Introduction to Python

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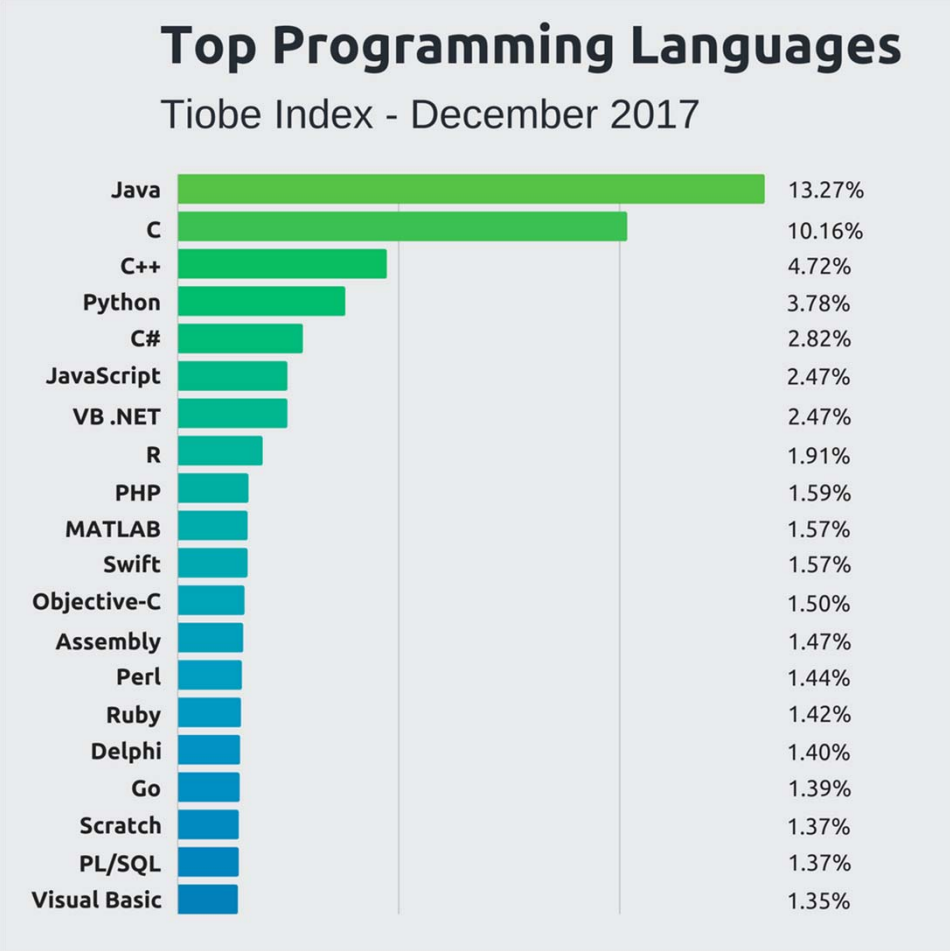
Which language to use?



- Java
  Web applications, Android
- C/C++
  Systems
- Python
  AI, Big Data, Robotics
- Fortran
  Science, Engineering

Language popularity

Very Long Term History

To see the bigger picture, please find below the positions of the top 10 programming languages of many years back. Please note that these are *average* positions for a period of 12 months.

Programming Language	2017	2012	2007	2002	1997	1992	1987
Java	1	2	1	1	15	-	-
C	2	1	2	2	1	1	1
C++	3	3	3	3	2	2	4
C#	4	5	7	11	-	-	-
Python	5	7	6	12	27	16	-
Visual Basic .NET	6	14	-	-	-	-	-
JavaScript	7	9	8	7	20	-	-
PHP	8	6	4	5	-	-	-
Perl	9	8	5	4	3	8	-
Delphi/Object Pascal	10	11	11	8	-	-	-
Lisp	31	12	15	13	8	4	2
Prolog	32	30	26	15	17	13	3

Brief History of Python

- Invented in the Netherlands, early 90s by Guido van Rossum, as a successor to ABC programming language.
- Python 2.0 was released in October 2000
- Python 3.0 was released in December 2008
- Named after Monty Python, a British surreal comedy troupe
- Open sourced from the beginning
- Considered a scripting language, but is much more
- Scalable, object oriented and functional from the beginning
- Used by Google from the beginning
- Increasingly popular

Python's Benevolent Dictator For Life

"Python is an experiment in how much freedom program-mers need. Too much freedom and nobody can read another's code; too little and expressive-ness is endangered."

