Matrix Programming

Basics

NumPy (http://numpy.scipy.org)

Provides MATLAB-style arrays for Python

And many other things

A *data parallel* programming model

- Write `x*A*x.T` to calculate xAx^T
- The computer takes care of the loops

All encapsulated in special objects called *arrays*

Create an array from a list

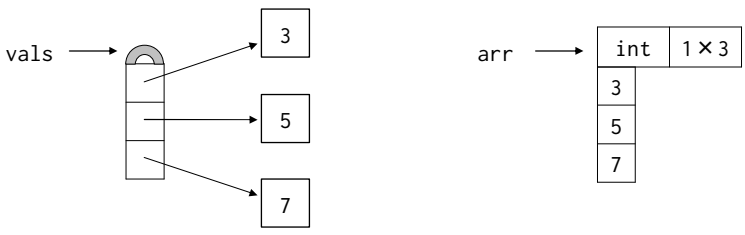
```
>>> import numpy
>>> vals = [1, 2, 3]
>>> arr = numpy.array(vals)
>>> arr
array([1, 2, 3])
```


Arrays are *homogeneous*

- I.e., all values have the same type

Allows values to be packed together

- Saves memory
- Faster to process



So what does this do?

```
>>> arr = numpy.array([1, 2.3])
>>> arr
array([1., 2.3])
```

A float, not an int

You can specify at creation time:

```
>>> array([1, 2, 3, 4], dtype=float32)
array([ 1., 2., 3., 4.])
```

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array([ 1., 2., 3., 4.])
```

Why would you want to specify a type?

You can also specify the data type later

```
>>> a = array([1, 2, 3, 4], dtype=float32)
>>> a.astype(int)
array([ 1, 2, 3, 4])
>>> a.dtype = int
>>> a
array([1065353216, 1073741824, 1077936128,
  1082130432])
```

Basic data types (in increasing order) are:

`bool`	`uint[8,16,32,64]`
`int`	`float`
`int8`	`float[32,64,128]`
`int16`	`complex`
`int32`	`complex[64,126]`
`int64`	

Many other ways to create arrays

```
>>> z = numpy.zeros((2, 3))
>>> z
array([[0., 0., 0.],
       [0., 0., 0.]])
```

Type is `float` unless something else specified

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Many other ways to create arrays

```
>>> z = numpy.zeros((2, 3))
>>> z
array([[0., 0., 0.],
       [0., 0., 0.]])
```

Type is `float` unless something else specified

What do these do?

```
>>> block = numpy.ones((4, 5))
>>> mystery = numpy.identity(4)
```


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Can create arrays without filling in values

```
>>> x = numpy.empty((2, 2))
>>> x
array([[3.82265e-297, 4.94944e+173],
       [1.93390e-309, 1.00000e+000]])
```

"Values" will be whatever bits were in memory

Should not be used without being initialized

Can create arrays without filling in values

```
>>> x = numpy.empty((2, 2))
>>> x
array([[3.82265e-297, 4.94944e+173],
       [1.93390e-309, 1.00000e+000]])
```

"Values" will be whatever bits were in memory

Should not be used without being initialized

When is this useful?

Assigning creates alias: does *not* copy data

```
>>> first = numpy.ones((2, 2))
>>> first
array([[1., 1.],
       [1., 1.]])
>>> second = first
>>> second[0, 0] = 9
>>> first
array([[9., 1.],
       [1., 1.]])
```

Assigning creates alias: does *not* copy data

```
>>> first = numpy.ones((2, 2))
>>> first
array([[1., 1.],
       [1., 1.]])
>>> second = first
>>> second[0, 0] = 9
>>> first
array([[9., 1.],
       [1., 1.]])
```

Not `second[0][0]`

Use the `array.copy` method

```
>>> first
array([[1., 1.],
       [1., 1.]])
>>> second = first.copy()
>>> second[0, 0] = 9
>>> first
array([[1., 1.],
       [1., 1.]])
```

Arrays also have properties

```
>>> first
array([[1., 1.],
       [1., 1.]])
>>> first.shape
(2, 2)
>>> block = numpy.zeros((4, 7, 3))
>>> block.shape
(4, 7, 3)
```


Arrays also have properties

```
>>> first
array([[1., 1.],
       [1., 1.]])
>>> first.shape
(2, 2)
>>> block = numpy.zeros((4, 7, 3))
>>> block.shape
(4, 7, 3)
```

Arrays also have properties

```
>>> first
array([[1., 1.],
       [1., 1.]])
>>> first.shape
(2, 2)
>>> block = numpy.zeros((4, 7, 3))
>>> block.shape
(4, 7, 3)
```

Consistent

`array.size` is the total number of elements

```
>>> first.size
4
```

2×2

```
>>> block.size
84
```

$4 \times 7 \times 3$

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Reverse on all axes with `array.transpose`

```
>>> first = numpy.array([[1, 2, 3],
                         [4, 5, 6]])
>>> first.transpose()
array([[1, 4],
       [2, 5],
       [3, 6]])
>>> first
array([[1, 2, 3],
       [4, 5, 6]])
```


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Flatten arrays using `array.ravel`

```
>>> first = numpy.zeros((2, 2, 2))
>>> second = first.ravel()
>>> second.shape
(8,)
```

Think about the 2×4 array A:

```
>>> A
array([[1, 2, 3, 4],
       [5, 6, 7, 8]])
```

A looks 2-dimensional

But computer memory is 1-dimensional

Must decide how to lay out values

Row-major order concatenates the rows

Used by C and Python

1	2	3	4
5	6	7	8

Logical

1	2	3	4	5	6	7	8

Physical

Column-major order concatenates the columns
Used by Fortran and MATLAB

1	2	3	4
5	6	7	8

Logical

1	5	2	6	3	7	4	8

Physical

No difference in usability or performance...
...but causes headaches when passing data from one language to another
(Just like 0-based vs. 1-based indexing)

No difference in usability or performance...
...but causes headaches when passing data from one language to another
(Just like 0-based vs. 1-based indexing)

What order are 3-dimensional arrays stored in?

Can *reshape* arrays in many other ways

```
>>> first = numpy.array([1, 2, 3, 4, 5, 6])
>>> first.shape
(6,)
```

Tuple with 1 element

```
>>> second = first.reshape(2, 3)
>>> second
array([[1, 2, 3],
       [4, 5, 6]])
```

Not packed into a tuple

Also aliases the data

New shape must have same size as old

```
>>> first = numpy.zeros((2, 2))
>>> first.reshape(3, 3)
ValueError: total size of new array must
be unchanged
```

Cannot possibly work because it is just creating an alias for the existing data

Change physical size using `array.resize`

```
>>> block
array([[ 10,  20,  30],
       [110, 120, 130],
       [210, 220, 230]])
>>> block.resize(2, 2)
>>> block
array([[ 10,  20],
       [110, 120]])
```

Change physical size using `array.resize`

```
>>> block
array([[ 10,  20,  30],
       [110, 120, 130],
       [210, 220, 230]])
>>> block.resize(2, 2)
>>> block
array([[ 10,  20],
       [110, 120]])
```

What happens when the array grows?

Review:

- Arrays are blocks of homogeneous data
- Most operations create aliases
- Can be reshaped (size remains the same)
- Or resized

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