Introduction to programming in Python

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Robot Programming and Simulation

2021

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What is Python?

Python

A powerful dynamic programming language, useful in a wide variety of application domains.

- dynamic
- interpreted
- object-oriented
- extensive ecosystem of 3rd party libraries
- extensible, easily integrated with C
- portable
- developed by Guido van Rossum (a mathematician)

Bottom line

Faster code development, easier maintenance.

Who uses Python and why?

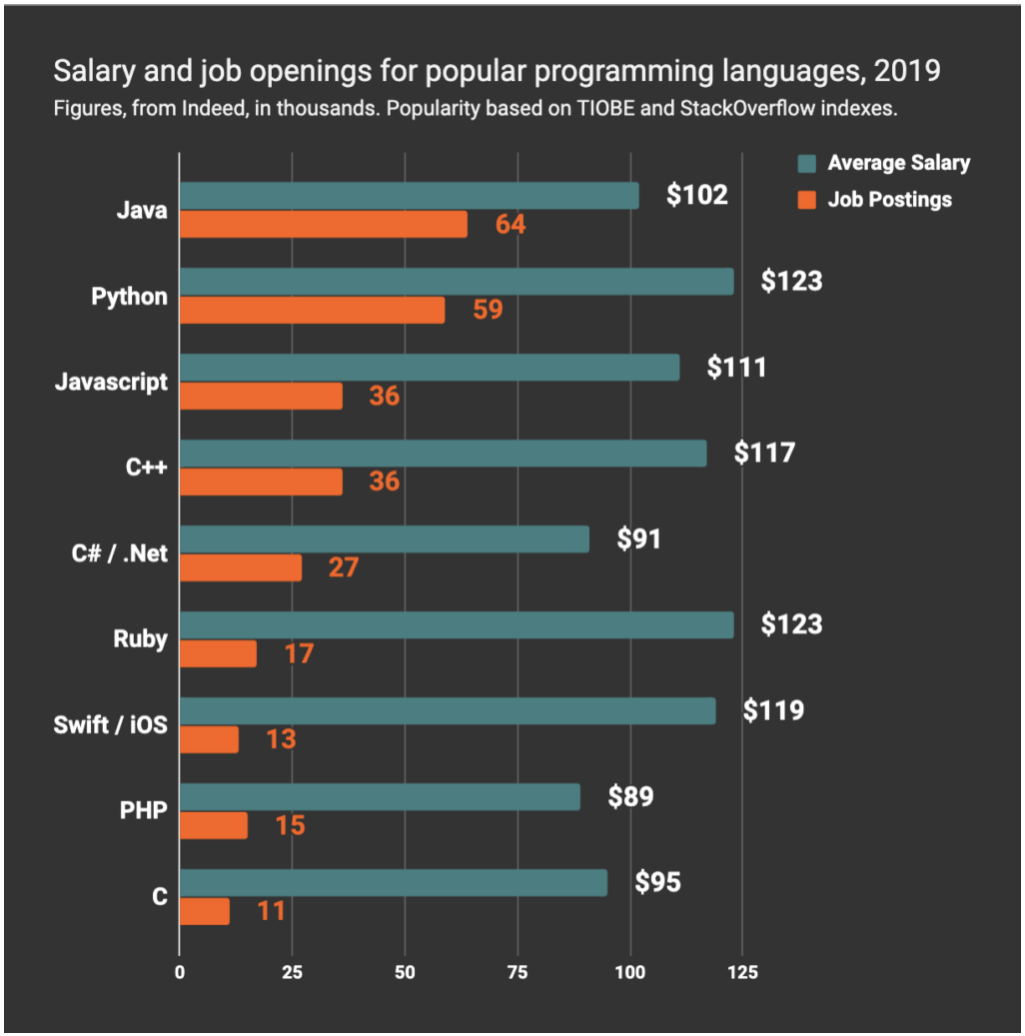
Python users

- Google (Search, YouTube,...)
- NASA (Integrated planning system)
- IBM
- Autodesk (Maya)

What is Python good for?

- Scripting, "Glue logic", prototyping
- Scientific and Numeric Computing (NumPy, SciPy)
- Machine learning and AI (scikit-learn, PyTorch)
- Network and web programming (Django, Flask)
- Games (Sims4, World of Tanks)

Why should I bother learning Python?



Source: Code Platoon

Installing Python

- On Linux, Python is already installed :)
- Binary installers exist for Windows

Python 2.7 or 3.x

- 3.x is actively developed, default in Ubuntu Focal/ROS Noetic
- 2.7 is officially EOL, but still used in Ubuntu Bionic/ROS Melodic

Using Python interactively

Starting an interactive Python session:

```
user@host:~$ python
>>> 5+7
12
>>>
```

The interactive shell

Python is interpreted, so we can try things out interactively.

