veggie', 'None', 'None', 'Vegan', 'None']
}
```

Pandas data frame (created from dictionary)

We load data into a data frame using `DataFrame()` whose input argument is our dictionary.

```
data_frame = pd.DataFrame(dataset)
```

```
print(data_frame)
```

	name	height (cm)	weight (kg)	age (years)	dietary preference
0	Aiden	185	80	23	Veggie
1	Bella	155	60	23	Veggie
2	Carlos	190	100	23	None
3	Dalia	185	85	21	None
4	Elena	160	62	19	Vegan
5	Farhan	170	75	25	None

Frame info

Frame columns (dictionary keys)

	name	height (cm)	weight (kg)	age (years)	dietary preference
0	Aiden	185	80	23	Veggie
1	Bella	155	60	23	Veggie
2	Carlos	190	100	23	None
3	Dalia	185	85	21	None
4	Elena	160	62	19	Vegan
5	Farhan	170	75	25	None

Frame indices

Frame column data (dictionary value)

Accessing data from Pandas frame

Suppose we have a frame named `frame_name`.

Command	Output
<code>frame_name.head(k)</code>	First k rows of frame
<code>frame_name.tail(k)</code>	Last k rows of frame
<code>frame_name.loc[i]</code>	Row with index i
<code>frame_name.loc[i,col_name]</code>	Element on row i in column <code>col_name</code>
<code>frame_name.loc[:,col_name]</code> or <code>frame_name[col_name]</code>	Column <code>col_name</code>

Accessing blocks of the frame

With `frame_name.loc[[i1,i2,...,iq],[col_1,...,col_r]]`:

- Block formed by row indices i_1, \dots, i_q and columns with name col_1, \dots, col_r

```
# Extract block with rows 2,4 and columns name, height and age.  
x = data_frame.loc[[2,4],['name','height (cm)', 'age (years)']]  
print(x)
```

	name	height (cm)	age (years)
2	Carlos	190	23
4	Elena	160	19

With `frame_name.loc[[i1,i2,...,iq]]`:

- Block formed by row indices i_1, \dots, i_q and all columns.

Accessing rows using Boolean list

For list x containing values True or False:

- Access True-rows with `frame_name.loc[x]`.

```
x = [False, False, True, False, True, False]
print(data_frame.loc[x])
```

	name	height (cm)	weight (kg)	age (years)	dietary preference
2	Carlos	190	100	23	None
4	Elena	160	62	19	Vegan

Accessing rows based on conditional statement

Suppose we only want the people whose dietary preference is 'None'.

- Conditional statement `data_frame.loc[:, 'dietary preference'] == 'None'`

```
x = data_frame.loc[:, 'dietary preference'] == 'None'  
print(x)
```

```
0    False
```

```
1    False
```

```
2     True
```

```
3     True
```

```
4    False
```

```
5     True
```

```
Name: dietary preference, dtype: bool
```

Accessing rows based on conditional statement (cont'd)

```
x = data_frame.loc[:, 'dietary preference'] == 'None'  
print(data_frame.loc[x])
```

	name	height (cm)	weight (kg)	age (years)	dietary preference
2	Carlos	190	100	23	None
3	Dalia	185	85	21	None
5	Farhan	170	75	25	None

Editing frame data

```
data = [  
    [2,4,-1,2],  
    [5,1,2,9],  
    [3,7,8,9]  
]  
  
frame = pd.DataFrame(data)  
  
print(frame)
```

	0	1	2	3
0	2	4	-1	2
1	5	1	2	9
2	3	7	8	9

Editing row names

Row and column names are stored in `frame.index` and `frame.columns`, respectively.

```
print(frame.index)
```

```
RangeIndex(start=0, stop=3, step=1)
```

```
frame.index = ['Row0', 'Row1', 'Row2']  
print(frame)
```

	0	1	2	3
Row0	2	4	-1	2
Row1	5	1	2	9
Row2	3	7	8	9

Editing column names

```
frame.columns = ['Col0', 'Col1', 'Col2', 'Col3']  
  
print(frame)
```

	Col0	Col1	Col2	Col3
Row0	2	4	-1	2
Row1	5	1	2	9
Row2	3	7	8	9

Editing entries

Editing entries can be done with `frame.loc[row_name,col_name] = new_value`

