Numpy

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Numpy

- Python supports lists of objects (as we've seen), but this is extremely inefficient for numerical operations.
- Mathematical operations are fastest when numbers are contiguously allocated in memory and homogenous.
- Numpy is designed to make numeric arrays a basic data type and optimize their performance (e.g. vectorization).

To use Numpy objects, you need to import the module:

```
import numpy
```

Though typically people shorten the package name (namespace) like this:

```
import numpy as np
```

Data Types

A numpy array can only contain one type of data; below is a list of some of them. Typically you should use the smallest data type as appropriate to your data.

Type	Range
np.int_	same as np.int32 or np.int64
np.int8	-128-127
np.int16	-32768 to 32767
np.int32	-2147483648 to 2147483647
np.float_	same as np.float64
np.float32	single precision float
np.float64	double precision float
np.str_	string type
np.object_	any Python object

See this for the full list and sizes:
http://docs.scipy.org/doc/numpy/user/basics.types.html
http://docs.scipy.org/doc/numpy/reference/arrays.scalars.html#arrays-scalars-built-in

Creating Numpy Arrays

New 10 element array filled with zeros or ones (the default type is “float”):

```
n1 = np.zeros(10, dtype=np.int)
n2 = np.zeros(10, dtype=np.float)
```

The default data type is “float”. A new empty array:

```
n3 = np.empty() # typically you don't use this
```

Create an array from a Python list of numbers:

```
a_list = [1,2,3,4,5]
n4 = np.array(a_list)
```

The *shape* is the dimensionality of the array (1D, 2D, etc.) – row x columns.
Create a 4x5 2D array:

shape is a tuple

```
n5 = np.array((4,5), dtype=np.float)
```

Can use generators:

```
n6 = np.array(range(4)) # array([0, 1, 2, 3])
n7 = np.array([x for x in range(10) if x % 2 == 0]) # array([0, 2, 4, 6, 8])
```

Creating Numpy Arrays

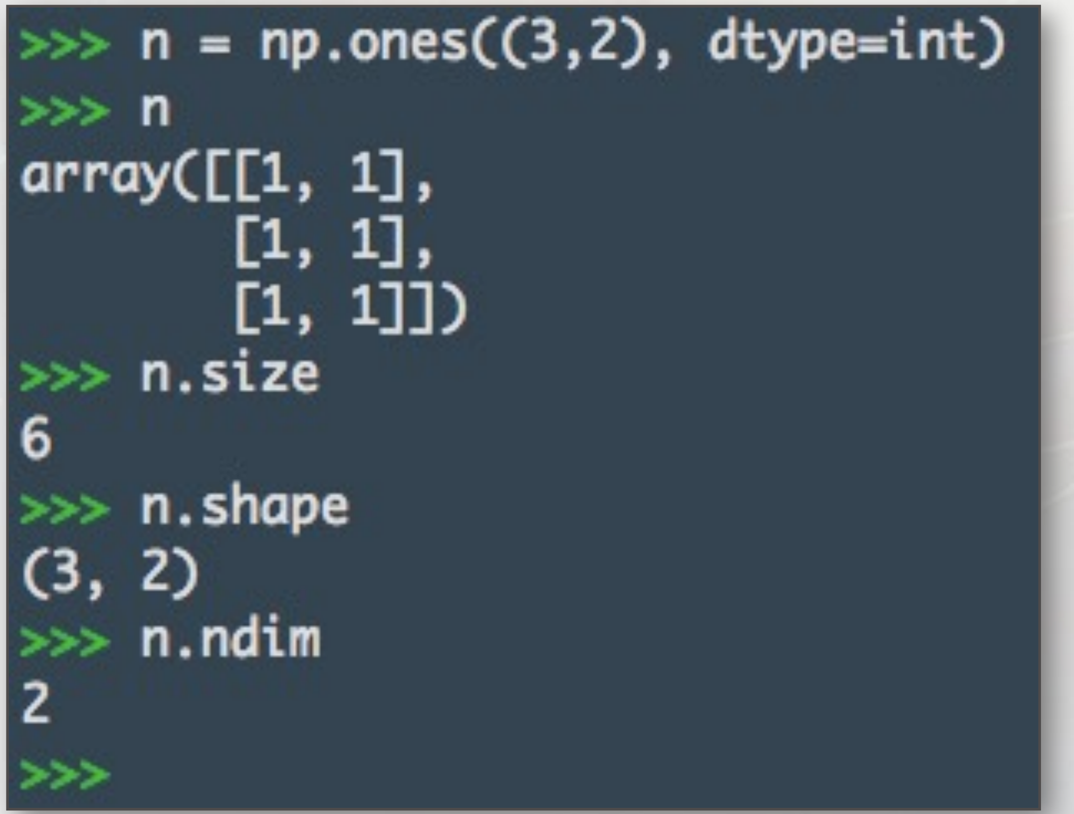
More ways to create an array:

```
>>> np.arange(start=10, stop=20, step=2)
array([10, 12, 14, 16, 18])

>>> np.linspace(start=0, stop=1, num=5) # num = number of elements
array([ 0.  ,  0.25,  0.5 ,  0.75,  1.  ])

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

Array Properties

Numpy arrays are proper objects– they know how to do things and are introspective.

(but not emo)



