COMPSCI 590N
Lecture 5: NumPy 1

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Outline

What is NumPy?

Numerical Python (NumPy) is the backbone of the Python scientific programming stack:

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Typical import convention:

```
import numpy as np
```

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  - Image pixel values
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- Mutable contents, but not size.
- In general, no mixed types.

Constructing Arrays

Arrays can be created manually:

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```
>>> a = np.array([1, 2]) # 1-D
>>> a
array([1, 2])
>>> b = np.array([[1,2],[3,4]]) # 2-D
>>> b
array([[1, 2],
       [3, 4]])
>>> c = np.array([[[1,2],[3,4]],[[5,6],[7,8]]]) # 3-D
>>> c
array([[[1, 2],
        [3, 4]],

       [[5, 6],
        [7, 8]]])
```

Constructing Arrays

Many functions exist to create NumPy Arrays:

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```
# Create a range
>>> np.arange(5)
array([0, 1, 2, 3, 4])
>>> np.arange(0,10,2) # start, end, step size
array([0, 2, 4, 6, 8])

# Or specify a number of points
>>> np.linspace(0,1,5) # start, end, number of points
array([ 0.  ,  0.25,  0.5 ,  0.75,  1.  ])
```

Constructing Arrays

Many functions exist to create NumPy Arrays:

```
# Create an array filled with ones
>>> np.ones(5)
array([ 1.,  1.,  1.,  1.,  1.])

# Or zeros
# Specify multiple dimensions as a tuple
>>> np.zeros((2,2))
array([[ 0.,  0.],
       [ 0.,  0.]])
```

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```
# Create an array filled with ones
>>> np.array([1,2,3], dtype=np.int32)
array([1, 2, 3], dtype=int32)

>>> np.array([1,2,3], dtype=np.float64)
array([ 1.,  2.,  3.])

>>> np.array([1,0,1], dtype=bool)
array([ True, False,  True], dtype=bool)
```

Interactive NumPy Demo

Interactive Demo

1. What do the attributes `size`, `shape`, `ndim`, and `dtype` store?
2. NumPy arrays can also be created using the following three methods. What does each one do?
   - `eye`
   - `diag`
   - `empty`
3. What are the default number of bits for numpy floats and ints?

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3. What are the default number of bits for numpy floats and ints?
   - `float64` and `int64`

Outline

1 Numpy and Arrays

2 Element-wise Operations and Indexing

Mathematical Operators

NumPy supports standard arithmetic operations between scalars and arrays:

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```
>>> np.ones(3) + 2
array([ 3.,  3.,  3.])

>>> np.ones(3) - 2
array([-1., -1., -1.])

>>> np.ones(3) * 2
array([ 2.,  2.,  2.])

>>> np.ones(3) / 2
array([ 0.5,  0.5,  0.5])
```

Mathematical Operators

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```
>>> np.arange(1,4) + np.arange(1,4)
array([2, 4, 6])

>>> np.arange(1,4) - np.arange(1,4)
array([0, 0, 0])

# Not matrix multiplication!
>>> np.arange(1,4) * np.arange(1,4)
array([1, 4, 9])

>>> np.arange(1,4) / np.arange(1,4)
array([ 1.,  1.,  1.])
```

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array([1, 4, 9])

>>> np.arange(1,4) / np.arange(1,4)
array([ 1.,  1.,  1.])
```

Note: Python has a special function for matrix multiplication.

Logical Operators

Logical operators work in a similar fashion:

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```
>>> np.arange(4) == 2
array([False, False,  True, False], dtype=bool)

>>> (np.array([[0,1],[2,3]]) % 2) == 0
array([[ True, False],
       [ True, False]], dtype=bool)

>>> np.array([1,2,3,4]) < np.array([0,9,9,0])
array([False,  True,  True, False], dtype=bool)
```

Indexing

Access a single element by providing an index for each dimension separated by commas:

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```
>>> a = np.arange(6)
>>> a
array([0, 1, 2, 3, 4, 5])
>>> a[5]
5

>>> b = np.diag(np.arange(3))
>>> b
array([[0, 0, 0],
       [0, 1, 0],
       [0, 0, 2]])
>>> b[2,2]
2
```

Slicing

Access multiple entries along a dimension using ":" notation. This is called *slicing*.

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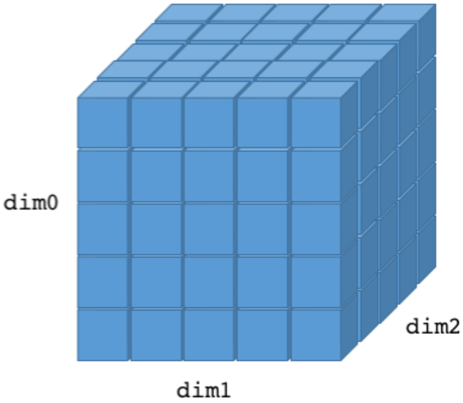
```
>>> a = np.arange(10)
>>> a
array([0, 1, 2, 3, 4, 5, 6, 7, 8, 9])
>>> a[1:9:2] # start, end, step size
array([1, 3, 5, 7])

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

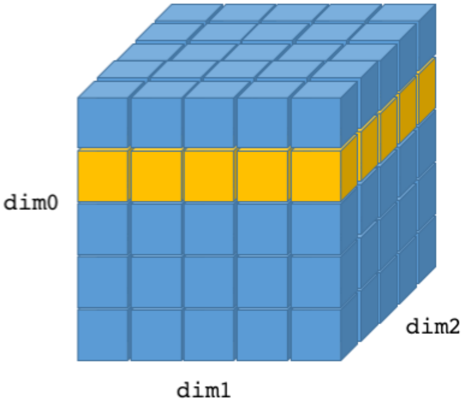
N-D Slicing

