Introduction to Python

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Python

- Open source general-purpose language
- Object Oriented, Procedural, Functional
- Easy to interface with C/C++/ObjC/Java/Fortran
- Great interactive environment

- Downloads: https://www.python.org
- Documentation: https://docs.python.org/

- In this course: **Python 3**
  - For a list of the main changes from Python 2.7 to Python 3:
  - https://sebastianraschka.com/Articles/2014_python_2_3_key_diff.html

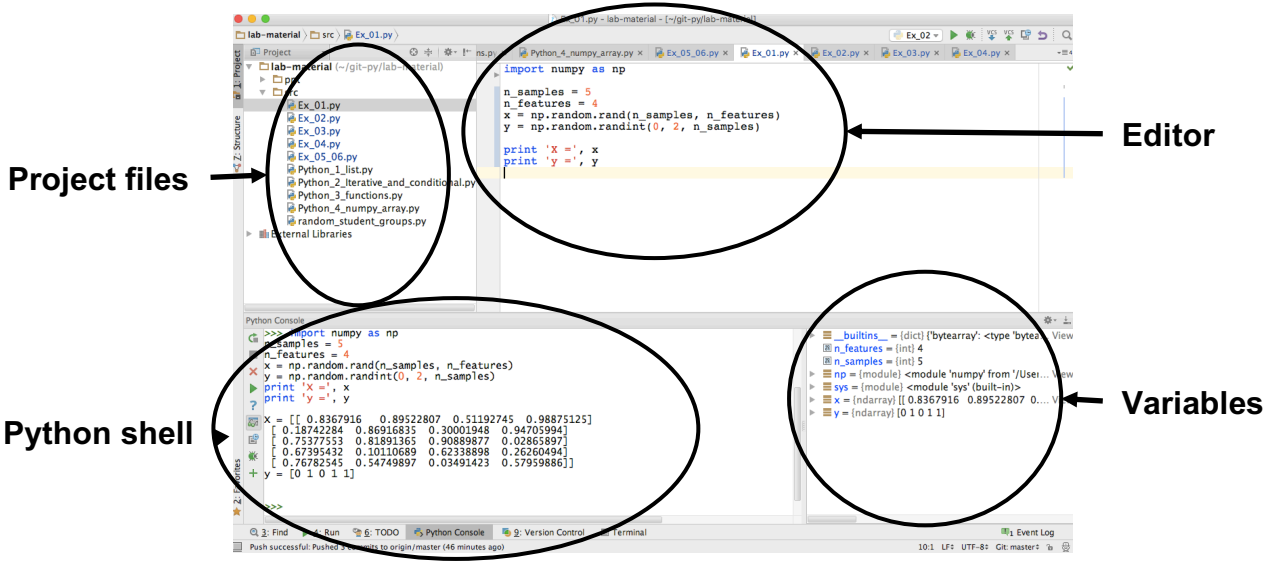
- Many available Python books/courses online
  - https://python-3-patterns-idioms-test.readthedocs.io/en/latest/index.html
  - https://dabeaz-course.github.io/practical-python/Notes/Contents.html

Why Python?

- Reasonable trade-off between a high-level language abstraction and computational efficiency
  - C/C++ is more efficient, but requires implementing at a lower abstraction level (e.g., considering memory allocation)
  - Matlab is maybe easier to program, but typically less efficient
- Python is a high-level programming language providing several third-party libraries that normally wrap C/C++ (efficient) code
- Availability of many third-party libraries (sklearn, tensorflow, pytorch, opencv)

PyCharm

- Development IDE https://www.jetbrains.com/pycharm/
- Easy to setup and use
  - Integration with repositories / versioning mechanisms (subversion, git)
- Compliant to PEP8 programming guidelines (after configuration)