- Guido van Rossum

Career:
Centrum Wiskunde & Informatica (CWI Netherlands), National Institute of Standards and Technology (NIST), Corporation for National Research Initiatives (CNRI). Zope, Elemental Security. Google, Dropbox, Microsoft.

What can Python do?

- Python can be used on a server to create web applications.
- Python can be used alongside software to create workflows.
- Python can connect to database systems. It can also read and modify files.
- Python can be used to handle big data and perform complex mathematics.
- Python can be used for rapid prototyping, or for production-ready software development.
- …

Why Python?

1. Python works on different platforms (Windows, Mac, Linux, Raspberry Pi, etc).

2. Python has a simple syntax similar to the English language.

3. Python has syntax that allows developers to write programs with fewer lines than some other programming languages.

4. Python runs on an interpreter system, meaning that code can be executed as soon as it is written. This means that prototyping can be very quick.

5. Python can be treated in a procedural way, an object-oriented way or a functional way.

Python

- Python is a high-level, dynamically typed multiparadigm programming language. Python code is often said to be almost like pseudocode, since it allows you to express very powerful ideas in very few lines of code while being very readable.
- An example: implementation of the classic quicksort algorithm

```
def quicksort(arr):
    if len(arr) <= 1:
        return arr
    pivot = arr[len(arr) // 2]
    left = [x for x in arr if x < pivot]
    middle = [x for x in arr if x == pivot]
    right = [x for x in arr if x > pivot]
    return quicksort(left) + middle + quicksort(right)

print(quicksort([3,6,8,10,1,2,1]))
```

```
[1, 1, 2, 3, 6, 8, 10]
```

A Code Sample

```
x = 34 - 23                 # A comment.
y = "Hello"                 # Another one.
z = 3.45
if z == 3.45 or y == "Hello":
    x = x + 1
    y = y + " World"        # String concat.
print(x)
print(y)
```

```
12
Hello World
```

Enough to Understand the Code

- **First assignment to a variable creates it**
  - Variable types don't need to be declared.
  - Python figures out the variable types on its own.
- **Assignment is `=` and comparison is `==`**
- **Start comments with `#`, rest of line is ignored**
- **For numbers `+ - * / %` are as expected**
  - Special use of `+` for string concatenation and `%` for string formatting (as in C's printf)
- **Logical operators are words (`and, or, not`) *not* symbols**
- **The basic printing command is `print`**

Basic Datatypes

- Like most languages, Python has a number of basic types including integers, floats, booleans, and strings.

- These data types behave in ways that are familiar from other programming languages.

Numbers

- **Integers (default for numbers)**

```
z = 5 / 2  # Answer 2, integer division
```

- **Floats**

```
x = 3.456
```

- **More examples**

- **Note that unlike many languages, Python does not have unary increment (x++) or decrement (x--)**
- **Python also has built-in types for complex numbers**

Booleans

- **Python implements all of the usual operators for Boolean logic, but uses English words rather than symbols (&&, ||, etc)**

```
t = True
f = False
```

- **Examples**

Strings

- **Python has great support for strings**
- Can use “” or ‘’ to specify with “abc” == ‘abc’
  - Unmatched can occur within the string: “matt’s”
  - Use triple double-quotes for multi-line strings or strings than contain both ‘ and “ inside of them: “““a‘b“c”””
- **String objects have a bunch of useful methods**
- **Examples**

Whitespace

Whitespace is meaningful in Python: especially indentation and placement of newlines

- Use a newline to end a line of code
  - Use `\` when must go to next line prematurely
- No braces `{}` to mark blocks of code, use *consistent* indentation instead
  - First line with *less* indentation is outside of the block
  - First line with *more* indentation starts a nested block
- Colons start of a new block in many constructs, e.g. function definitions, then clauses

Assignment

- *Binding a variable* in Python means setting a *name* to hold a *reference* to some *object*
  - *Assignment creates references, not copies*
- Names in Python do not have an intrinsic type, objects have types
  - Python determines the type of the reference automatically based on what data is assigned to it
- You create a name the first time it appears on the left side of an assignment expression:

```
x = 3
```

Naming Rules

- Names are case sensitive and cannot start with a number. They can contain letters, numbers, and underscores.

```
bob   Bob   _bob   _2_bob_   bob_2   BoB
```

