CME 211 Lecture 10 - Numpy

Motivation

Python is kind of slow

One of the main disadvantages of a higher level language is that, while comparatively easy to program, it is typically slow compared to C/C++, Fortran, or other lower level languages

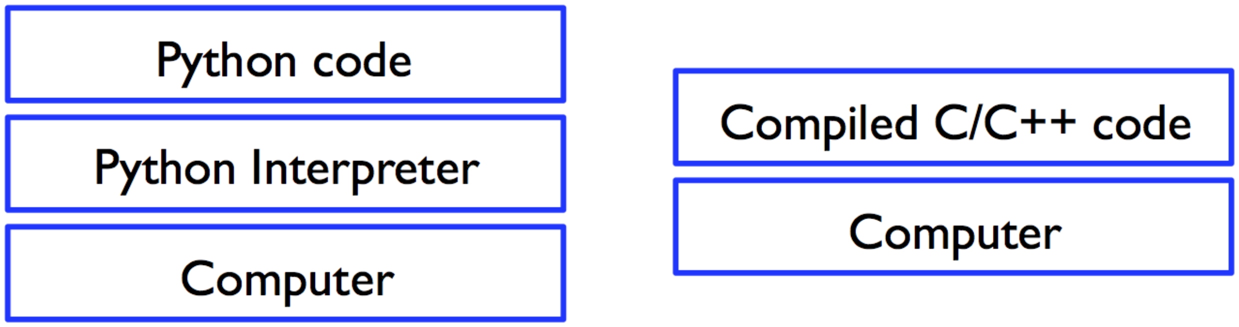
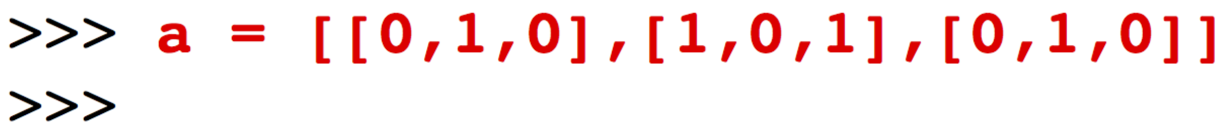


Figure 1: fig

Object overhead



```
>>> a = [[0,1,0],[1,0,1],[0,1,0]]
>>>
```

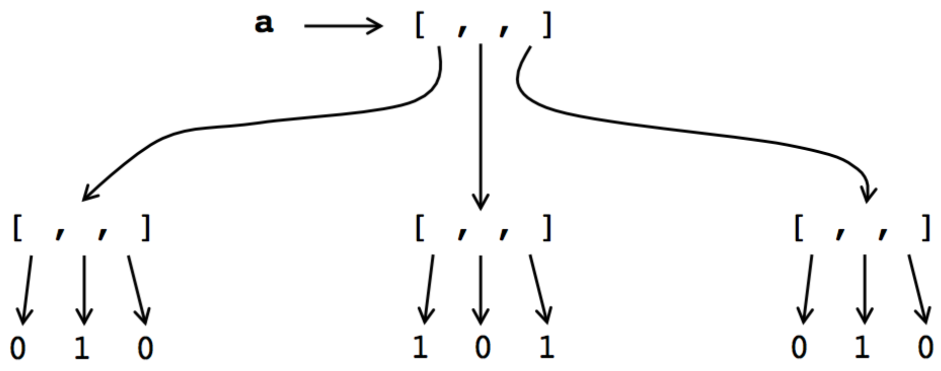


Figure 2: fig

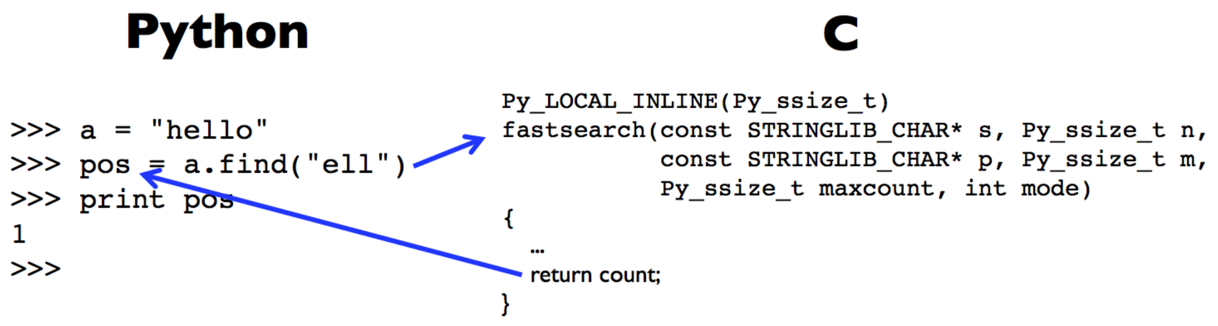
Options for better performance

- Python is great for quick projects, prototyping new ideas, etc.