Numbers and booleans

```
>>> a = 3
>>> 3**a
>>> 3/2; 3.0/2
>>> b = (a+2)*7
>>> b = -7
>>> a > b
>>> a | True
>>> not True
```

Strings

Strings in Python are a fundamental data type.

```
>>> s1 = 'feeble '; s2="humans"
>>> greeting = s1+s2
>>> len(greeting)
>>> s1*5
>>> greeting.replace('a','HAHAHAHA')
>>> greeting
>>> shout = greeting.upper()
```

Useful information

- Everything in Python is an object
- Objects have functions[1] that operate on their data
  ```
  >>> shout.lower()
  ```
- Listing all functions belonging to an object
  ```
  >>> dir(shout)
  ```
- Getting help on any function
  ```
  >>> help(shout.lower)
  ```
- Objects can be mutable or immutable ("constant")
  ```
  >>> shout[3] = 'c'
  ```

[1] functions belonging to objects are sometimes called methods

String formatting

f-Strings (recommended):

```
>>> f"The {'meaning'} of life is {42}"
```

Formatting method calls:

```
>>> "Six by {0}. Fourty {1}".format('nine', 2)
```

Formatting expressions (legacy):

```
>>> "Six by %s. Fourty %d" % ('nine', 2)
```

Exercise

Create the variables `name`, `surname`, `age`, containing your respective personal information, with all small letters. Using the variables `name` and `surname` and appropriate functions, create a new variable `full_name` which contains your full name, correctly capitalized. Using all three of the above methods and the variables `full_name` and `age`, create the string `hello` with a sentence that introduces you, e.g. `"Hello, I'm Arthur Dent and I'm 42 years old"`.

Dynamic typing and references (Part I)