The Python Interpreter

- Interactive interface to Python

```
bat:~ bat$ python
Python 2.7.13 |Continuum Analytics, Inc.| (default, Dec 20 2016, 23:05:08)
[GCC 4.2.1 Compatible Apple LLVM 6.0 (clang-600.0.57)] on darwin
Type "help", "copyright", "credits" or "license" for more information.
Anaconda is brought to you by Continuum Analytics.
Please check out: http://continuum.io/thanks and https://anaconda.org
>>> 2 * 3
6
>>> exit()
bat:~ bat$
```

- Python interpreter evaluates inputs:
  >>> 2*3
  6
- Python prompts with '>>>'
- To exit Python: press CTRL-D or type exit()

Running Programs on UNIX

% python filename.py

- You could make the *.py file executable (e.g., chmod +x filename.py) and add the following ***#!/usr/bin/env python*** to the top to make it runnable

Built-in Libraries Available

- Large collection of proven modules included in the standard distribution
- https://docs.python.org/3.7/py-modindex.html

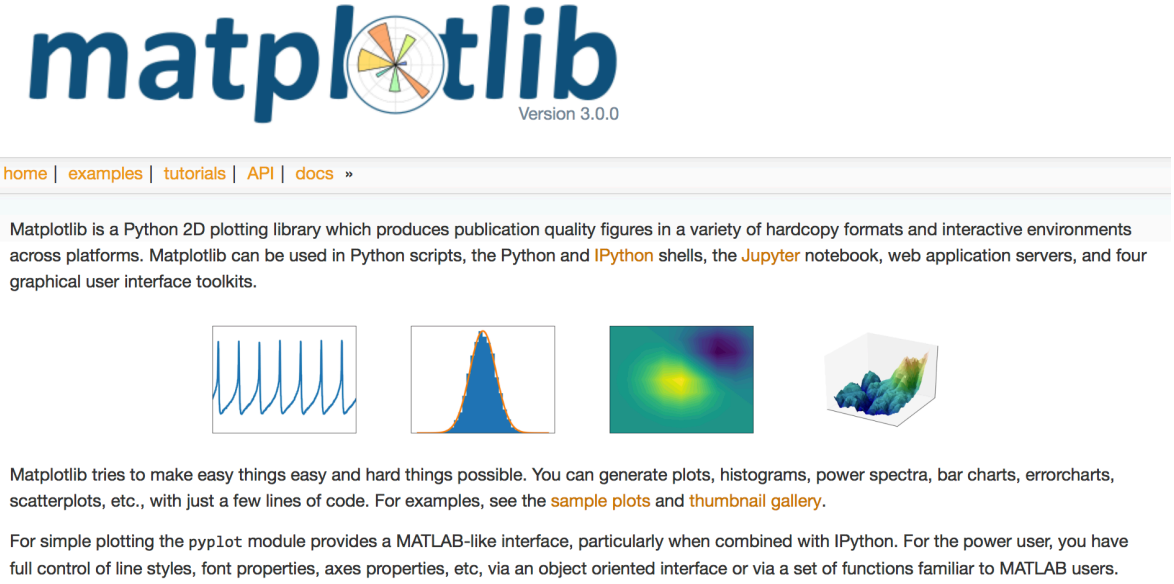
Numpy (Scipy)

- Offers Matlab-like capabilities within Python Fast array operations
- 2D arrays, multi-dimensional arrays, linear algebra etc.

- Website: http://www.numpy.org
- Tutorial: https://docs.scipy.org/doc/numpy/user/quickstart.html

Matplotlib

- Plotting library
- Website: https://matplotlib.org



Python Basics

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)
```

Enough to Understand the Code

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

Basic Datatypes

- **Integers (default for numbers)**

```
z = 5 // 2   # Answer is 2, integer division (new in Python 3!)
z = 5 / 2    # Answer is 2.5 (this returns 2 in Python 2 - cast to int)
```

- **Floats**