- There are some reserved words:

```
and, assert, break, class, continue,
def, del, elif, else, except, exec,
finally, for, from, global, if,
import, in, is, lambda, not, or,
pass, print, raise, return, try,
while
```

Assignment

- You can assign to multiple names at the same time

```
>>> x, y = 2, 3
>>> x
2
>>> y
3
```

This makes it easy to swap values

```
>>> x, y = y, x
```

- Assignments can be chained

```
>>> a = b = x = 2
```

Accessing Non-Existent Name

Accessing a name before it's been properly created (by placing it on the left side of an assignment), raises an error

```
>>> y

Traceback (most recent call last):
  File "<pyshell#16>", line 1, in -toplevel-
    y
NameError: name 'y' is not defined
>>> y = 3
>>> y
3
```

Containers

- **Python includes several built-in container types: lists, dictionaries, sets, and tuples**

Lists

- A list is the Python equivalent of an array, but is resizeable and can contain elements of different types
- Examples

```
xs = [3, 1, 2]    # Create a list
print(xs, xs[2])  # Prints "[3, 1, 2] 2"
print(xs[-1])
xs[2] = 'foo'     # Lists can contain elements of different types
print(xs)         # Prints "[3, 1, 'foo']"
xs.append('bar')  # Add a new element to the end of the list
print(xs)         # Prints "[3, 1, 'foo', 'bar']"
x = xs.pop()
print(x, xs)
```

Slicing

- In addition to accessing list elements one at a time, Python provides concise syntax to access sublists; this is known as slicing
- Examples

```
nums = list(range(5))     # range is a built-in function that creates a list of integers
print(nums)               # Prints "[0, 1, 2, 3, 4]"
print(nums[2:4])          # Get a slice from index 2 to 4 (exclusive); prints "[2, 3]"
print(nums[2:])           # Get a slice from index 2 to the end; prints "[2, 3, 4]"
print(nums[:2])           # Get a slice from the start to index 2 (exclusive)
print(nums[:])            # Get a slice of the whole list; prints "[0, 1, 2, 3, 4]"
print(nums[:-1])          # Slice indices can be negative; prints "[0, 1, 2, 3]"
nums[2:4] = [8, 9]        # Assign a new sublist to a slice
print(nums)
```

Loops

- You can loop over the elements of a list like this

```
animals = ['cat', 'dog', 'monkey']
for animal in animals:
    print(animal)
```

- If you want access to the index of each element within the body of a loop, use the built-in “enumerate” function

```
animals = ['cat', 'dog', 'monkey']
for idx, animal in enumerate(animals):
    print('#%d: %s' % (idx + 1, animal))
```

List comprehensions

- When programming, frequently we want to transform one type of data into another.
- As a simple example, consider the following code that computes square numbers:

```
nums = [0, 1, 2, 3, 4]
squares = []
for x in nums:
    squares.append(x ** 2)
print(squares)
```

List comprehensions

- You can make this code simpler using a list comprehension

```
nums = [0, 1, 2, 3, 4]
squares = [x ** 2 for x in nums]
print(squares)
```

- List comprehensions can also contain conditions:

```
nums = [0, 1, 2, 3, 4]
even_squares = [x ** 2 for x in nums if x % 2 == 0]
print(even_squares)
```

Dictionaries

- A dictionary stores (key, value) pairs, similar to a “Map” in Java or an object in Javascript

```
d = {'cat': 'cute', 'dog': 'furry'}  # Create a new dictionary with some data
print(d['cat'])       # Get an entry from a dictionary; prints "cute"
print('cat' in d)     # Check if a dictionary has a given key; prints "True"
d['fish'] = 'wet'     # Set an entry in a dictionary
print(d['fish'])      # Prints "wet"
# print(d['monkey'])  # KeyError: 'monkey' not a key of d
print(d.get('monkey', 'N/A'))  # Get an element with a default; prints "N/A"
print(d.get('fish', 'N/A'))    # Get an element with a default; prints "wet"
del d['fish']         # Remove an element from a dictionary
print(d.get('fish', 'N/A')) # "fish" is no longer a key; prints "N/A"
```

Dictionaries

- Loops: It is easy to iterate over the keys in a dictionary

```
d = {'person': 2, 'cat': 4, 'spider': 8}
for animal in d:
    legs = d[animal]
    print('A %s has %d legs' % (animal, legs))
```