Variables are only named references to objects!

```
>>> a = 3
>>> b = a
>>> a = 'spam'
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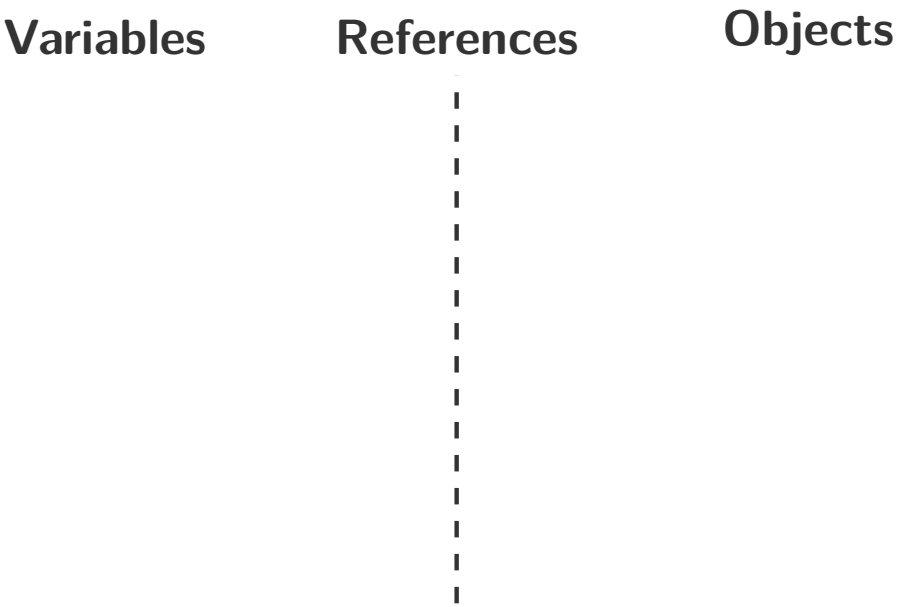

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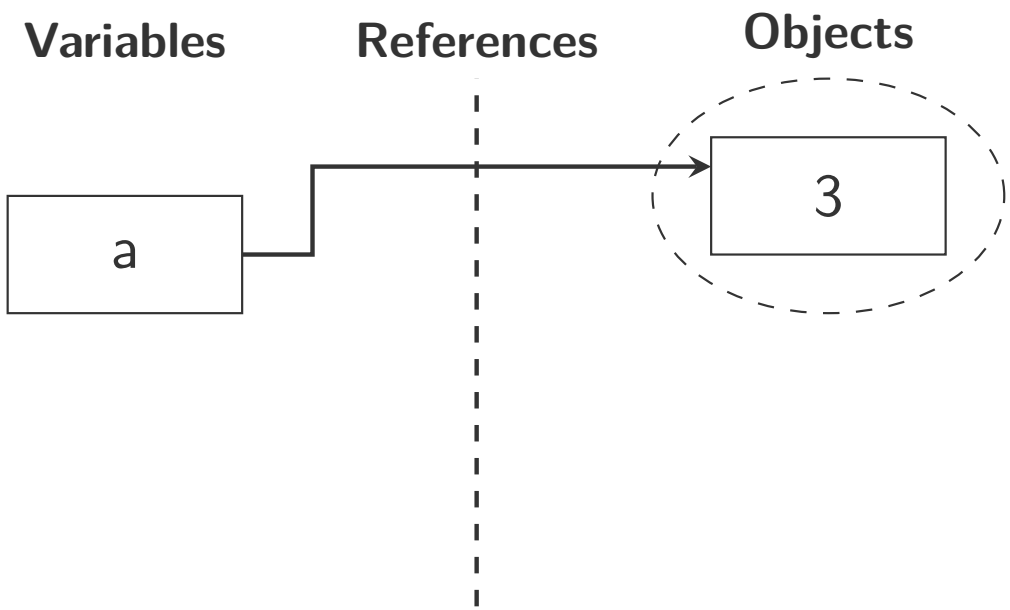

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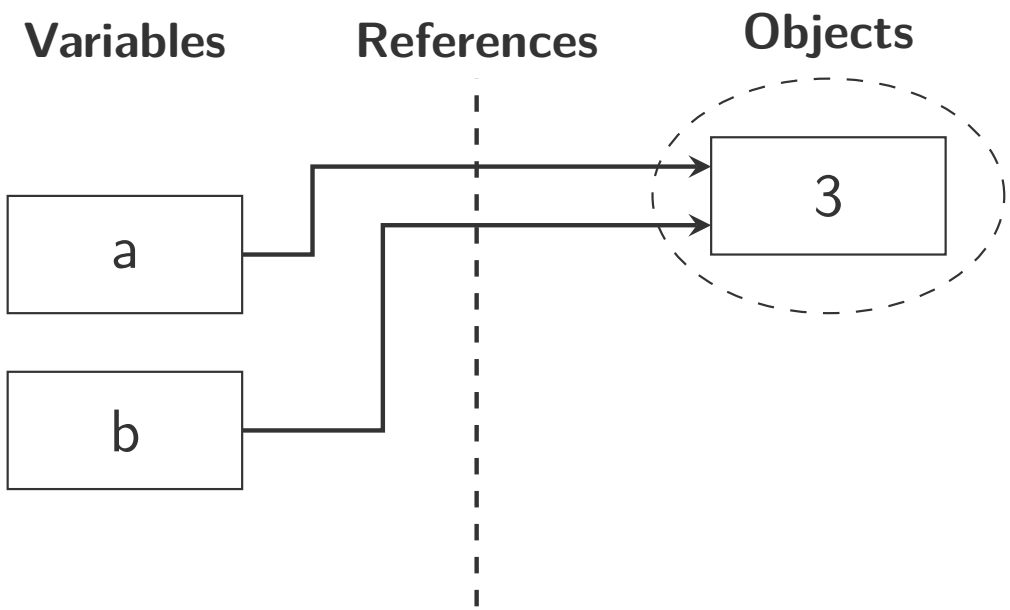

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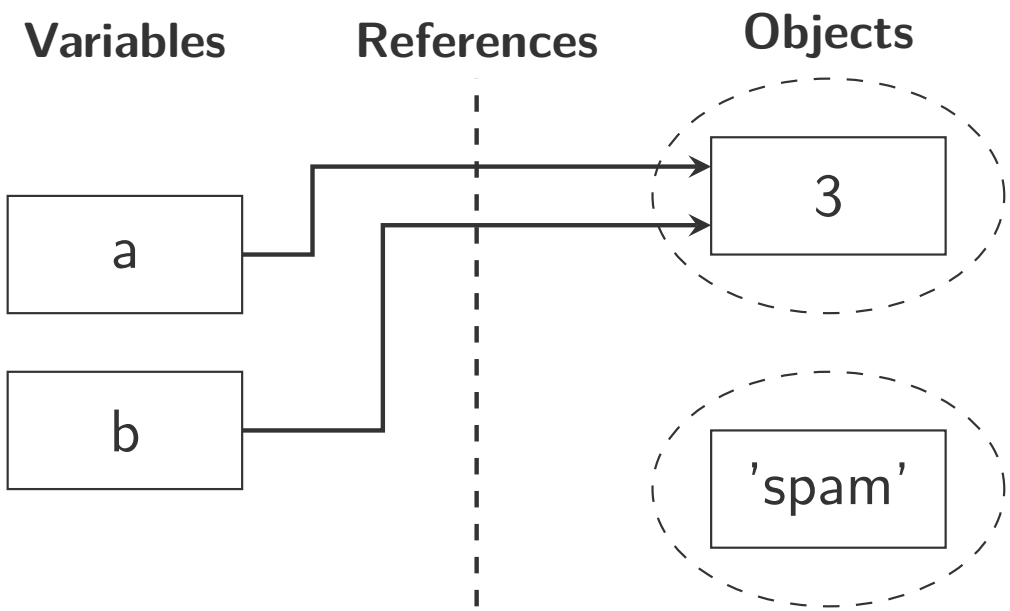

