

Advanced



Lisa Schwetlick, ASPP 2020



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IMN

Numpy

```
Python 3.8.0 (default, Feb  3 2020, 09:42:15)
Type 'copyright', 'credits' or 'license' for more information
IPython 7.12.0 -- An enhanced Interactive Python. Type '?' for help.

In [1]: import numpy as np
```

... it's that library you always load, without even thinking about it.

REALLY, REALLY BASIC

~~Advanced~~



that you never thought
about

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IMN

1. Numpy Array Warmup

2. Indexing

- Python lists
- Numpy indexes, slices, and some fancy-ness

3. At the heart of Numpy

- Underneath the ndarray
- Views and copies

Coffee Break

3. At the heart of Numpy

- Broadcasting

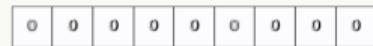
4. Tricks, Conventions, and Applications

- Saving stuff
- Errors
- Reshaping

Topic 1: Numpy Arrays

Making them (1D)

```
np.array([0,0,0,0,0,0,0,0,0])
```



```
np.zeros(9)
```



```
np.ones(9)
```



```
np.arange(9)
```



```
np.random.randint(0,9,(1,9))
```



Topic 1: Numpy Arrays

Making them (2D)

```
np.array(  
[[0,0,0,0,0,0,0,0,0],  
[0,0,0,0,0,0,0,0,0],  
[0,0,0,0,0,0,0,0,0],  
[0,0,0,0,0,0,0,0,0],  
[0,0,0,0,0,0,0,0,0],  
[0,0,0,0,0,0,0,0,0]])
```

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

```
np.zeros((5,9))
```

0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0

```
np.ones((5,9))
```

1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1
1	1	1	1	1	1	1	1	1

```
np.arange(5*9).reshape(5,9)
```

0	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	26
27	28	29	30	31	32	33	34	35
36	37	38	39	40	41	42	43	44

```
np.random.randint(0,9,(5,9))
```

2	5	7	6	1	3	1	6	7
5	0	0	3	3	3	2	5	7
7	6	2	8	8	3	8	5	1
1	3	5	7	2	2	8	4	4
4	6	8	8	0	3	7	4	3

Topic 1: Numpy Arrays

Making Grids

```
yy, xx = np.ogrid[1:5, 1:9]
```

1
2
3
4

1	2	3	4	5	6	7	8
---	---	---	---	---	---	---	---

```
yy, xx = np.mgrid[1:5, 1:9]
```

1	1	1	1	1	1	1	1
2	2	2	2	2	2	2	2
3	3	3	3	3	3	3	3
4	4	4	4	4	4	4	4

1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8
1	2	3	4	5	6	7	8

> Exercise 1

1. Make a random 10x10 numpy array and visualize it.
2. Simulate some roulette rounds in Python and using Numpy. Test which is faster.
3. Use `print(hex(id(mylist)))` to look at tuples and lists and when you change them.

see file `Exercises_Notebook_1.py`

Topic 2: Indexing

Reminder of basic python indexes

Lists can be indexed with a single number:

```
1 my_list = [1,2,3,4,5]
2 print(my_list)
```

Topic 2: Indexing

Reminder of basic python indexes

Lists can be indexed with a single number:

```
1 my_list = [1,2,3,4,5]
2 print(my_list)
```

```
>>> [1,2,3,4,5]
```

Topic 2: Indexing

Reminder of basic python indexes

Lists can be indexed with a single number:

```
1 my_list = [1,2,3,4,5]
2 print(my_list)
```

```
>>> [1,2,3,4,5]
```

```
1 print(my_list[2])
```

Topic 2: Indexing

Reminder of basic python indexes

Lists can be indexed with a single number:

```
1 my_list = [1,2,3,4,5]
2 print(my_list)
```

```
>>> [1,2,3,4,5]
```

```
1 print(my_list[2])
```

```
>>> 3
```

Topic 2: Indexing

Reminder of basic python indexes

What is this?

```
1 my_list = [1,2,3,4,5]
2 print(my_list[2:4])
```

Topic 2: Indexing

Reminder of basic python indexes

What is this?

```
1 my_list = [1,2,3,4,5]
2 print(my_list[2:4])
```

```
>>> [3,4]
```

... it's a slice!