```
z = 3.456
```

- **Strings**
  - Can use “” or ‘’ to specify.
    `“abc”  ‘abc’` (Same thing.)
  - 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”””`

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 in Python… Use *consistent* indentation instead
  - The first line with less indentation is outside of the block
  - The first line with more indentation starts a nested block
- Often a colon appears at the start of a new block (e.g., for function and class definitions)

Comments

- Start comments with # – the rest of line is ignored.
- Can include a "documentation string" as the first line of any new function or class that you define.
- The development environment, debugger, and other tools use it
  - it's good style to include one

```
def my_function(x, y):
"""This is the docstring. This  function does blah blah blah."""
# The code would go here...
```

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 the data object assigned to it

- **You create a name the first time it appears on the left side of an assignment expression:**

```
x = 3
```

- **A reference is deleted via garbage collection after any names bound to it have passed out of scope.**

Accessing Non-Existent Names

- **If you try to access a name before it's been properly created (by placing it on the left side of an assignment), you'll get 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
```

Multiple Assignment

- **You can also assign to multiple names at the same time.**

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

Understanding Reference Semantics in Python

Understanding Reference Semantics

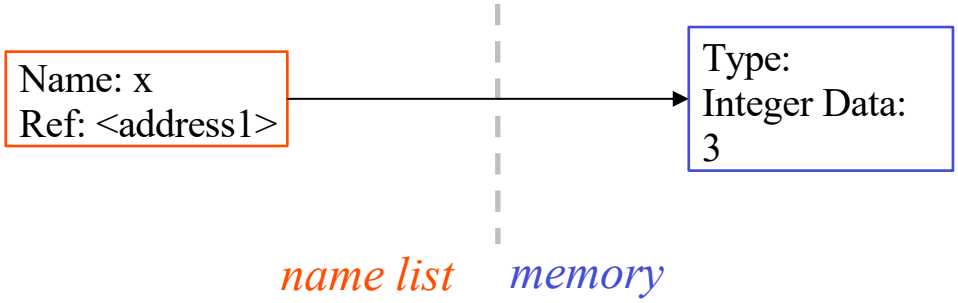
- **Assignment manipulates references**
  - x = y **does not make a copy** of the object y references
  - x = y makes x **reference** the object y references
- **Very useful; but beware!**
- **Example:**

```
>>> a = [1, 2, 3]     # a now references the list [1, 2, 3]
>>> b = a             # b now references what a references
>>> a.append(4)       # this changes the list a references
>>> print b           # if we print what b references,
[1, 2, 3, 4]          # SURPRISE!  It has changed…
```

Why?

Understanding Reference Semantics

- **There is a lot going on when we type:**
  - `x = 3`
- **First, an integer *3* is created and stored in memory**
- **A name *x* is created**
- **A *reference* to the memory location storing the *3* is then assigned to the name *x***
- **So, when we say that the value of *x* is *3*, we mean that *x* now refers to the integer *3***



Understanding Reference Semantics

- The data 3 we created is of type integer. In Python, the datatypes **integer**, **float**, and **string** (and **tuple**) are "**immutable**"

- This doesn't mean we can't change the value of x
  - i.e., change what x refers to …

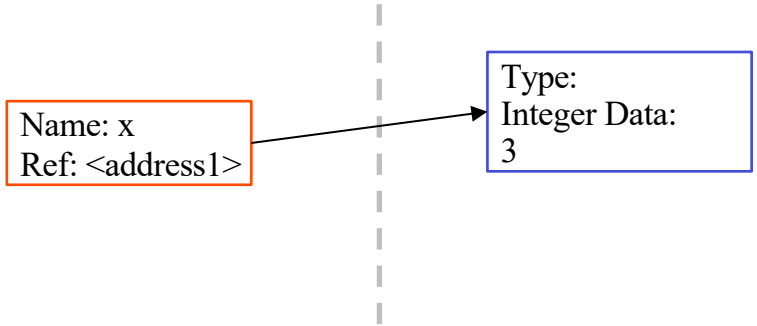
- For example, we could increment x:

```
>>> x = 3
>>> x = x + 1
>>> print x
4
```