- If you want access to keys and their corresponding values, use the "items" method

```
d = {'person': 2, 'cat': 4, 'spider': 8}
for animal, legs in d.items():
    print('A %s has %d legs' % (animal, legs))
```

Sets

- A set is an unordered collection of distinct elements. As a simple example, consider the following

```
animals = {'cat', 'dog'}
print('cat' in animals)   # Check if an element is in a set; prints "True"
print('fish' in animals)  # prints "False"
animals.add('fish')       # Add an element to a set
print('fish' in animals)  # Prints "True"
print(len(animals))       # Number of elements in a set; prints "3"
animals.add('cat')        # Adding an element that is already in the set does nothing
print(len(animals))       # Prints "3"
animals.remove('cat')     # Remove an element from a set
print(len(animals))       # Prints "2"
```

Sequence Types

1. **Tuple: ('john', 32, [CMSC])**
   - A simple *immutable* ordered sequence of items
   - Items can be of mixed types, including collection types
2. **Strings: "John Smith"**
   - *Immutable*
   - Conceptually very much like a tuple
3. **List: [1, 2, 'john', ('up', 'down')]**
   - *Mutable* ordered sequence of items of mixed types

Similar Syntax

- All three sequence types (tuples, strings, and lists) share much of the same syntax and functionality.
- Key difference:
  - Tuples and strings are *immutable*
  - Lists are *mutable*
- The operations shown in this section can be applied to *all* sequence types
  - most examples will just show the operation performed on one

Sequence Types 1

- Define tuples using parentheses and commas

```
>>> tu = (23, 'abc', 4.56, (2,3), 'def')
```

- Define lists are using square brackets and commas

```
>>> li = ["abc", 34, 4.34, 23]
```

- Define strings using quotes (", ', or """).

```
>>> st = "Hello World"
>>> st = 'Hello World'
>>> st = """This is a multi-line
string that uses triple quotes."""
```

Sequence Types 2

- Access individual members of a tuple, list, or string using square bracket “array” notation
- *Note that all are 0 based…*

```
>>> tu = (23, ‘abc’, 4.56, (2,3), ‘def’)
>>> tu[1]     # Second item in the tuple.
 ‘abc’

>>> li = [“abc”, 34, 4.34, 23]
>>> li[1]      # Second item in the list.
 34

>>> st = “Hello World”
>>> st[1]   # Second character in string.
 ‘e’
```

Positive and negative indices

```
>>> t = (23, 'abc', 4.56, (2,3), 'def')
```

Positive index: count from the left, starting with 0

```
>>> t[1]
'abc'
```

Negative index: count from right, starting with –1

```
>>> t[-3]
4.56
```

Slicing: return copy of a subset

```
>>> t = (23, 'abc', 4.56, (2,3), 'def')
```

Return a copy of the container with a subset of the original members. Start copying at the first index, and stop copying *before* second.

```
>>> t[1:4]
('abc', 4.56, (2,3))
```

Negative indices count from end

```
>>> t[1:-1]
('abc', 4.56, (2,3))
```

Slicing: return copy of a =subset

```
>>> t = (23, 'abc', 4.56, (2,3), 'def')
```

Omit first index to make copy starting from beginning of the container

```
>>> t[:2]
(23, 'abc')
```

Omit second index to make copy starting at first index and going to end

```
>>> t[2:]
(4.56, (2,3), 'def')
```

Copying the Whole Sequence

- [:] makes a *copy* of an entire sequence

```
>>> t[:]
(23, ‘abc’, 4.56, (2,3), ‘def’)
```

The ‘in’ Operator

- Boolean test whether a value is inside a container:

```
>>> t = [1, 2, 4, 5]
>>> 3 in t
False
>>> 4 in t
True
>>> 4 not in t
False
```

- For strings, tests for substrings

```
>>> a = 'abcde'
>>> 'c' in a
True
>>> 'cd' in a
True
>>> 'ac' in a
False
```

- Be careful: the *in* keyword is also used in the syntax of *for loops* and *list comprehensions*

The + Operator

The + operator produces a *new* tuple, list, or string whose value is the concatenation of its arguments.

```
>>> (1, 2, 3) + (4, 5, 6)
 (1, 2, 3, 4, 5, 6)

>>> [1, 2, 3] + [4, 5, 6]
 [1, 2, 3, 4, 5, 6]

>>> “Hello” + “ ” + “World”
 ‘Hello World’
```

