Numpy and Scipy

Numerical Computing in Python

What is Numpy?

- Numpy, Scipy, and Matplotlib provide MATLAB-like functionality in python.
- Numpy Features:
  - Typed multidimentional arrays (matrices)
  - Fast numerical computations (matrix math)
  - High-level math functions

Why do we need NumPy

Let’s see for ourselves!

Why do we need NumPy

- Python does numerical computations slowly.
- 1000 x 1000 matrix multiply
  - Python triple loop takes > 10 min.
  - Numpy takes ~0.03 seconds

Logistics: Versioning

- In this class, your code will be tested with:
  - Python 2.7.6
  - Numpy version: 1.8.2
  - Scipy version: 0.13.3
  - OpenCV version: 2.4.8

- Two easy options:
  - Class virtual machine (always test on the VM)
  - Anaconda 2 (some assembly required)

NumPy Overview

1. Arrays
2. Shaping and transposition
3. Mathematical Operations
4. Indexing and slicing
5. Broadcasting

Arrays

Structured lists of numbers.

- Vectors
- Matrices
- Images
- Tensors
- ConvNets

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$$\begin{bmatrix} p_x \\ p_y \\ p_z \end{bmatrix}$$

$$\begin{bmatrix} a_{11} & \cdots & a_{1n} \\ \vdots & \ddots & \vdots \\ a_{m1} & \cdots & a_{mn} \end{bmatrix}$$

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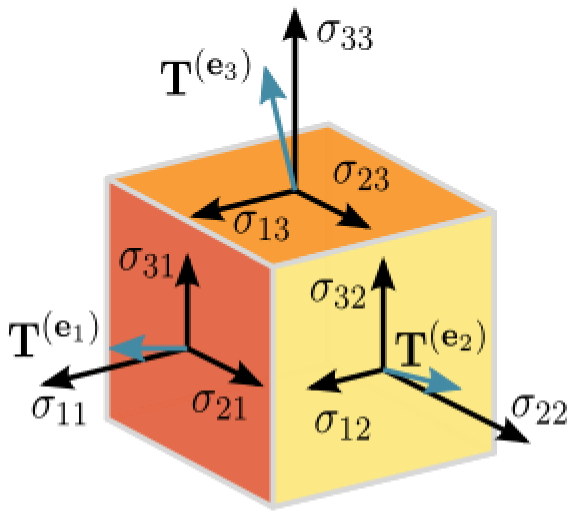

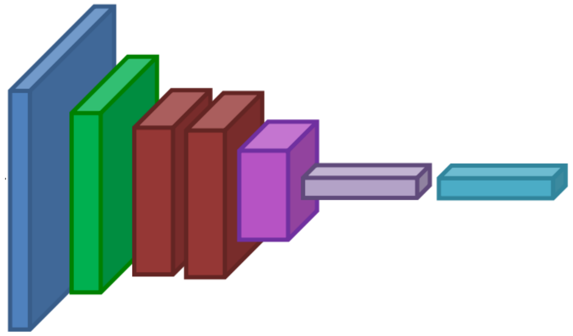

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Arrays, Basic Properties

```
import numpy as np
a = np.array([[1,2,3],[4,5,6]],dtype=np.float32)
print a.ndim, a.shape, a.dtype
```

1. Arrays can have any number of dimensions, including zero (a scalar).
2. Arrays are typed: np.uint8, np.int64, np.float32, np.float64
3. Arrays are dense. Each element of the array exists and has the same type.

Arrays, creation

- np.ones, np.zeros
- np.arange
- np.concatenate
- np.astype
- np.zeros_like, np.ones_like
- np.random.random

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```
>>> np.ones((3,5),dtype=np.float32)
array([[ 1.,  1.,  1.,  1.,  1.],
       [ 1.,  1.,  1.,  1.,  1.],
       [ 1.,  1.,  1.,  1.,  1.]], dtype=float32)
```

```
>>> np.zeros((6,2),dtype=np.int8)
array([[0, 0],
       [0, 0],
       [0, 0],
       [0, 0],
       [0, 0],
       [0, 0]], dtype=int8)
```

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```
>>> np.arange(1334,1338)
array([1334, 1335, 1336, 1337])
```