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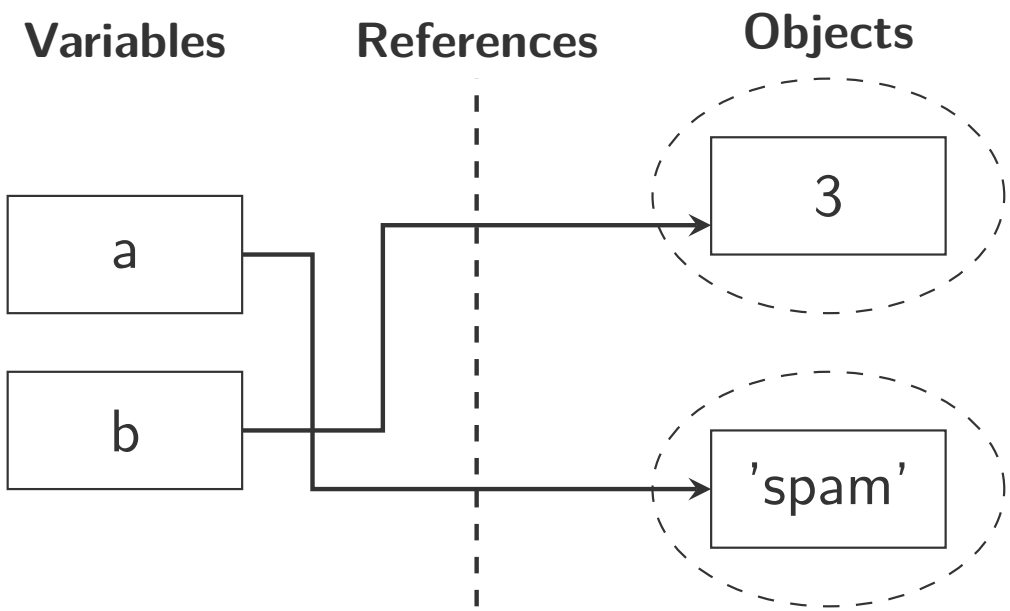

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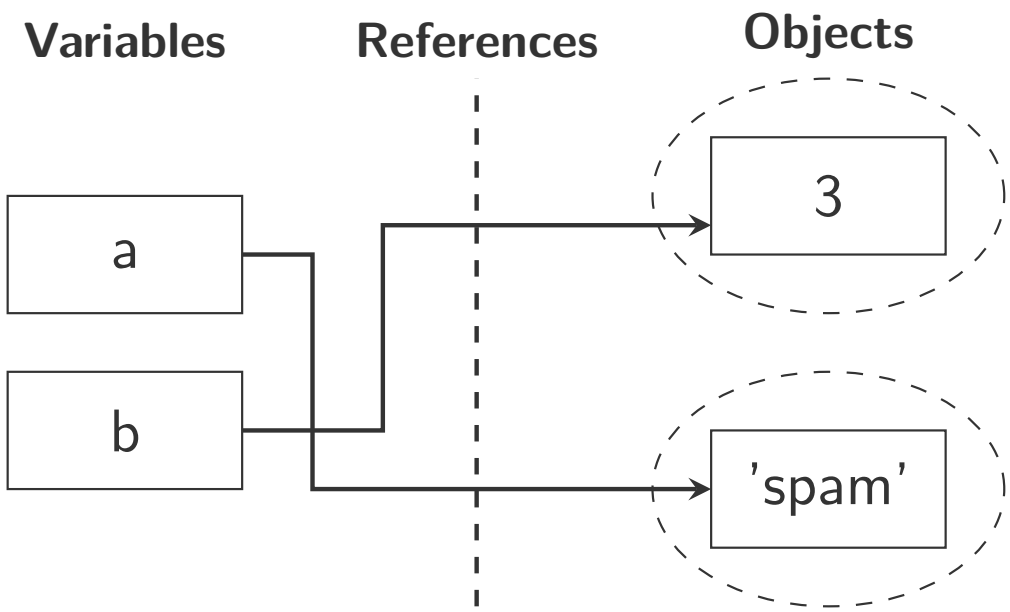


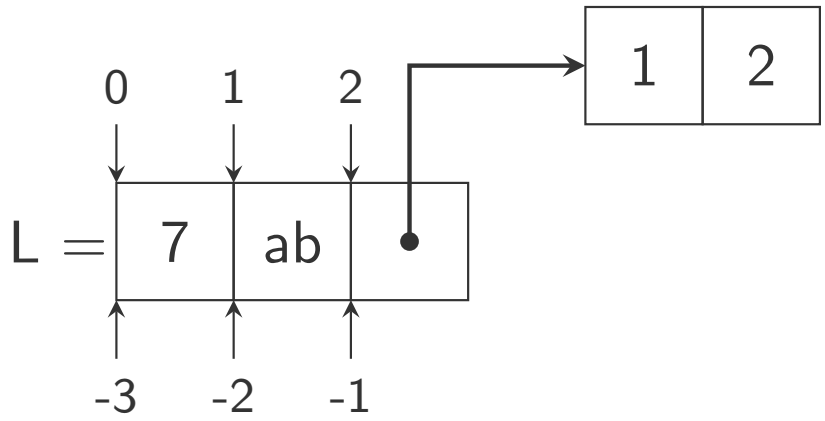
Note

- Variable types are never declared
- Different datatypes can be assigned to the same variable!
- Integers, floats, booleans and strings are immutable types

Lists

- Ordered collections of arbitrary objects, accessed by offset (index)