```
# Edit entry on row 1, column 2
frame.loc['Row1','Col2'] = 10

print(frame)
```

	Col0	Col1	Col2	Col3
Row0	2	4	-1	2
Row1	5	1	10	9
Row2	3	7	8	9

Editing whole row

Replace row with list y: `frame.loc[row_name,:] = y`

```
# Replace row 2
y = [-2,-2,-2,-2]
frame.loc['Row2'] = y #frame.loc['Row2',:] = y also works

print(frame)
```

	Col0	Col1	Col2	Col3
Row0	2	4	-1	2
Row1	5	1	10	9
Row2	-2	-2	-2	-2

Editing whole column

Replace column with list y: `frame.loc[:,col_name] = y`

```
# Replace column 2
y = [-1,-1,-1]
frame.loc[:, 'Col2'] = y

print(frame)
```

	Col0	Col1	Col2	Col3
Row0	2	4	-1	2
Row1	5	1	-1	9
Row2	-2	-2	-1	-2

Editing whole column according to a mathematical function

Suppose we want to square every number in the column 'Col1'.

```
def f(x):  
    return x**2
```

Use `apply()` function and overwrite entries in 'Col1' (don't use `frame.loc['Col1']!`)

```
frame['Col1'] = frame['Col1'].apply(f)  
  
print(frame)
```

	Col0	Col1	Col2	Col3
Row0	2	16	-1	2
Row1	5	1	-1	9
Row2	-2	4	-1	-2

Adding new row

New rows appear at the bottom of the frame.

```
# Add a row  
frame.loc['New row'] = [5,5,3,1]  
print(frame)
```

	Col0	Col1	Col2	Col3
Row0	2	16	-1	2
Row1	5	1	-1	9
Row2	-2	4	-1	-2
New row	5	5	3	1

Adding new column

New columns appear at the right of the frame.

```
frame.loc[:, 'New column'] = [1,1,1,1]  
print(frame)
```

	Col0	Col1	Col2	Col3	New column
Row0	2	16	-1	2	1
Row1	5	1	-1	9	1
Row2	-2	4	-1	-2	1
New row	5	5	3	1	1

Inserting a new column

Can also insert column at specified location using `frame.insert()`

- Takes as input insertion position, column name and column data.

```
# Insert column with name 'New column' and data [10,10,10,10] at position 2.  
frame.insert(2,'Inserted column', [10,10,10,10])  
  
print(frame)
```

	Col0	Col1	Inserted column	Col2	Col3	New column
Row0	2	16	10	-1	2	1
Row1	5	1	10	-1	9	1
Row2	-2	4	10	-1	-2	1
New row	5	5	10	3	1	1

Computing statistics of column data

Can compute properties of data like minimum, maximum, mean, etc.

```
print(frame)
```

	Col0	Col1	Inserted column	Col2	Col3	New column
Row0	2	16	10	-1	2	1
Row1	5	1	10	-1	9	1
Row2	-2	4	10	-1	-2	1
New row	5	5	10	3	1	1

```
# Minimum of the first column
```

```
min_col1 = frame.loc[:, 'Col1'].min() #Use .max()/mean() for maximum/mean  
print(min_col1)
```

Classroom exercise

```
data = [  
    [2,4,-1,2],  
    [5,1,2,9],  
    [3,7,8,9]  
]  
  
frame = pd.DataFrame(data)  
frame.index = ['Row0', 'Row1', 'Row2']  
frame.columns = ['Col0', 'Col1', 'Col2', 'Col3']
```

Create the following Pandas data frame that has an extra row with the maximum per column

	Col0	Col1	Col2	Col3
Row0	2	4	-1	2
Row1	5	1	2	9
Row2	3	7	8	9
Maximum	5	7	8	9

Importing data into Python

Data from, e.g., comma-separated values (CSV) file can be imported into Python using `read_csv()`.

```
csv_to_frame = pd.read_csv('dataset.csv')  
  
print(csv_to_frame)
```

	name	height (cm)	weight (kg)	age (years)	dietary preference
0	Aiden	185	80	23	Veggie
1	Bella	155	60	23	Veggie
2	Carlos	190	100	23	None
3	Dalia	185	85	21	None
4	Elena	160	62	19	Vegan
5	Farhan	170	75	25	None
6	Geert	178	80	25	Veggie

Data header

Python interprets first line of .csv file as header with column names for the Pandas frame.

- No header present? Set `header=None` as an additional argument in `read_csv()`.