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```
>>> A = np.ones((2,3))
>>> B = np.zeros((4,3))
>>> np.concatenate([A,B])
array([[ 1.,  1.,  1.],
       [ 1.,  1.,  1.],
       [ 0.,  0.,  0.],
       [ 0.,  0.,  0.],
       [ 0.,  0.,  0.],
       [ 0.,  0.,  0.]])
>>>
```

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```
>>> A = np.ones((4,1))
>>> B = np.zeros((4,2))
>>> np.concatenate([A,B], axis=1)
array([[ 1.,  0.,  0.],
       [ 1.,  0.,  0.],
       [ 1.,  0.,  0.],
       [ 1.,  0.,  0.]])
```

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```
>>> A
array([[ 4670.5,  4670.5,  4670.5],
       [ 4670.5,  4670.5,  4670.5],
       [ 4670.5,  4670.5,  4670.5],
       [ 4670.5,  4670.5,  4670.5],
       [ 4670.5,  4670.5,  4670.5]], dtype=float32)
>>> print(A.astype(np.uint16))
[[4670 4670 4670]
 [4670 4670 4670]
 [4670 4670 4670]
 [4670 4670 4670]
 [4670 4670 4670]]
```

Arrays, creation

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- np.arange
- np.concatenate
- np.astype
- **np.zeros_like, np.ones_like**
- np.random.random

```
>>> a = np.ones((2,2,3))
>>> b = np.zeros_like(a)
>>> print(b.shape)
```

Arrays, creation

- np.ones, np.zeros
- np.arange
- np.concatenate
- np.astype
- np.zeros_like, np.ones_like
- **np.random.random**

```
>>> np.random.random((10,3))
array([[ 0.61481644,  0.55453657,  0.04320502],
       [ 0.08973085,  0.25959573,  0.27566721],
       [ 0.84375899,  0.2949532 ,  0.29712833],
       [ 0.44564992,  0.37728361,  0.29471536],
       [ 0.71256698,  0.53193976,  0.63061914],
       [ 0.03738061,  0.96497761,  0.01481647],
       [ 0.09924332,  0.73128868,  0.22521644],
       [ 0.94249399,  0.72355378,  0.94034095],
       [ 0.35742243,  0.91085299,  0.15669063],
       [ 0.54259617,  0.85891392,  0.77224443]])
```

Arrays, danger zone

- Must be dense, no holes.
- Must be one type
- Cannot combine arrays of different shape

```
>>> np.ones([7,8]) + np.ones([9,3])
Traceback (most recent call last):
  File "<stdin>", line 1, in <module>
ValueError: operands could not be broadcast together
 with shapes (7,8) (9,3)
```

Shaping

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

a = a.reshape(3,2)

a = a.reshape(2,-1)

a = a.ravel()
```

1. Total number of elements cannot change.
2. Use -1 to infer axis shape
3. Row-major by default (MATLAB is column-major)

Return values

- Numpy functions return either **views** or **copies**.
- Views share data with the original array, like references in Java/C++. Altering entries of a view, changes the same entries in the original.
- The numpy documentation says which functions return views or copies
- Np.copy, np.view make explicit copies and views.

Transposition

```
a = np.arange(10).reshape(5,2)

a = a.T

a = a.transpose((1,0))
```

np.transpose permutes axes.

a.T transposes the first two axes.

Saving and loading arrays

```
np.savez(‘data.npz’, a=a)
data = np.load(‘data.npz’)
a = data[‘a’]
```

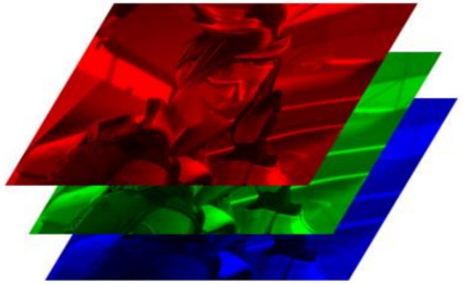
1. NPZ files can hold multiple arrays
2. np.savez_compressed similar.

Image arrays

Images are 3D arrays: width, height, and channels

Common image formats:

- height x width x RGB (band-interleaved)
- height x width (band-sequential)



Gotchas:

- Channels may also be BGR (OpenCV does this)
- May be [width x height], not [height x width]

Saving and Loading Images

SciPy: `skimage.io.imread,skimage.io.imsave`

height x width x RGB

PIL / Pillow: `PIL.Image.open, Image.save`

width x height x RGB

OpenCV: `cv2.imread, cv2.imwrite`

height x width x BGR

Recap

We just saw how to create arrays, reshape them, and permute axes

Questions so far?

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We just saw how to create arrays, reshape them, and permute axes

Questions so far?