Understanding Reference Semantics

- **If we increment x, then what's really happening is:**
  1. *The reference of name **x** is looked up.*
  2. *The value at that reference is retrieved.*

```
>>> x = x + 1
```



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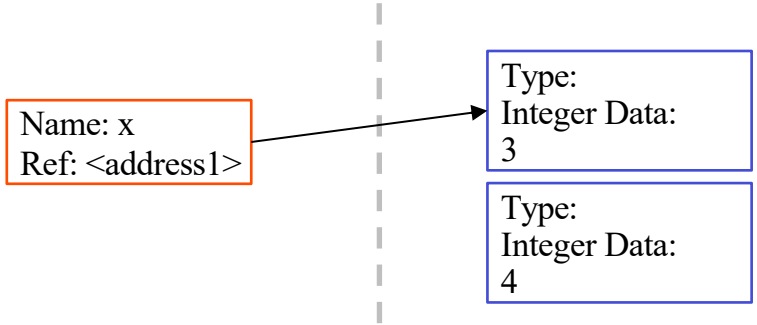

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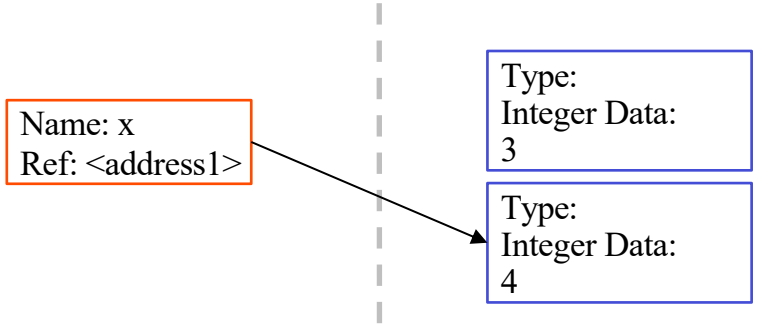

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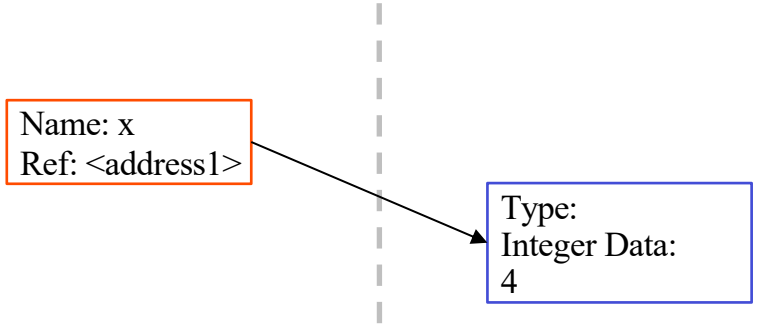
  3. *The 3+1 calculation occurs, producing a new data element 4 which is assigned to a fresh memory location with a new reference.*
  4. *The name x is changed to point to this new reference.*
  5. *The old data 3 is garbage collected if no name still refers to it.*

```
>>> x = x + 1
```



Assignment 1

- So, for simple built-in datatypes (integers, floats, strings), assignment behaves as one expects:

```
>>> x = 3     # Creates 3, name x refers to 3
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>>> y = 4     # Creates ref for 4. Changes y.
>>> print x   # No effect on x, still ref 3.
3
```

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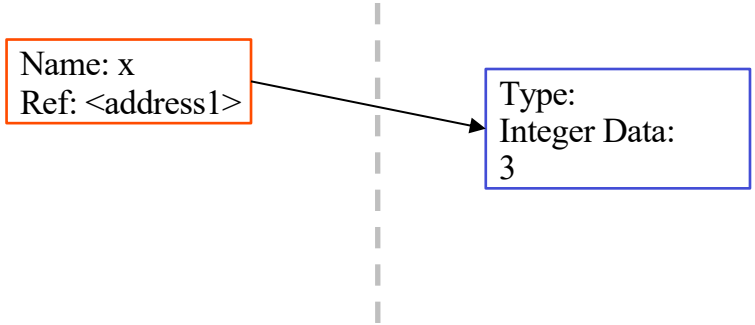