```
csv_to_frame = pd.read_csv('dataset.csv', header=None)
print(csv_to_frame)
```

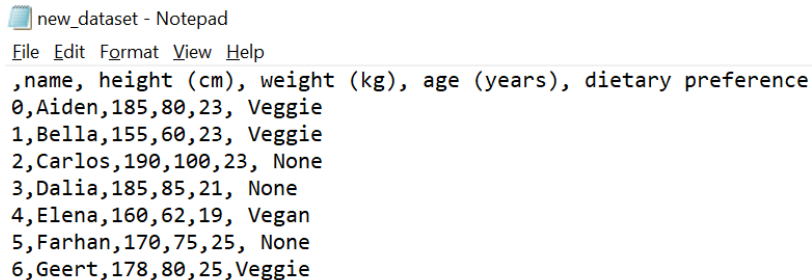
	0	1	2	3	4
	name	height (cm)	weight (kg)	age (years)	dietary preference
0	Aiden	185	80	23	Veggie
1	Bella	155	60	23	Veggie
2	Carlos	190	100	23	None
3	Dalia	185	85	21	None
4	Elena	160	62	19	Vegan
5	Farhan	170	75	25	None
6	Geert	178	80	25	Veggie

Exporting data out of Python

Can export Pandas frame to a .csv file using `to_csv()`.

```
frame.to_csv('new_dataset.csv')
```

This creates new file in same folder as Python script with the given name.



The screenshot shows a Notepad window titled 'new_dataset - Notepad'. The menu bar includes 'File', 'Edit', 'Format', 'View', and 'Help'. The text content is a CSV file with a header row and seven data rows. Each data row starts with an index from 0 to 6, followed by a name, height in cm, weight in kg, age in years, and dietary preference. The data is as follows:

	name	height (cm)	weight (kg)	age (years)	dietary preference
0	Aiden	185	80	23	Veggie
1	Bella	155	60	23	Veggie
2	Carlos	190	100	23	None
3	Dalia	185	85	21	None
4	Elena	160	62	19	Vegan
5	Farhan	170	75	25	None
6	Geert	178	80	25	Veggie

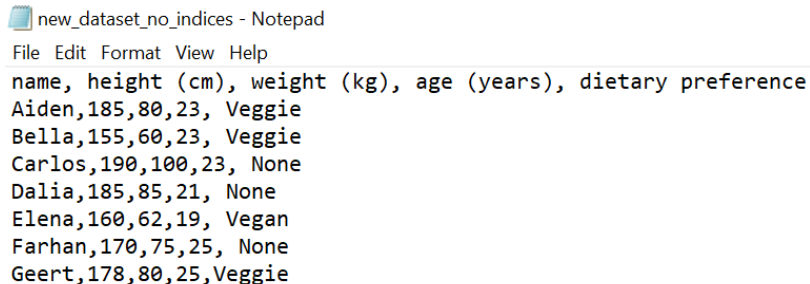
Figure 1: Exported data in .csv file (with row indices)

Suppressing row indices in exported file

By default, Python includes the row indices in the exported .csv file.

- Suppress row indices in exported file with `index=False` in `to_csv()`.

```
frame.to_csv('new_dataset.csv', index=False)
```



new_dataset_no_indices - Notepad

File Edit Format View Help

name	height (cm)	weight (kg)	age (years)	dietary preference
Aiden	185	80	23	Veggie
Bella	155	60	23	Veggie
Carlos	190	100	23	None
Dalia	185	85	21	None
Elena	160	62	19	Vegan
Farhan	170	75	25	None
Geert	178	80	25	Veggie

Figure 2: Exported data in .csv file (without row indices)

Chapter 10 - Object oriented programming

Object oriented programming

Python is structured around **objects** that contain data and on which functions can be performed.

For example,

- List: Can edit or add elements
- Data frame: Can edit or add rows/columns

Class

A **class** is a blueprint for objects of a certain type.

- Determines the **attributes** (properties) that an object has and the **methods** (functions) that can be performed on the objects.

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Data frame example

- Attributes: Column names, row names, (initial) data
- Methods: Add row, add column, rename row, rename column, compute summary statistics

Class

A **class** is a blueprint for objects of a certain type.

- Determines the **attributes** (properties) that an object has and the **methods** (functions) that can be performed on the objects.

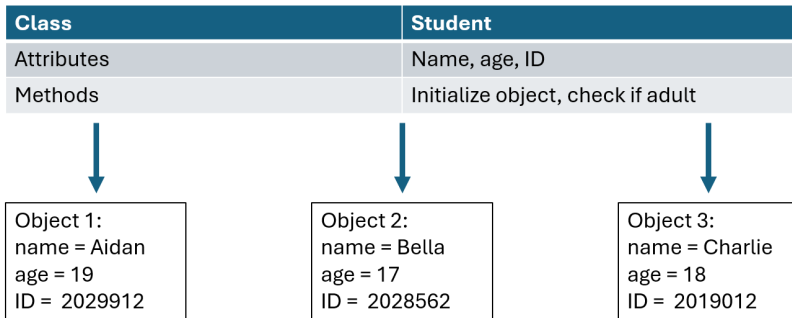
Data frame example

- Attributes: Column names, row names, (initial) data
- Methods: Add row, add column, rename row, rename column, compute summary statistics

Methods either change the attributes or yields additional information of an object.

Student example

We will create a class `Student` whose objects are students with attributes: name, age, (student) ID.



We will write a method that checks if student is an adult (≥ 18) or not.

Initializing objects

Initialization is always done with `__init__()` function.