Now: let's do some math

Mathematical operators

- Arithmetic operations are element-wise
- Logical operator return a bool array
- In place operations modify the array

Mathematical operators

- **Arithmetic operations are element-wise**
- Logical operator return a bool array
- In place operations modify the array

```
>>> a
array([1, 2, 3])
>>> b
array([ 4,  4, 10])
>>> a * b
array([ 4,  8, 30])
```

Mathematical operators

- Arithmetic operations are element-wise
- **Logical operator return a bool array**
- In place operations modify the array

```
>>> a
array([[ 0.93445601,  0.42984044,  0.12228461],
       [ 0.06239738,  0.76019703,  0.11123116],
       [ 0.14617578,  0.90159137,  0.89746818]])
>>> a > 0.5
array([[ True, False, False],
       [False,  True, False],
       [False,  True,  True]], dtype=bool)
```

Mathematical operators

- Arithmetic operations are element-wise
- Logical operator return a bool array
- **In place operations modify the array**

```
>>> a
array([[ 4, 15],
       [20, 75]])
>>> b
array([[ 2,  5],
       [ 5, 15]])
>>> a /= b
>>> a
array([[2, 3],
       [4, 5]])
```

Math, upcasting

Just as in Python and Java, the result of a math operator is cast to the more general or precise datatype.

uint64 + uint16 => uint64

float32 / int32 => float32

Warning: upcasting does not prevent overflow/underflow. You must manually cast first.

Use case: images often stored as uint8. You should convert to float32 or float64 before doing math.

Math, universal functions

Also called ufuncs

Element-wise

Examples:

- np.exp
- np.sqrt
- np.sin
- np.cos
- np.isnan

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Examples:

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```
>>> a
array([[ 1,  4],
       [ 9, 16],
       [25, 36]])
>>> np.sqrt(a)
array([[ 1.,  2.],
       [ 3.,  4.],
       [ 5.,  6.]])
```

Indexing

```
x[0,0]    # top-left element
x[0,-1]   # first row, last column
x[0,:]    # first row (many entries)
x[:,0]    # first column (many entries)
```

Notes:

- Zero-indexing
- Multi-dimensional indices are comma-separated (i.e., a tuple)

Indexing, slices and arrays

```
I[1:-1,1:-1]        # select all but one-pixel border
I = I[:,:,::-1]     # swap channel order
I[I<10] = 0         # set dark pixels to black
I[[1,3], :]         # select 2nd and 4th row
```

1. Slices are **views**. Writing to a slice overwrites the original array.
2. Can also index by a list or boolean array.

Python Slicing

Syntax: start:stop:step

```
a = list(range(10))

a[:3] # indices 0, 1, 2

a[-3:] # indices 7, 8, 9

a[3:8:2] # indices 3, 5, 7

a[4:1:-1] # indices 4, 3, 2 (this one is tricky)
```

Axes

```
a.sum() # sum all entries

a.sum(axis=0) # sum over rows

a.sum(axis=1) # sum over columns

a.sum(axis=1, keepdims=True)
```

1. Use the axis parameter to control which axis NumPy operates on
2. Typically, the axis specified will disappear, keepdims keeps all dimensions

Broadcasting

```
a = a + 1 # add one to every element
```

When operating on multiple arrays, broadcasting rules are used.

Each dimension must match, from right-to-left

1. Dimensions of size 1 will broadcast (as if the value was repeated).
2. Otherwise, the dimension must have the same shape.
3. Extra dimensions of size 1 are added to the left as needed.

Broadcasting example

Suppose we want to add a color value to an image

a.shape is 100, 200, 3

b.shape is 3

a + b will pad b with two extra dimensions so it has an effective shape of 1 x 1 x 3.

So, the addition will broadcast over the first and second dimensions.

Broadcasting failures

If a.shape is 100, 200, 3 but b.shape is 4 then a + b will fail. The trailing dimensions must have the same shape (or be 1)

Tips to avoid bugs

1. Know what your datatypes are.
2. Check whether you have a view or a copy.
3. Use matplotlib for sanity checks.
4. Use pdb to check each step of your computation.
5. Know np.dot vs np.mult.

Average images

Who is this?

Practice exercise (not graded)

Compute the average image of faces.

1. Download Labeled Faces in the Wild dataset (google: LFW face dataset). Pick a face with at least 100 images.
2. Call numpy.zeros to create a 250 x 250 x 3 float64 tensor to hold the result
3. Read each image with skimage.io.imread, convert to float and accumulate
4. Write the averaged result with skimage.io.imsave