- What if you need better performance?
- One option is to completely rewrite your program in something like C/C++

Python C API

- Python has a C API which allows the use of compiled modules



```
>>> a = "hello"
>>> pos = a.find("ell")
>>> print pos
1
>>>
```

```
Py_LOCAL_INLINE(Py_ssize_t)
fastsearch(const STRINGLIB_CHAR* s, Py_ssize_t n,
           const STRINGLIB_CHAR* p, Py_ssize_t m,
           Py_ssize_t maxcount, int mode)
{
  ...
  return count;
}
```

Figure 3: fig

- The actual implementation of `string.find()` can be viewed at:

http://svn.python.org/view/python/trunk/Objects/stringlib/fastsearch.h

Python compiled modules

- Python code in a `.py` file is actually executed in a hybrid approach by a mix of the interpreter and compiled modules that come with Python

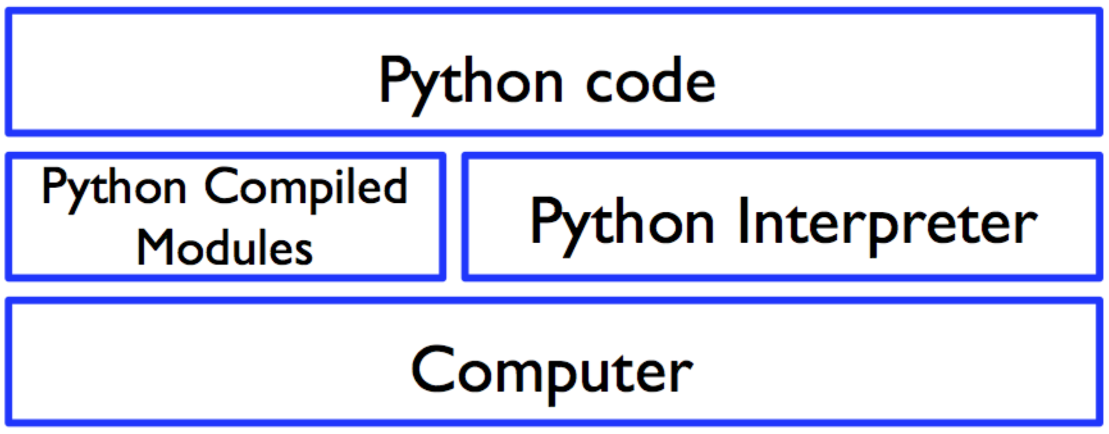


Figure 4: fig

Extension modules

- The same Python C API used by the developers of Python itself also allows other programmers to develop and build their own compiled extension modules

- These modules extend the functionality of Python with high performance implementations of common operations
- Other languages, such as C++ and Fortran, are also supported by using the C API

NumPy, SciPy, matplotlib

- NumPy - multidimensional arrays and fundamental operations on them
- SciPy - Various math functionality (linear solvers, FFT, optimization, etc.) utilizing NumPy arrays
- matplotlib - plotting and data visualization
- None of these packages seek to clone MATLAB, if you want that try something like GNU Octave