```
>>> n = np.ones((3,2), dtype=int)
>>> n
array([[1, 1],
       [1, 1],
       [1, 1]])
>>> n.size
6
>>> n.shape
(3, 2)
>>> n.ndim
2
>>>
```

Other useful methods:

```
n.max()
n.min()
n.mean()
n.sort() # sort array in place (returns None)
```

Functions

```
np.sum(n)
np.mean(n)
np.median(n)
```

Operations can be chained (aka *generative*)

```
s = np.array([1,2,3,4]).min()
```

Make an array read-only (protection against accidentally changing fixed values):

```
n.flags.writeable = False
```

Appending Items to a Numpy Array

In short, don't.

Creating an array is "expensive". Arrays must be contiguous – appending a value to an array actually creates a new one. If you can, initialize your array, then fill in the values.

```
from __future__ import print_function

import numpy as np
import time

n = 10000
start = time.time()

a = np.empty(0)
for i in range(10000):
    a = np.append(a, i)

print("Time 1: {0:.4f} " +
     "seconds".format(time.time() - start))

start = time.time()
a = np.zeros(10000)
for i in range(10000):
    a[i] = i

print("Time 2: {0:.4f} " +
    "seconds".format(time.time() - start))

# Time 1: 0.0687 seconds
# Time 2: 0.0015 seconds
```

10,000 objects created

1 object created

Operating on Arrays

Array operations work on a per-element basis. This is different than Python lists.

```
>>> [1,2,3,4] * 5
[1, 2, 3, 4, 1, 2, 3, 4, 1, 2, 3, 4, 1, 2, 3, 4, 1, 2, 3, 4]
>>> np.array([1,2,3,4]) * 10
array([10, 20, 30, 40])

>>> [1,2,3,4] + [5,6,7,8]
[1, 2, 3, 4, 5, 6, 7, 8]
>>> np.array([1,2,3,4]) + np.array([5,6,7,8])
array([ 6,  8, 10, 12])
```

Working with arrays is much faster than Python lists.

```
>>> a = [x**2 for x in range(10000)]
>>> a = np.arange(10000)**2
```

Numpy is 70x faster here!

Reshaping An Array

An array’s dimensions can be changed (reshaped). For example, let’s say I want to change a 1x9 array to a 3x3 matrix:

```
>>> a = np.array([0,1,2,3,4,5,6,7,8])
>>> b = a.reshape(3,3)
>>> a
array([0, 1, 2, 3, 4, 5, 6, 7, 8])
>>> b
array([[0, 1, 2],
       [3, 4, 5],
       [6, 7, 8]])
>>> print(a.shape, b.shape)
((9,), (3, 3))
```

Array Indexing

Array indexing works in the same way that Python lists do. Indexing can be performed on multiple dimensions:

```
>>> a = np.array(range(9)).reshape((3,3))
>>> a
array([[0, 1, 2],
       [3, 4, 5],
       [6, 7, 8]])
>>> a[1:2]
array([[3, 4, 5]])
>>> a[2,1:2]
array([7])
```

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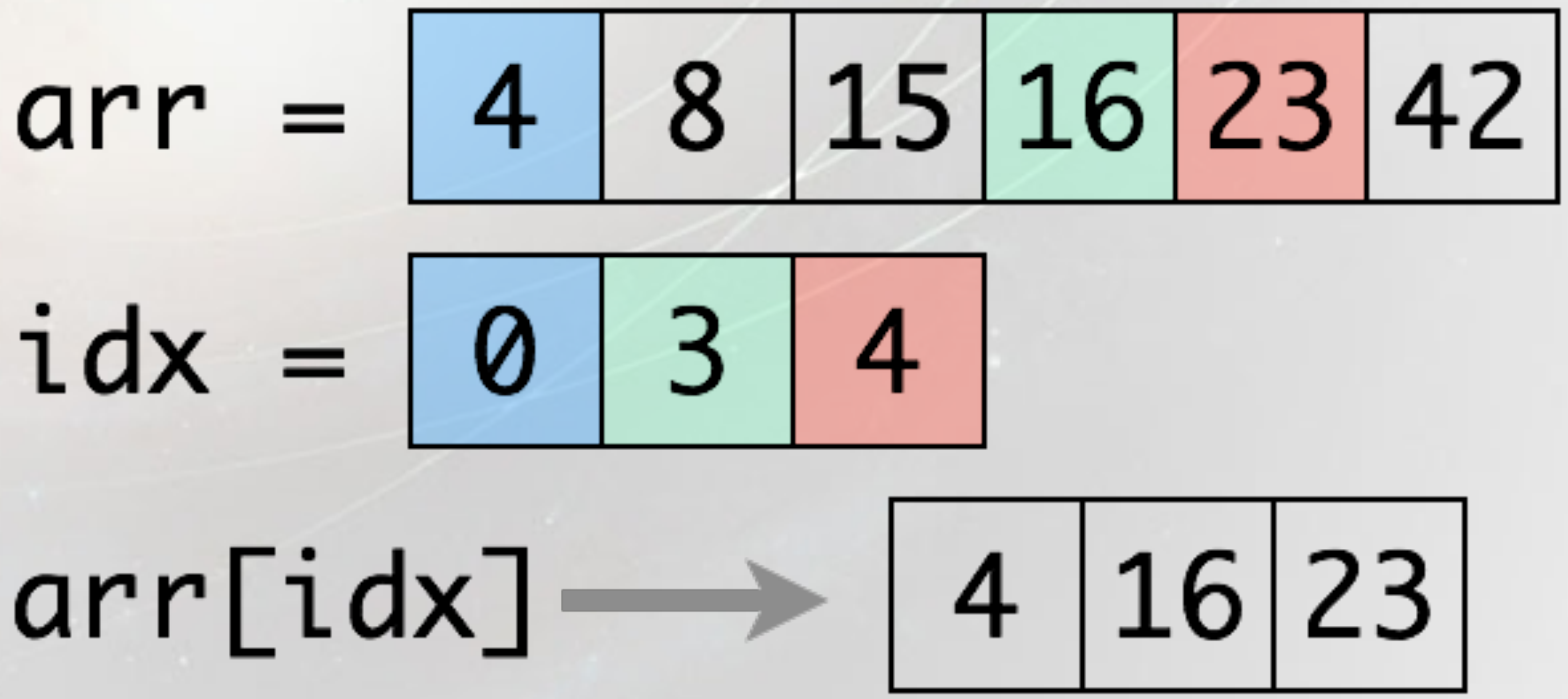

can be a Python list or a Numpy array

```
>>> a = np.array([4,8,15,16,23,42])
>>> a[[0,3,4]]
array([ 4, 16, 23])
>>> a[np.array([0,3,4])]
array([ 4, 16, 23])
>>> a[np.array([True, False, False, True, True, False])]
array([ 4, 16, 23])
```

Boolean values work too, but must be a Numpy Boolean array

Selecting Elements with Some Criteria

You can select elements that match some criteria (similar to "where" in IDL):

```
>>> a = np.array([1,2,3,5,8,13])
>>> a
array([ 1,  2,  3,  5,  8, 13])
>>> a > 3
array([False, False, False,  True,  True,  True], dtype=bool)
```

result is a Boolean array

Expressions can be combined:

must use "|" for OR and "&" for —
"or", "and" don't work

```
>>> (a > 3) | (a == 1)
array([ True, False, False,  True,  True,  True], dtype=bool)
>>> (a > 2) & (a < 10)
array([False, False,  True,  True,  True, False], dtype=bool)
```

The inverse operator:

```
>>> ~np.array([True, True, False])
array([False, False,  True], dtype=bool)
```

Selecting Elements with Some Criteria

Example: selecting elements from a catalog:

```
idx = (ra > 11.1324) & (ra < 31.5134)
selected = ra[idx]
not_selected = ra[~idx]
```

Structured Arrays

Standard arrays have homogeneous data types (e.g. all integers, all floats). A structured array can contain different types of data – think of a table with each column having a different type.

Name	ID	Height	Active
"Mulder"	11605	6.0	False
"Scully"	42115	5.5	True

```
data = [("mulder", 11605, 6.0, False), ("scully", 42115, 5.5, True)]
arr = np.array(data, dtype=[("Name", str), ("ID", int),
                            ("Height", float), ("Active", bool)])
arr["ID"] -> [11605, 42115]
arr[0] -> ("mulder", 11605, 6.0, True)
```

access a column by name

access a row by the row number

Dimensionality Reduction

Aggregate functions "flatten" an array:

```
>>> a = np.array(range(9)).reshape((3,3))
>>> a
array([[0, 1, 2],
       [3, 4, 5],
       [6, 7, 8]])
>>> np.sum(a)
36
```

These operations can act on a specified axis:

```
>>> np.sum(a, axis=0)
array([ 9, 12, 15])
>>> np.sum(a, axis=1)
array([ 3, 12, 21])
```