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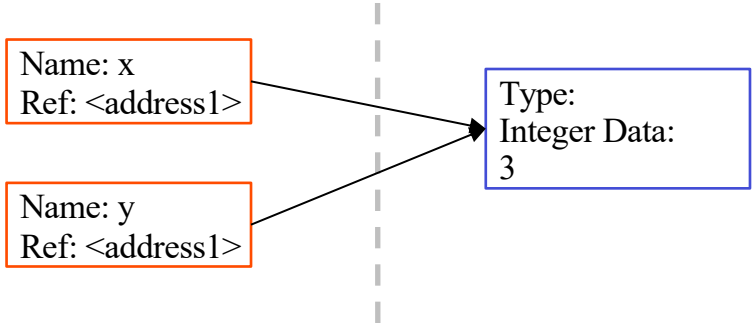

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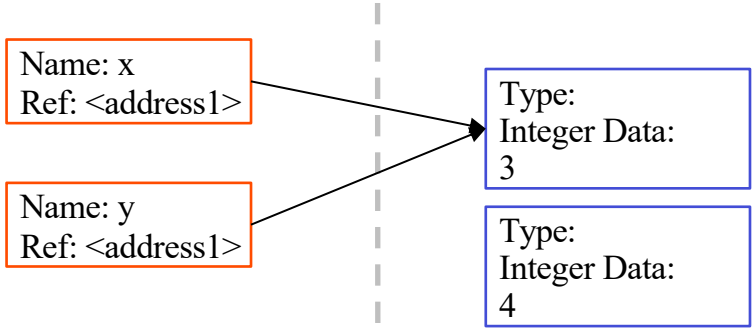
3
```



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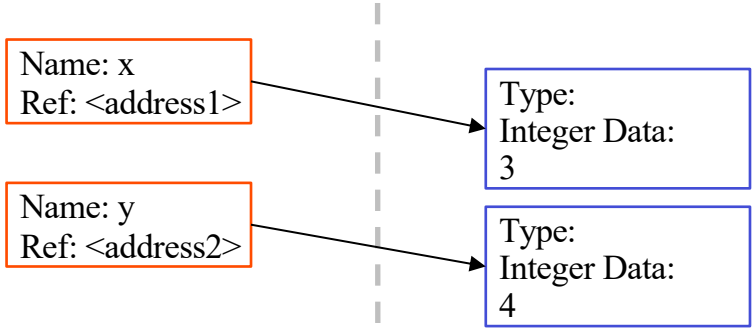

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3
```
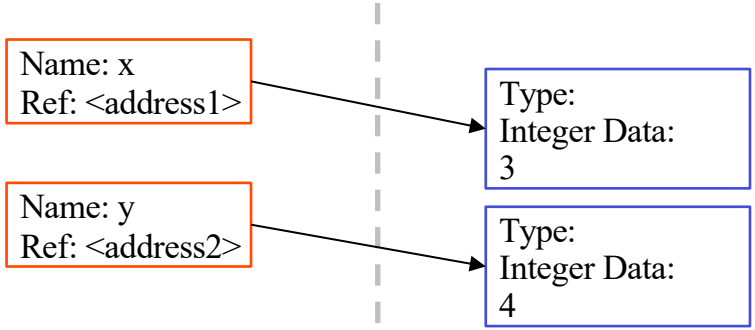



Assignment 2

- For other data types (lists, dictionaries, user-defined types), assignment works differently.
  - These data types are "**mutable**"
  - When we change these data, we do it ***inplace***
- We do not copy them into a new memory address each time
- If we type y=x and then modify y, both x and y are changed