```
L = [7,'ab',[1,2]]
L[1]; L[-1][0];
L[1:-1]; L[1:] # Slicing!
L[1] = 3.14
len(L)
L.remove(7)
L.extend([-3,22,-0.1])
```



Exericses

1. What effect do arithmetic operators like '+' and '*' have on lists?
2. Try different slicing options, e.g., [:5], [-1:3], ...
3. Insert [0.17, 'c', 12] into L as individual elements.

Dynamic tpying and references (Part II)

Lists are mutable. This, combined with the "variables are references" semantics has non-obvious side-effects.

A quick experiment:

```
>>> L1 = ['a','b','c']
>>> L2 = L1
>>> L2[1] = 17
>>> print(L1)
```

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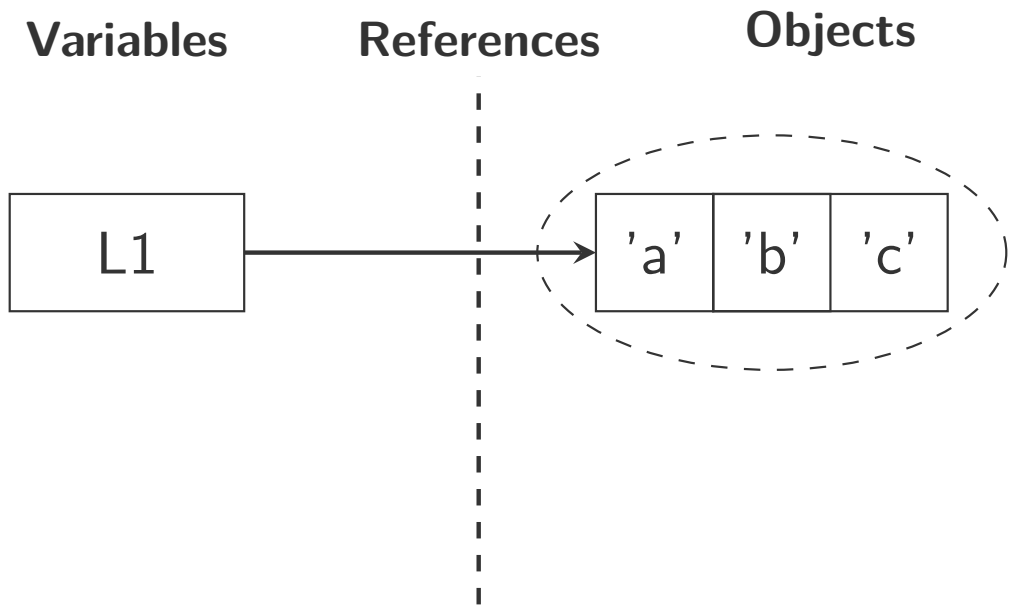

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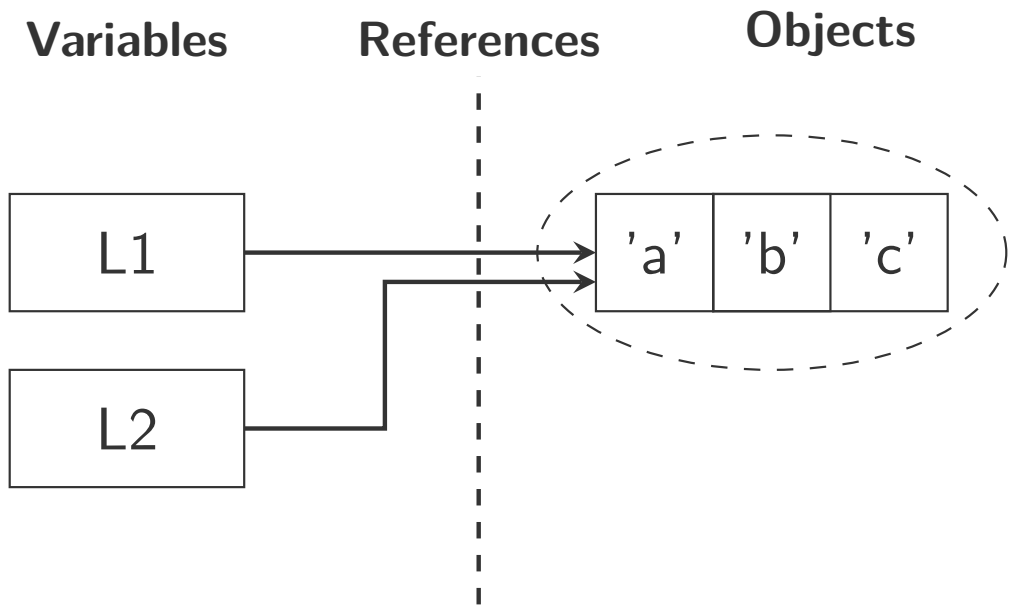

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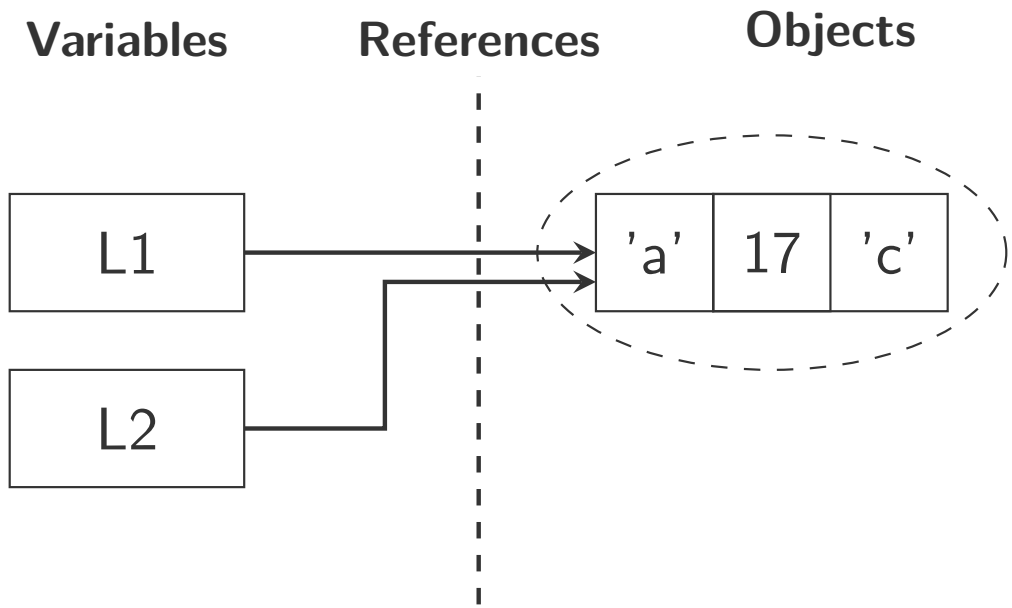

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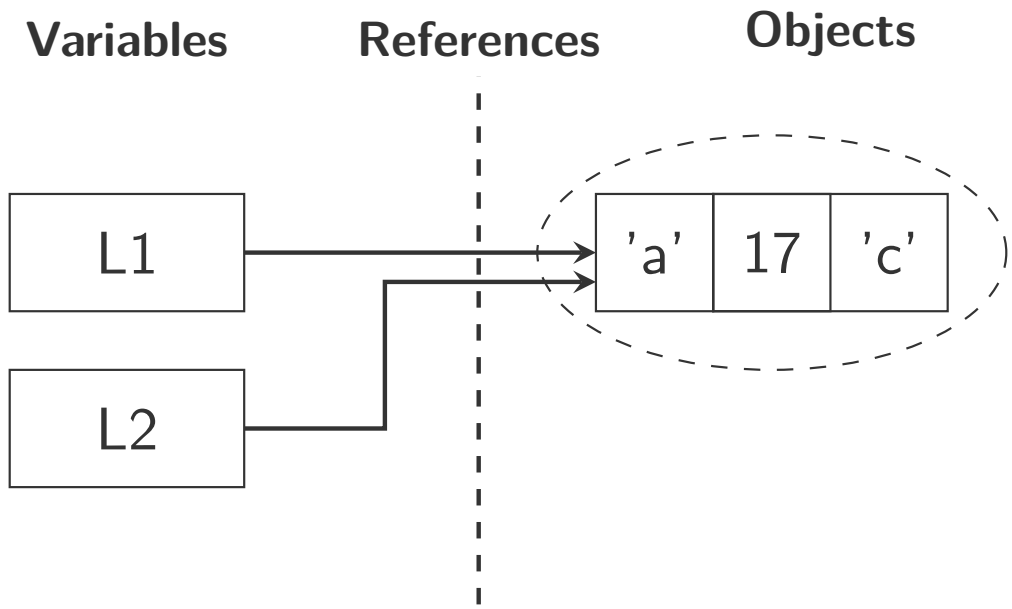

Notes

- Lists are mutable!
- Objects in Python are garbage collected!

Safely copying mutable objects