```
class Student:
    # This function initializes an object of the class Student
    # by setting the attributes (name, age and ID) of an object.
    def __init__(self,name,age,student_number):
        self.name = name
        self.age = age
        self.ID = student_number
```

The argument `self` should be thought of as the object that we want to create.

- The use of `self` as a variable name for this is standard in Python

Methods

Methods are Python functions in a class. `__init__()` is also a method of the class.

```
class Student:
    def __init__(self,name,age,student_number):
        self.name = name
        self.age = age
        self.ID = student_number

    # Check if student is adult
    def adult(self):
        if self.age >= 18:
            return print(self.name," is an adult")
        else:
            return print(self.name,"is not an adult")
```

- Every method has first input argument `self`.
- Attribute `attribute_name` can be accessed in method using `self.attribute_name`.

Additional inputs and changing attributes

Methods can require additional input arguments beside `self`.

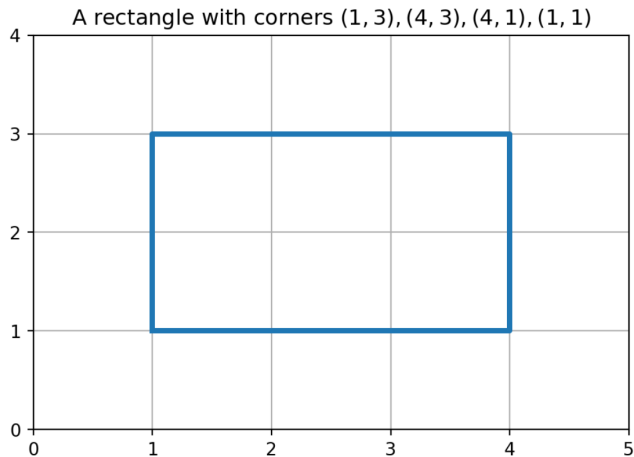
- See `reg_check()` example in course document.

Methods can be used to manipulate attributes.

- See `addCourse()/delCourse` example in course document.

Mathematical example: Rectangles

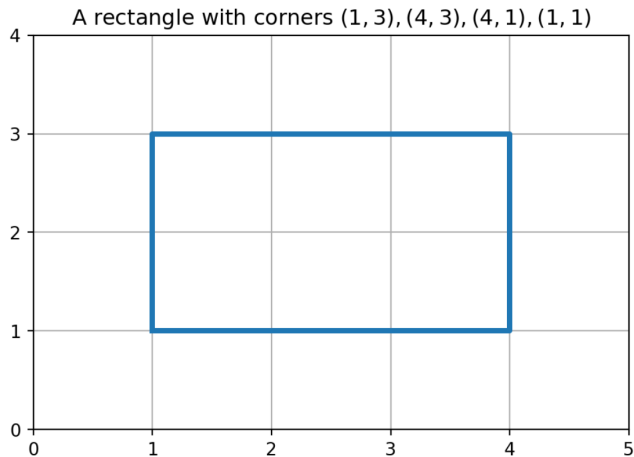
We create a class `Rectangle` whose objects are rectangles in a two-dimensional plane.



How to model a rectangle? What should the attributes be?

Mathematical example: Rectangles

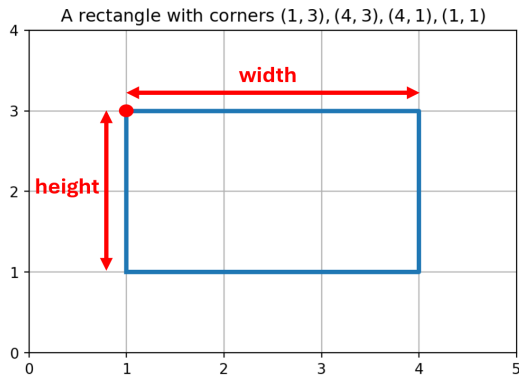
We create a class `Rectangle` whose objects are rectangles in a two-dimensional plane.



How to model a rectangle? What should the attributes be? Depends on desired methods...

Rectangle attributes

To uniquely determine a rectangle, it suffices to know: Upper-left corner point, width and height.



Rectangle __init__() method