Immutable

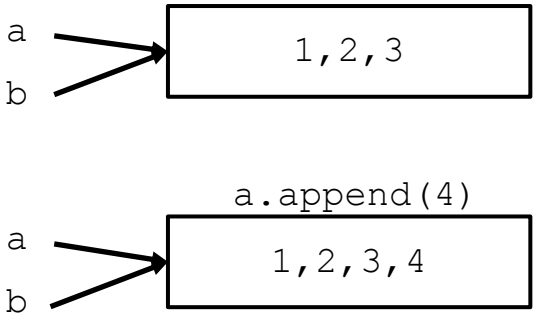
```
>>> x=3
>>> y=x
>>> y=4
>>> print x
3
```

Mutable

```
x = some mutable object
y = x
make a change to y look at x
x will be changed as well
```

Why? Changing a Shared List

```
>>> a = [1, 2, 3]
>>> b = a

>>> a.append(4)
>>> print b
[1, 2, 3, 4]
```



Our Surprising Example No Longer Surprising...

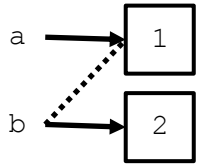
- **So now, here's our code:**

```
>>> a = [1, 2, 3]     # a now references the list [1, 2, 3]
>>> b = a             # b now references what a references
>>> a.append(4)       # this changes the list a references
>>> print b           # if we print what b references,
[1, 2, 3, 4]          # SURPRISE!  It has changed…
```

Recap: Mutable vs Immutable Objects

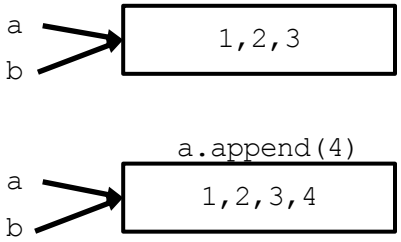
- Immutable objects can not be modified (reference changes!)

```
>>> a = 1
>>> b = a
>>> b = 2
>>> print a, b
1 2
```



- Mutable objects (like ***lists***) can be modified (by ***in-place*** functions)

```
>>> a = [1, 2, 3]
>>> b = a

>>> a.append(4)
>>> print b
[1, 2, 3, 4]
```



Sequence types: Tuples, Lists, and Strings

Sequence Types

1. **Tuple**
   - A simple ***immutable*** ordered sequence of items
   - Items can be of mixed types, including collection types

2. **Strings**
   - ***Immutable***
   - Conceptually very much like a tuple

3. **List**
   - ***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 differences:**
  - 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

- **Tuples are defined using parentheses (and commas).**

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

- **Lists are defined using square brackets (and commas).**

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

- **Strings are defined using quotes (", ', or """).**

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

Sequence Types 2

- We can 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 lookup: count from right, starting with –1.

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

Slicing: Return Copy of a Subset 1

```
>>> 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* the second index.

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

You can also use negative indices when slicing.

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

Slicing: Return Copy of a Subset 2

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

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

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

Omit the second index to make a copy starting at the first index and going to the end of the container.

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

Copying the Whole Sequence

To make a *copy* of an entire sequence, you can use `[:]`.

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

Note the difference between these two lines for mutable sequences:

```
>>> list2 = list1     # 2 names refer to 1 ref
                      # Changing one affects both

>>> list2 = list1[:] # Two independent copies, two refs
```

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

Tuples: 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')
```

Lists: 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.**
- **The mutability of lists means that they aren't as fast as tuples.**

Operations on Lists Only 1

```
>>> li = [1, 11, 3, 4, 5]
>>> li.append('a') # Our first exposure to 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 the + operator

- **+ creates a fresh list (with a new memory reference)**
- ***extend* operates on list** li **in place**

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

- ***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 3

```
>>> li = ['a', 'b', 'c', 'b']

>>> li.index('b')  # index of first occurrence
1

>>> li.count('b') # number of occurrences
2

>>> li.remove('b') # remove first occurrence
>>> li
['a', 'c', 'b']
```

Operations on Lists Only 4