```
>>> L2 = L1[:]
>>> L2 = L1.copy() # Python >= 3.3
>>> import copy
>>> L2 = copy.copy(L); L2[0] = 0; L2[1][0] = 0
>>> L3 = copy.deepcopy(L); L3[0] = 3; L3[1][0] = 'L3'
```

Safe copying

The slicing operator `[:]` and `copy.copy()` are safe only for "flat" objects. For nested objects (e.g. lists containing lists), use `copy.deepcopy()`.

Quitting the shell:

```
$ exit()
```

or press `Ctrl-D` (EOF)

List exercises

Exercise: List indexing

Using the list `L=[1,2,5,6,9,10]`

1. Create a new list, `L2`, containing all the numbers from `1` to `10`, in sequential order, using the `list.insert` method
2. Same as the above, but using list arithmetic (slicing and the `+` operator)
3. Same as the above, but using `list.append` and `list.sort` methods
4. Demonstrate three ways of creating a new list `L3`, containing the first three elements of `L2`

How to run Python programs?

Our first Python program:

```
$ mkdir -p ~/psr/python
$ cd ~/psr/python
$ gedit helloworld.py &
```

```
print("I'll be back!")
```

```
$ python helloworld.py
```

Modules

A text file, with extension .py, containing Python code

```
"""
This is a docstring.
Python can automatically generate documentation from it.
"""

print("I'll be back!")

# This is a block comment. Use comments in your code!
# Below, we do some vector arithmetic.
v1 = [1,2,3]
v1x2 = 2*v1

print('2*{0}={1}'.format(v1,v1x2) )          # Inline comment.
```

for loops

Tip

Set up your editor options to insert spaces instead of tabs!

- Looping over a sequence

```
v1x2 = []
for x in v1:
    v1x2.append(2*x)
```

- Indentation delimits blocks of code (no {})
- Iterator pattern: no need to generate indexes explicitly!
- If we really need indexes[2], there's the `range()` function

```
for i in range(len(v1)):
    v1[i] += 1
```

[2] The only time we really need indexes is when we're modifying the list in-place

List Comprehensions

- Powerful combination of lists and for loops
- List comprehensions are used for generating lists quickly
  `v1pow2 = [x**2 for x in v1]`
- Much faster than for loops!
- Lists can be combined using the `zip` command
  `v2 = [x+y for (x,y) in zip(v1,v1x2)]`
- The `(x,y)` object is a tuple, which is an immutable list

Exercise

Implement the dot product of two lists: $\mathbf{x} \cdot \mathbf{y} = \sum_{i=1}^{n} x_i y_i$

Files, iterators and for loops

```
$ gedit fileio.py &
```

- Files are elementary data types in Python
- Writing to a text file