```
X = np.ones((5,5,5))
```



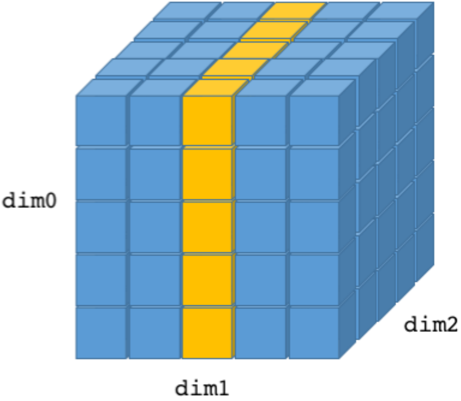
N-D Slicing

```
X = np.ones((5,5,5))
A = X[1,:,:]
```



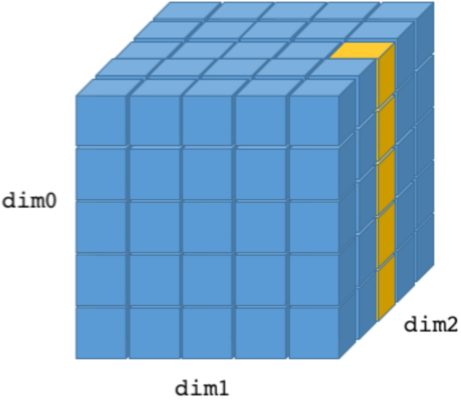
N-D Slicing

```
X = np.ones((5,5,5))
A = X[1,:,:]
B = X[:,2,:]
```



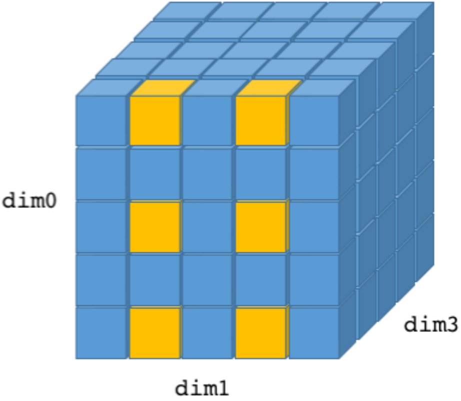
N-D Slicing

```
X = np.ones((5,5,5))
A = X[1,:,:]
B = X[:,2,:]
C = X[:,4,2]
```



N-D Slicing

```
X = np.ones((5,5,5))
A = X[1,:,:]
B = X[:,2,:]
C = X[:,4,2]
D = X[::2,1::2,0]
```



N-D Slicing

If a single index is passed for a dimension, the result will have one fewer dimensions than the original array.

```
>>> a = np.ones((2,3,4))
>>> a[:,1,:].shape
(2,4)
```

Entry/Slice Assignment

As with lists, we can assign to individual array entries or slices.

```
>>> a = np.ones((3,3))
>>> a[2,1] = 9
>>> a
array([[ 1.,  1.,  1.],
       [ 1.,  1.,  1.],
       [ 1.,  9.,  1.]])
>>> a[:,0] = 5
>>> a
array([[ 5.,  1.,  1.],
       [ 5.,  1.,  1.],
       [ 5.,  9.,  1.]])
>>> a[0,:] = np.arange(3)
>>> a
array([[ 0.,  1.,  2.],
       [ 5.,  1.,  1.],
       [ 5.,  9.,  1.]])
```

Interactive Demo

Interactive Demo

1. Create an the following array:
   - $a_j = 2^{3j} - j,\ j = 1, ..., 10$
2. `np.all` and `np.any` are NumPy functions that operate on boolean arrays. What do these functions do?
3. How do you extract matrix B from matrix A with only indexing?

$$A = \begin{bmatrix} 1 & 2 & 3 & 4 & 5 \\ 6 & 7 & 8 & 9 & 10 \\ 11 & 12 & 13 & 14 & 15 \\ 16 & 17 & 18 & 19 & 20 \\ 21 & 22 & 23 & 24 & 25 \end{bmatrix} \quad B = \begin{bmatrix} 25 & 23 & 21 \\ 15 & 13 & 11 \\ 5 & 3 & 1 \end{bmatrix}$$

Interactive Demo

Interactive Demo

1. Create an the following array:
   - $a_j = 2^{3j} - j,\ j = 1, ..., 10$
   - `a = 2**(3*np.arange(1,11))-np.arange(1,11)`
2. `np.all` and `np.any` are NumPy functions that operate on boolean arrays. What do these functions do?
   - `np.all` returns `True` if all elements of the array are true.
   - `np.any` returns `True` if any elements of the array are true.
3. How do you extract matrix B from matrix A with only indexing?
   - `B = A[::-2,::-2]`