```
>>> 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
```

Recap of Basic Operations (Lists)

- Creation

```
>>> a = [1, 2, 3]
>>> a = range(0,5)
>>> print a
[0, 1, 2, 3, 4]
>>> a = range(0,5,2)
>>> print a
[0, 2, 4]
```

- Indexing

```
>>> a = [1, 2, 3]
>>> print a[0], a[1], a[-1]
1 2 3
>>> print a[1:]  # slicing from index 1 to end
[2,3]
>>> print a[:2]  # slicing from index 0 to 2 (excluded)
[1,2]
```

Recap of Basic Operations (Lists)

- Reference and copy

```
>>> a = [1, 2, 3]
>>> b = a  # reference assignment. a and b are modified
>>> a[0] = 2
>>> print a, b
[2, 2, 3] [2, 2, 3]

>>> b = a[:]  # this is a copy. now a and b are different
>>> a[0] = 2
>>> print a, b
[2, 2, 3] [1, 2, 3]
```

- Other operations

```
>>> a = [3, 1, 2]
>>> len(a)  # returns number of elements in list
3
>>> a.sort()  # sorts list in ascending order [1, 2, 3]
>>> a.append(4)  # appends element at end -> [1, 2, 3, 4]
```

Tuples vs. Lists

- Lists are slower but more powerful than tuples
  - Lists can be modified, and they have many handy operations we can perform on them
  - 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)`

Dictionaries

Dictionaries: A Mapping Type

- **Dictionaries store a mapping between a set of keys and a set of values**
  - Defined within *braces* {...}
  - `a = {'key1': 0, 'key2': 1}`

- Keys can be any ***immutable*** type
  - Values can be any type
  - A single dictionary can store values of different types

- **You can define, modify, view, lookup, and delete the *key-value pair*s (or *items*) in the dictionary.**

Using Dictionaries

```
>>> d = {'user':'bat', 'pswd':1234}
>>> d['user']
'bat'
>>> d['pswd']
1234
>>> d['bat']
Traceback (innermost last): File
'<interactive input>' line 1, in ?
KeyError: bat

>>> d = {'user':'bat', 'pswd':1234}
>>> d['user'] = 'clown'
>>> d
{'user':'clown', 'pswd':1234}

>>> d['id'] = 45
>>> d
{'user':'clown', 'id':45, 'pswd':1234}
```

Using Dictionaries

```
>>> d = {'user':'bat', 'p':1234, 'i':34}
>>> del d['user']  # remove 'user'
>>> d
{'p':1234, 'i':34}

>>> d.clear()  # remove all
>>> d
{}
```

Using Dictionaries

```
>>> d = {'user':'bat', 'p':1234, 'i':34}

>>> d.keys()  # List of keys
['user', 'p', 'i']

>>> d.values()  # List of values
['bat', 1234, 34]

>>> d.items()  # List of item tuples
[('user','bat'), ('p',1234), ('i',34)]
```

Functions

Functions

- *def* creates a function and assigns it a name
- return sends a result back to the caller
- Arguments are passed by assignment
- Arguments and return types are not declared

```
def <name>(arg1, arg2, ..., argN):
    <statements>
    return <value>

def times(x,y):
    return x*y
```

Passing Arguments to Functions

- Arguments are passed by assignment
- Passed arguments are assigned to local names
- Assignments to argument names don't affect the caller
- Changing a mutable argument may affect the caller

```
def changer (x,y):
    x = 2  # changes local value of x only
    y[0] = 'hi'  # changes shared object
```

Optional Arguments

- Can define defaults for *optional* arguments

```
def func(a, b, c=10, d=100):
    print(a, b, c, d)