```
class Rectangle:
    # Here corner is the upper-left corner point which
    # should be a list containing the x- and y-coordinate.
    def __init__(self, corner, height, width):
        self.corner= corner
        self.height = height
        self.width = width

rectangle1 = Rectangle([1,3],2,3)

# Print upper left corner of the rectangle
print(rectangle1.corner)
```

[1, 3]

Rectangle methods: Area and circumference

```
class Rectangle:
    # Initialize rectangle by providing upper-left corner, width and height
    def __init__(self, corner, width, height):
        self.corner = corner
        self.height = height
        self.width = width

    # Compute area = width*height of rectangle
    def area(self):
        return self.height*self.width

    # Compute circumference = 2*width + 2*height of rectangle
    def circumference(self):
        return 2*self.width + 2*self.height
```

Rectangle methods: Compute all corner points

```
class Rectangle:
    # Initialize rectangle by providing upper-left corner, width and height
    def __init__(self, corner, height, width):
        self.corner= corner
        self.height = height
        self.width = width

    # Compute corner points: the output has the points in the
    # order [upper-left, upper-right, lower-right, lower-left]
    def corners(self):
        up_right = [self.corner[0] + self.width, self.corner[1]]
        low_right=[self.corner[0]+self.width,self.corner[1]-self.height]
        low_left = [self.corner[0], self.corner[1] - self.height]
        return [self.corner, up_right, low_right, low_left]
```

Rectangle methods: Plotting

You can find the `plotting()` method in the course document. The idea is as follows:

- Determine all corner points using the `corners()` method.
- Plot the points in order: upper-left, upper-right, lower-right, lower-left, upper-left.

Rectangle methods: Plotting

You can find the `plotting()` method in the course document. The idea is as follows:

- Determine all corner points using the `corners()` method.
- Plot the points in order: upper-left, upper-right, lower-right, lower-left, upper-left.

The `plot()` function plots these five points and connects them with a line segment (resulting in a rectangle shape).

- Plot list with all x -coordinates against list with all y -coordinates of the five points.

Chapter 11 - Errors and debugging

Error types

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Logical error: Python can execute your code, but the answer is incorrect.

Syntax errors

Examples:

- Forgetting colon : in function definition
- Using non-matching quotes when defining a string
- Not using the correct indentation

Runtime errors

- `IndexError`: Index out of range
- `TypeError`: Wrong input data
- `AttributeError`: Trying to access non-existing attribute
- `ZeroDivisionError`: Trying to divide by zero

Classroom exercise

Identify (at least) four errors in the code below and fix them.

```
def total_revenue(x,k):  
    # Input: price of product x, list of daily sales k  
    # Output: x*(k[0] + k[1] + k[2] + ...)  
  
    sum = x*k[0]  
    for i in k:  
        sums += k[i]  
    retturn sum  
  
answer = total_revenue(1,1,3,2)
```

Exceptions

Can try to catch error with try-except statement. Python tries to execute piece of code, and is told what to do if error of a certain type occurs.

```
try:
    # Some code that Python should execute
    x = 5
except SomeError:
    # If an error of the type SomeError occurs
    # then do ...
    print("Is x an integer?")
except AnotherError:
    # If an error of the type AnotherError
    # occurs, then do ...
    print("Is x positive?")
```

Exceptions (example)

```
try:  
    5/0  
except ZeroDivisionError:  
    print("You cannot divided by zero.")
```

You cannot divided by zero.

Debugging (tips)

Some helpful ways to try and find mistakes in your code:

- Use `print()` statements to keep track of the value of variables in a function
- Use `assert()` to make sure certain conditions (that could cause issues) are satisfied
- Use the Spyder debugging tool.