The * Operator

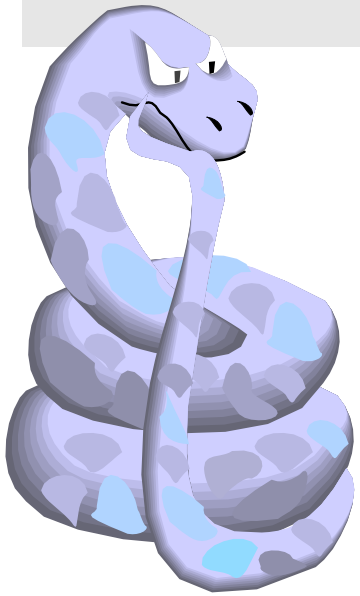
- The * operator produces a *new* tuple, list, or string that “repeats” the original content.

```
>>> (1, 2, 3) * 3
(1, 2, 3, 1, 2, 3, 1, 2, 3)

>>> [1, 2, 3] * 3
[1, 2, 3, 1, 2, 3, 1, 2, 3]

>>> “Hello” * 3
‘HelloHelloHello’
```

Mutability: Tuples vs. Lists



Lists are mutable

```
>>> li = ['abc', 23, 4.34, 23]
>>> li[1] = 45
>>> li
  ['abc', 45, 4.34, 23]
```

- We can change lists *in place.*
- Name *li* still points to the same memory reference when we're done.

Tuples are immutable

```
>>> t = (23, ‘abc’, 4.56, (2,3), ‘def’)
>>> t[2] = 3.14

Traceback (most recent call last):
  File "<pyshell#75>", line 1, in -toplevel-
    tu[2] = 3.14
TypeError: object doesn't support item assignment
```

- You can’t change a tuple.
- You can make a fresh tuple and assign its reference to a previously used name.

```
>>> t = (23, ‘abc’, 3.14, (2,3), ‘def’)
```

- *The immutability of tuples means they’re faster than lists.*

Operations on Lists Only

```
>>> li = [1, 11, 3, 4, 5]

>>> li.append('a')  # Note the method
  syntax
>>> li
[1, 11, 3, 4, 5, 'a']

>>> li.insert(2, 'i')
>>>li
[1, 11, 'i', 3, 4, 5, 'a']
```

The *extend* method vs +

- + creates a fresh list with a new memory ref
- *extend* operates on list `li` in place.

```
>>> li.extend([9, 8, 7])
>>> li
[1, 2, 'i', 3, 4, 5, 'a', 9, 8, 7]
```

- *Potentially confusing*:
  - *extend* takes a list as an argument.
  - *append* takes a singleton as an argument.

```
>>> li.append([10, 11, 12])
>>> li
[1, 2, 'i', 3, 4, 5, 'a', 9, 8, 7, [10,
  11, 12]]
```

Operations on Lists Only

Lists have many methods, including index, count, remove, reverse, sort

```
>>> li = ['a', 'b', 'c', 'b']
>>> li.index('b')  # index of 1st occurrence
1
>>> li.count('b')  # number of occurrences
2
>>> li.remove('b') # remove 1st occurrence
>>> li
  ['a', 'c', 'b']
```

Operations on Lists Only

```
>>> li = [5, 2, 6, 8]

>>> li.reverse()    # reverse the list *in place*
>>> li
  [8, 6, 2, 5]

>>> li.sort()       # sort the list *in place*
>>> li
  [2, 5, 6, 8]

>>> li.sort(some_function)
    # sort in place using user-defined comparison
```

Tuple details

- The **comma** is the tuple creation operator, not parens

```
>>> 1,
(1,)
```

- Python shows parens for clarity (best practice)

```
>>> (1,)
(1,)
```

- Don't forget the comma!

```
>>> (1)
1
```

- Trailing comma only required for singletons others

Summary: Tuples vs. Lists

- Lists slower but more powerful than tuples
  - Lists can be modified, and they have lots of handy operations and mehtods
  - Tuples are immutable and have fewer features
- To convert between tuples and lists use the list() and tuple() functions:

```
li = list(tu)
tu = tuple(li)
```

Functions

- Python functions are defined using the “def” keyword.

```
def sign(x):
    if x > 0:
        return 'positive'
    elif x < 0:
        return 'negative'
    else:
        return 'zero'

for x in [-1, 0, 1]:
    print(sign(x))
# Prints "negative", "zero", "positive"
```