>>> func(1,2)
1 2 10 100

>>> func(1,2,3,4)
1,2,3,4
```

More on Functions

- **All functions in Python have a return value**
  - even if no return line inside the code

- **Functions without a return return the special value *None*.**

- **There is no function overloading in Python.**
  - Two different functions can't have the same name, even if they have different arguments.

- **Functions can be used as any other data type. They can be:**
  - Arguments to function
  - Return values of functions
  - Assigned to variables
  - Parts of tuples, lists, etc

Control of Flow

Control of Flow

- **if** *condition*:
  statements
  elif *condition*:
  statements
  else:
  statements

```
a=0
if a<0:
    print 'a is negative'
elif a>0:
    print 'a is positive'
else:
    print 'a is zero'
```

- **for** *var* **in** *sequence:*
  statements

```
a=['a','b','c']
for elem in a:
    print elem
```

- **while** *condition is True:*
  statements

```
a = 5
while a > 0:
    a = a - 1
    print a
```

Numpy Arrays

Numpy Arrays (array)

```
import numpy as np

a = np.array([[1, 2, 3],
              [4, 5, 6]])
>>> a.shape
(2, 3)

>>> a.dtype
dtype('int64')

n_rows, n_cols = 2, 4
a = np.zeros(shape=(n_rows, n_cols))
>>> a
array([[ 0.,  0.,  0.,  0.],
       [ 0.,  0.,  0.,  0.]])
```

Other Array Creation Methods

```
a = np.ones(shape=(n_rows, n_cols))  # creates matrix of ones

a = np.eye(n_rows, n_cols)  # creates identity matrix
>>> a
array([[ 1.,  0.,  0.,  0.],
       [ 0.,  1.,  0.,  0.]])

# random numbers from Normal distribution
# with zero mean and unit variance
a = np.random.randn(n_rows, n_cols)

# random numbers from Uniform distribution in [0,1]
a = np.random.rand(n_rows, n_cols)
>>> a
[[ 0.02413213  0.27179266  0.8904404   0.78110291]
 [ 0.66329305  0.57972581  0.19168138  0.44013989]]

>>> np.random.randint(0, 5, [n_rows, n_cols])  # random integers
[[ 0  2  1  0]
 [ 1  4  3  1]]
```

Array Indexing

- This can be rather complicated
  - https://docs.scipy.org/doc/numpy/reference/arrays.indexing.html
- Let's keep it simple, using some simple rules
  - Index arrays with shape = (n,) (flat arrays, vectors) with a single index
  - Index matrices with shape = (n, m) using two indices
  - In general, if shape.size == K, we should use K indices

```
a = np.eye(3)
>>> a
array([[ 1.,  0.,  0.],
       [ 0.,  1.,  0.],
       [ 0.,  0.,  1.]])
>>> a[0, 0]  # picks the first element (returns float)
1.0
>>> a[0, :]  # picks the first row (returns flat array)
array([ 1.,  0.,  0.])
>>> a[:, 1]  # picks the second column (returns flat array)
array([ 0.,  1.,  0.])
```

Array Indexing

```
a = np.eye(3)
>>> a
array([[ 1.,  0.,  0.],
       [ 0.,  1.,  0.],
       [ 0.,  0.,  1.]])

>>> a[0:2, 0:2]  #selects submatrix with slicing operators
array([[ 1.,  0.],
       [ 0.,  1.]])

b = np.array([1, 1, 0])
>>> a[b==1, :] # b used to index rows (picks first and second here)
array([[ 1.,  0.,  0.],
       [ 0.,  1.,  0.]])
```

Other Operation on Arrays

```
a = np.array([1, 2, 3])
b = np.array([4, 5, 6])

>>> np.vstack((a, b))  # stack rows (vertical stacking)
array([[1, 2, 3],
       [4, 5, 6]])

>>> np.hstack((a, b)) # stack columns (horizontal stacking)
array([1, 2, 3, 4, 5, 6])

>>> a.dot(b)  # scalar product
32

# other operations include: reshape, transpose, min/max, etc.
# we will see more througout the course, when required
```