```
output = open('myfile.txt', 'w')
output.write('A nice, blank file!\n')
output.write(str(42))
output.close()
```

- Reading from a text file (iterator pattern, again)

```
for line in open('myfile.txt', 'r'):
    print(2*line)
```

- Read and write methods always work on strings!
- There are safer ways of accessing files using `with`/`as` context managers

while loops, if tests and user input

```
$ gedit volume.py &
```

- Looping over an unknown number of iterations

```
num = 1
while num != 0:
  num = input('Enter the side length: ')
  if num > 1000:
    print('{0} is Too big for me!'.format(num))
  else:
    print('{0}^3 = {1}'.format(num,num**3))
```

- Don't forget the colons :)

Exercises: loops and file I/O

Exercise: User input and writing to a file

Create a script which lets the user input a sequence of numbers, one by one, until the number 0 is entered. Store the numbers in a list. After user input has been finished, compute the sum of the sequence (you can use the built-in `sum` function). Open the file `sequence.txt` for writing and write the original sequence of numbers on the first line, separated by a single space. Write the computed sum on the second line and close the file.

Exercise: Reading from a file and list comprehensions

Open the file `sequence.txt` for reading and read the first two lines. Convert the first line to a list of floating point numbers using the `split` method, `float` function and a list comprehension. Convert the second line to a floating point number. Check if the number on the second line corresponds to the sum of numbers on the first line. Print the result.

Functions

```
$ gedit func.py &
```

- The basic tool for code reuse
- Defined with a def statement

```
def add(x, y):
        """ Returns x+y """
        return x+y
print(add(5,3))
```

- Inherent polymorphism!

```
add('Py', 'thon')
```

Arrays as function arguments

```
$ gedit plusone.py &
```

```
def plusone(vin):
        """ Increments the input vector by one """
        for (i,x) in enumerate(vin):
            vin[i] = x+1
        return vin

if __name__ == '__main__':
        v = [1,2,3]
        v1 = plusone(v)
        dv = [y-x for (x,y) in zip(v,v1)]
        print(dv)
```

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        v = [1,2,3]
        v1 = plusone(v)
        dv = [y-x for (x,y) in zip(v,v1)]
        print(dv)
```

Passing arrays to functions

Remember, in Python, all objects are passed by reference!

Function scoping rules

Scoping rules

Local – Enclosing – Global – Builtin

- Global scope is visible everywhere
- Local scope overrides global scope

```
X = 7; Y = 17 #Global scope
def printer():
        X = 0  #Local scope
        print(X,Y)
```

- Builtin names can be overriden[3]

```
def override(L):
        len = 7
        print(len(L))
override([1,2,3])
```

[3] Which is almost never what you intended to do :)

Advanced function concepts

- Arguments can be passed by name and have defaults

```
def power(x, y = 0):
        """Returns x^y"""
        return x**y
power(y = 3, x = 2)
```

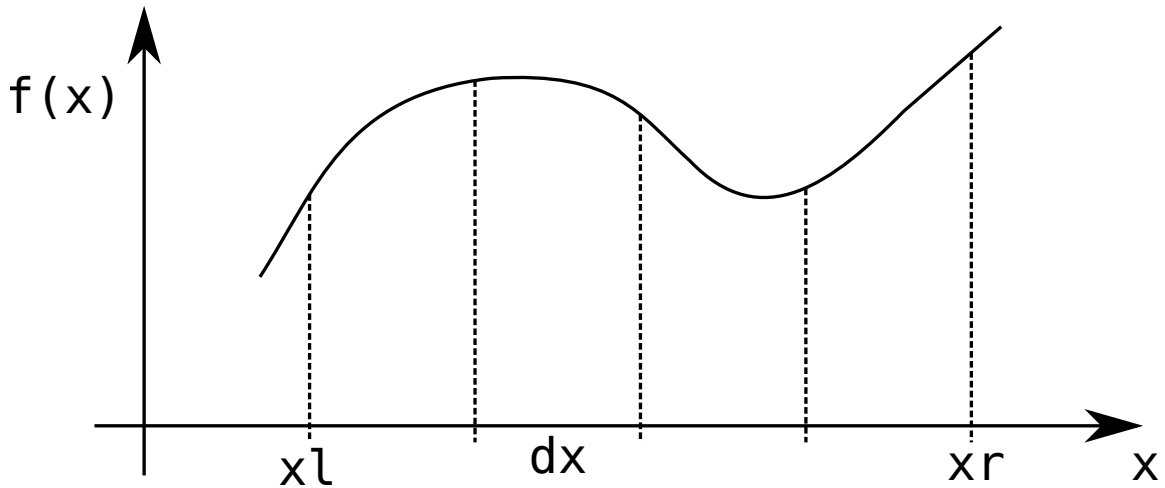
- In Python, everything is an object, including functions
- Like all objects, functions can be assigned (=> Function pointer!)

```
g = power
print(g(2,3))
```

Function "pointer" exercise

Exercise: Function "pointer"

Write a function that performs simple one-dimensional numerical integration, using constant function approximation. The prototype is `def integral(f,xl,xr,dx)`. To test your code, compute $\int_2^4 x^2 dx$ and $\int_0^{3.14} \sin(x) dx$ with step `dx` $= 0.001$; the results should be close to 18.667 and 2 respectively. (Hint: You will need `from math import sin` and `def sq(x)`.)