Python software stack

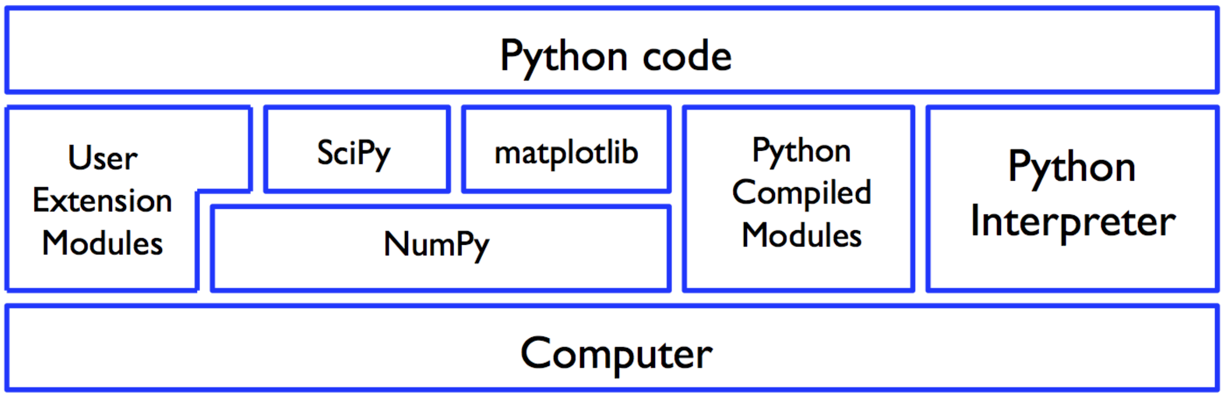


Figure 5: fig

NumPy

NumPy provides a numeric array object:

```
import numpy as np
a = np.array([7, 42, -3])
print(a)
```

```
a[1]
```

```
a[1] = 19
a
```

Arrays are not lists

```
a[0] = "hello"
```

```
a.append(8)
```

NumPy arrays

- NumPy arrays contain **homogeneous** data (all elements must have same type)
- Size is fixed, i.e. you can't append or remove

Data types

- Integers
- 8, 16, 32, and 64 bit signed and unsigned (np.int8, np.uint8, etc.)
- Floating point
- 32, 64, 128 bit (np.float32, np.float64, etc.)
- Complex, strings, and Python object references also supported

Data type examples

```
a = np.array([ 7, 19, -3], dtype=np.float32)
a
```

```
a[0] = a[0]/0.
a
```

```
b = np.array([4, 7, 19], dtype=np.int8)
b
```

```
b[0] = 437
b
```

Multidimensional arrays

- Arrays can have multiple dimensions called *axes*
- The number of *axes* is called the *rank*
- These terms come from the NumPy community and should not be confused with linear algebra terms for *rank*, etc.

Multidimensional arrays

```
a = np.array([(7, 19, -3), (4, 8, 17)], dtype=np.float64)
a
```

```
a.ndim
```

```
a.dtype
```

```
a.shape
```

```
a.size
```