Numpy

- **Numpy** is the core library for scientific computing in Python.
- It provides a high-performance multidimensional array object, and tools for working with these arrays.
- Arrays: A numpy array is a grid of values, all of the same type, and is indexed by a tuple of nonnegative integers. The number of dimensions is the ***rank*** of the array; the ***shape*** of an array is a tuple of integers giving the size of the array along each dimension

Arrays

- We can initialize numpy arrays from nested Python lists, and access elements using square brackets:

```
import numpy as np

a = np.array([1, 2, 3])   # Create a rank 1 array
print(type(a))            # Prints "<class 'numpy.ndarray'>"
print(a.shape)            # Prints "(3,)"
print(a[0], a[1], a[2])   # Prints "1 2 3"
a[0] = 5                  # Change an element of the array
print(a)                  # Prints "[5, 2, 3]"

b = np.array([[1,2,3],[4,5,6]])    # Create a rank 2 array
print(b.shape)                     # Prints "(2, 3)"
print(b[0, 0], b[0, 1], b[1, 0])   # Prints "1 2 4"
```

Arrays

- Numpy also provides many functions to create arrays:

```
import numpy as np

a = np.zeros((2,2))
print(a)
b = np.ones((1,2))
print(b)
c = np.full((2,2), 7)
print(c)
d = np.eye(2)
print(d)
e = np.random.random((2,2))
print(e)
```

Arrays: Datatypes

- Every numpy array is a grid of elements of the same type. Numpy provides a large set of numeric datatypes that you can use to construct arrays. Numpy tries to guess a datatype when you create an array, but functions that construct arrays usually also include an optional argument to explicitly specify the datatype.

```
import numpy as np

x = np.array([1, 2])   # Let numpy choose the datatype
print(x.dtype)         # Prints "int64"
x = np.array([1.0, 2.0])   # Let numpy choose the datatype
print(x.dtype)             # Prints "float64"

x = np.array([1, 2], dtype=np.int64)   # Force a particular datatype
print(x.dtype)                         # Prints "int64"
```

Arrays: math

- Basic mathematical functions operate elementwise on arrays, and are available both as operator overloads and as functions in the numpy module

```
import numpy as np

x = np.array([[1,2],[3,4]], dtype=np.float64)
y = np.array([[5,6],[7,8]], dtype=np.float64)
print(x + y)
print(np.add(x, y))
print(x - y)
print(np.subtract(x, y))
print(x * y)
print(np.multiply(x, y))
print(x / y)
print(np.divide(x, y))
print(np.sqrt(x))
```

Arrays: math

- * is elementwise multiplication, not matrix multiplication.
- .dot function to compute inner product of vectors, to multiply a vector by a matrix, and to multiply matrices

```
import numpy as np

x = np.array([[1,2],[3,4]])
y = np.array([[5,6],[7,8]])
v = np.array([9,10])
w = np.array([11, 12])
print(v.dot(w))
print(np.dot(v, w))
print(x.dot(v))
print(np.dot(x, v))
print(x.dot(y))
print(np.dot(x, y))
```

Arrays: math

- Numpy provides many useful functions for performing computations on arrays

```
import numpy as np

x = np.array([[1,2],[3,4]])


print(np.sum(x))  # Compute sum of all elements; prints "10"
print(np.sum(x, axis=0))  # Compute sum of each column; prints "[4 6]"
print(np.sum(x, axis=1))  # Compute sum of each row; prints "[3 7]“

print(x)
print(x.T)
```

Matplotlib

- **Matplotlib** is a plotting library. `matplotlib.pyplot` provides a plotting system similar to that of MATLAB.
- The most important function in matplotlib is “plot”, which allows you to plot 2D data

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

# Compute the x and y coordinates for points on a sine curve
x = np.arange(0, 3 * np.pi, 0.1)
y = np.sin(x)

# Plot the points using matplotlib
plt.plot(x, y)
plt.show()  # You must call plt.show() to make graphics appear.
```

Plotting

- With just a little bit of extra work we can easily plot multiple lines at once, and add a title, legend, and axis labels

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

x = np.arange(0, 3 * np.pi, 0.1)
y_sin = np.sin(x)
y_cos = np.cos(x)
# Plot the points using matplotlib
plt.plot(x, y_sin)
plt.plot(x, y_cos)
plt.xlabel('x axis label')
plt.ylabel('y axis label')
plt.title('Sine and Cosine')
plt.legend(['Sine', 'Cosine'])
plt.show()
```