Function design concepts

- Use functions :)
- Keep functions as simple as possible (one function, one purpose)
- Don't use global variables
- Use arguments for inputs and return values for outputs
- Watch out for mutable arguments!
- "Black box design"
- Write docstrings!

Module organization

Modules have two use-cases:

- "Direct execution" of code
- Importing of code (like including header files in C)

```
# Class and function definitions
# That can be imported by other modules
def add(x,y):
    """ Returns x+y """
    return x+y

if __name__ == '__main__':
    # This code is not executed
    # When the module is imported
    print(add(5,7))
```

Importing code from modules

- Importing executes the module[4]
- Objects defined within the module become available in the current context
- We can import all objects from a module

```
>>> import func
>>> func.add(12,-3)
```

- Or a specific object

```
>>> from func import add
>>> add(3,4)
```

- Imported modules are not updated automatically when the source changes!
- The help function shows the docstring

```
>>> help(add)
```

[4] Remember, Python is interpreded!

Making python scripts executable

Allows us to execute Python programs as shell scripts.

1. Add the shebang[5] line

```
#!/usr/bin/env python
# -*- coding: utf-8 -*-
```

(the second line allows us to use non-ascii characters)

2. Make the script executable

```
$ chmod +x func.py
$ ./func.py
```

[5] shebang = hash(#) + bang(!)

Python libraries

Standard library modules

- Mathematical modules: math, cmath, fractions
- Time and date representations: datetime, calendar
- Operating system interface: os, sys
- Interprocess communication: socket, ssl, asyncore
- Dozens of others...

Third party modules

- Scientific computing tools: NumPy, Matplotlib, SciPy
- Graphics, UI, multimedia: PyGame
- Interprocess communication: ZeroMQ
- Thousands of others...

IPython: a user-friendly shell (and more)

- install IPython

```
$ sudo apt install ipython
```

- start IPython (a Matlab-like shell)

```
$ ipython
In[1]:
```

- getting help

```
In[2]: ?len
```

- supports *tab completion*, *command history* and much more
- For a Matlab like experince, invoke with the `-pylab` option

```
$ ipython --pylab
```

- for more info, check out the tutorial

IPython basics

- Running python code

```
In[3]: run func
```

- All objects from global scope are available in the workspace

```
In[4]: add(4,-3)
```

- Start debugging on error

```
In[5]: pdb on
In[6]: run scoping.py
```

- Reloads modules automatically
- Behavior is configurable through scripts in `/.ipython`

Troubleshooting whitespace issues

Whitespace issues

Python is picky about whitespace. The **Draw Spaces** plugin for the *gedit* editor can help you troubleshoot whitespace issues e.g. when you get some code which has tabs and spaces mixed together.

```
$ sudo apt install gedit-plugins
```

Activatig the **Draw Spaces** plugin

In *gedit* go to `Edit->Preferences->Plugins` check the box next to **Draw Spaces** and click `Close`. Spaces will be indicated by dots and tabs by arrows.

Useful links

Tutorials:

- Google's Python tutorial
- A Byte of Python

Libraries:

- Official website of the Python programming language
- Ipython: A Matlab-like Python shell
- SciPy: Scientific computing tools for Python
- PyGame: A Python game engine

Further reading

Beginner tutorials:

- E. Matthes, Python Crash Course 2nd Ed, No Starch Press 2019 (project-based)
- A. Scopatz, K.D. Huff, Effective Computation in Physics, O'Reilly 2015 (includes useful material on data visualization, Bash and git)
- M. Lutz, Learning Python 5th Ed., O'Reilly 2013 (very detailed)
- Think Python (free online book)

Homework assignments: Tic-tac-toe

Assignment 1: The Tic-tac-toe game

Write a simple version of the Tic-tac-toe game for two human players. Here are some hints:

- Use a list of lists for keeping track of the game state
- A handy way for initializing a 3x3 list of lists is the following comprehension [[-1 for j in range(3)] for i in range(3)]
- Take care in structuring your code: use functions
- Display the playing field after each move
- You have to validate every move
- Use docstrings and comments!
- (Optional) Implement an "AI" strategy to enable human players to play against the computer

Homework assignments: Connect four

Assignment 2: The Connect four game

Write a simple version of the Connect four game for two human players. Here are some hints:

- Use a list of lists for keeping track of the game state
- A handy way for initializing a 6x7 list of lists is the following comprehension [[-1 for j in range(7)] for i in range(6)]
- Take care in structuring your code: use functions
- Display the playing field after each move
- You have to validate every move
- Use docstrings and comments!
- (Optional) Implement an "AI" strategy to enable human players to play against the computer

Homework assignments: Memory

Assignment 3: The Memory game

Write a simple version of the Memory game for two human players. Here are some hints:

- Use a list of lists for keeping track of the score
- Take care in structuring your code: use functions
- On Linux, you can use the `os.system('clear')` call to clear the screen, hiding the previously revealed fields
- You can use numbers and letters as "images"; For a fancier version, you can use "unicode icons", e.g., `print(unichr(0x263a))` prints a smiley
- You have to validate every user selection
- Use docstrings and comments!
- (Optional) Implement an "AI" strategy to enable human players to play against the computer