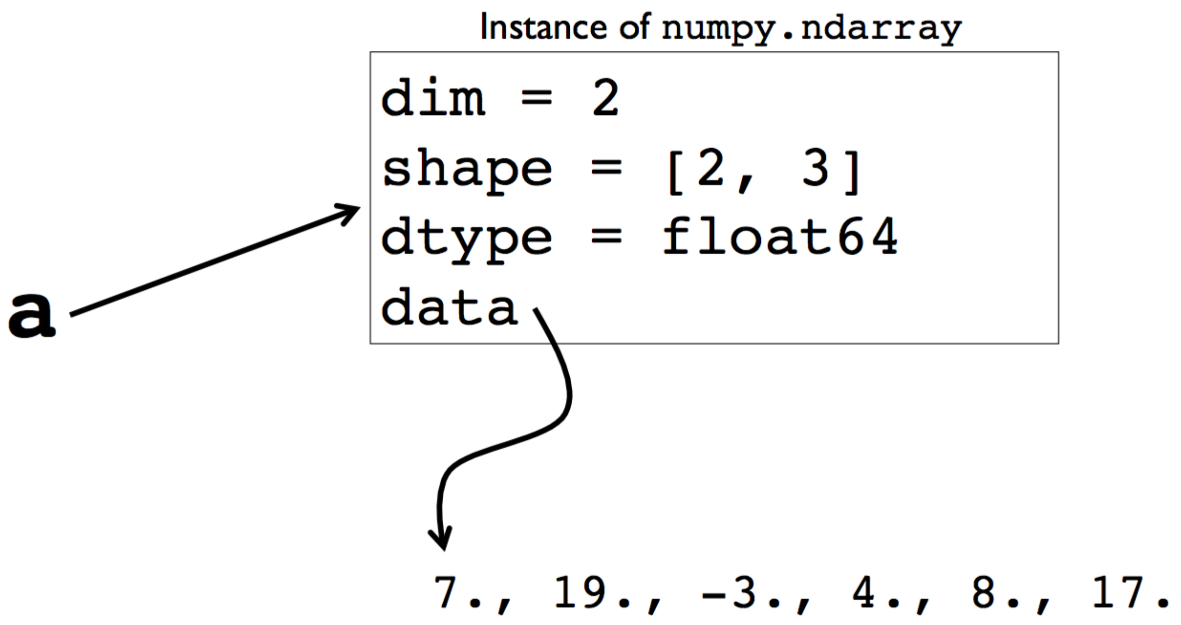


Figure 6: fig

Internal representation

Creating arrays

```
a = np.empty((3,3))
a
```

```
a = np.zeros((3,3))
a
```

```
a = np.ones((3,3))
a
```

```
a = np.eye(3)
a
```

```
a = np.arange(9, dtype=np.float64)
a
```

```
a = np.arange(9, dtype=np.float64).reshape(3,3)
a
```

Reading data from a file

```
$ cat numbers.txt
7. 19. -3.
4. 8. 17.
```

```
a = np.loadtxt('numbers.txt', dtype=np.float64)
a
```

```
a = a + 1
np.savetxt('numbers2.txt', a)
```

Remove single dimension entry

```
a = np.arange(3)
a
```

```
a.shape
b = np.arange(3).reshape(3,1)
print(b)
print(b.shape)
b = np.squeeze(b)
print(b)
print(b.shape)
```

Array operations

```
a = np.arange(9, dtype=np.float64)
a
```

```
# a slice
a[3:7]
```

```
# assign to a slice
a[3:7] = 0
a
```

```
2*a
```

```
a*a
```

```
sum(a)
```

```
min(a)
```

```
max(a)
```

Array operations

```
a = np.arange(9, dtype=np.float64)
print(a)

# bad idea
total = 0.
for n in range(len(a)):
    total += a[n]*a[n]

math.sqrt(total)
```

```
# better idea
import math
math.sqrt(np.dot(a,a))
```

```
# best idea
np.linalg.norm(a)
```

Speed of array operations

```
%timeit total = sum(np.ones(1000000,dtype=np.int32))
```

```
%timeit total = np.sum(np.ones(1000000,dtype=np.int32))
```

Loops vs. array operations

- Loops you write in Python will be executed by the interpreter
- Some of the overloaded operators (e.g. `min`, `max`, `sum`, etc.) work albeit slowly
- Calling NumPy function or methods of the array object will invoke high performance implementations of these operations

Matrix operations

```
a = np.arange(9, dtype=np.float64).reshape(3,3)
a
```

```
a.transpose()
```

```
np.trace(a)
```

```
a*a # element wise multiplication
```

```
np.dot(a,a) # matrix-matrix multiplication
```

```
# new matrix multiply operator in Python 3.5
a @ a
```

array vs matrix

- NumPy has a dedicated matrix class
- However, the matrix class is not as widely used and there are subtle differences between a 2D array and a matrix
- It is highly recommended that you use 2D arrays for maximum compatibility with other NumPy functions, SciPy, matplotlib, etc.
- See here for more details:

http://www.scipy.org/NumPy_for_Matlab_Users

(`array' ormatrix`'? Which should I use?)

References to an array

```
a = np.arange(9, dtype=np.float64).reshape(3,3)
a
```

```
b = a
b[0,0] = 42
b
```

```
a
```

Array slices and references

```
a = np.arange(9, dtype=np.float64)
a
```

```
b = a[2:7]
b
```

```
b[2] = -1
b
```

```
a
```

Array copies

```
a = np.arange(9, dtype=np.float64)
a
```

```
b = a.copy()
b
```

```
b[4] = -1
b
```

```
a
```

Universal functions (ufuncs)

```
import numpy
a = np.arange(9, dtype=np.float64)
a
```

```
import math
math.sqrt(a)
```

```
np.sqrt(a)
```

Beyond just arrays

- NumPy has some support for some useful operations beyond the usual vector and matrix operations:
- Searching, sorting, and counting within arrays
- FFT (Fast Fourier Transform)
- Linear Algebra
- Statistics
- Polynomials
- Random number generation
- SciPy has largely replaced much of this functionality, plus added much more

Warning

- Once you start making use of extension modules such as NumPy, SciPy, etc. the chances of code "breaking" when you run it on different machines goes up significantly
- If you do some of your development on machines other than corn (which isn't the model we advise) you may run into issues

Further Reading

- MATLAB users: http://www.scipy.org/NumPy_for_Matlab_Users
- NumPy tutorial at: http://www.scipy.org/Tentative_NumPy_Tutorial
- Official docs at: http://docs.scipy.org/