Topic 2: Indexing

Reminder of basic python indexes

```
1 my_list = [1,2,3,4,5]
```

Indexing python lists also works using a *slice* object:

- ▶ it is made using the *slice()* function OR triggered when there is a ":" inside "[]"
- ▶ sliced lists return a part of the original list
- ▶ can be used to modify *in-place*

```
1 print(my_list[2:4])
2 print(my_list[::-2])
3 print(my_list[slice(0,4,2)]) # equivalent
```

```
>>> [3,4]
>>> [1,3,5]
>>> [1,3,5]
```

Topic 2: Indexing

Reminder of basic python indexes

```
1 my_list = [1,2,3,4,5]
```

Indexing python lists also works using a *slice* object:

- ▶ it is made using the *slice()* function OR triggered when there is a ":" inside "[]"
- ▶ sliced lists return a part of the original list
- ▶ can be used to modify *in-place*

```
1 print(my_list[2:4])
```

```
>>> [3,4]
```

Topic 2: Indexing

Reminder of basic python indexes

```
1 my_list = [1,2,3,4,5]
```

Indexing python lists also works using a *slice* object:

- ▶ it is made using the *slice()* function OR triggered when there is a ":" inside "[]"
- ▶ sliced lists return a part of the original list
- ▶ can be used to modify *in-place*

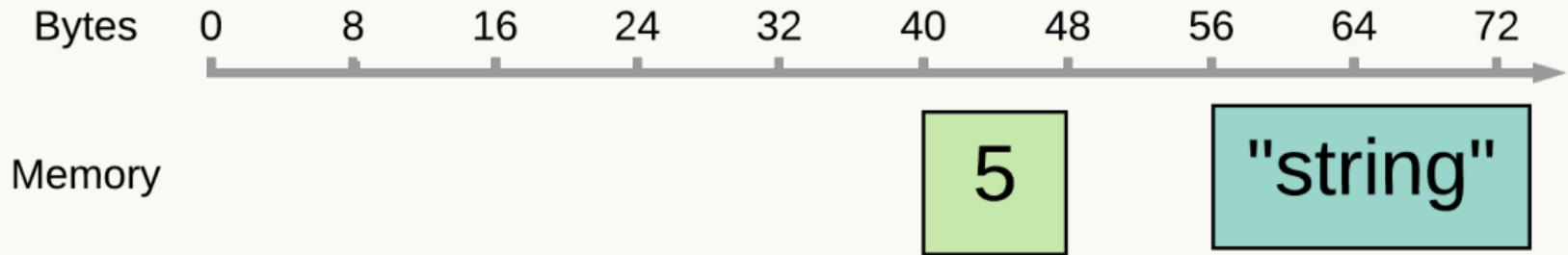
```
1 print(my_list, "at", hex(id(my_list)))
2 my_list[2:4] = [9,8]
3 print(my_list, "at", hex(id(my_list)))
```

```
>>> [1, 2, 3, 4, 5] at 0x127885500
>>> [1, 2, 9, 8, 5] at 0x127885500
```

Topic 1: Numpy Arrays

actually, what is a list?

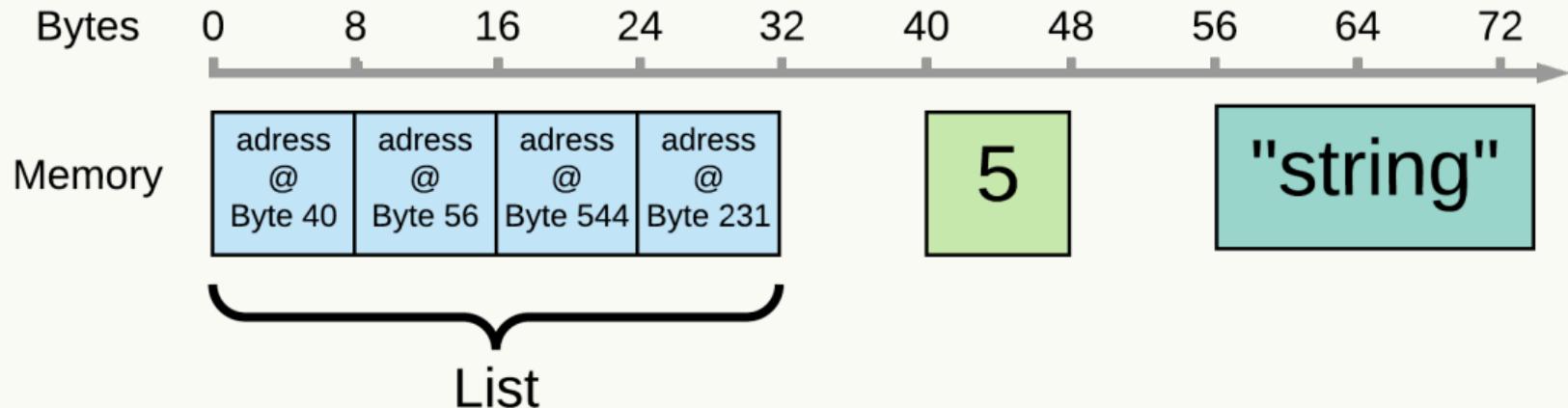
```
[In [2]: list = [5, "string", 3.5, ('tu', 'ple')]
```



Topic 1: Numpy Arrays

actually, what is a list?

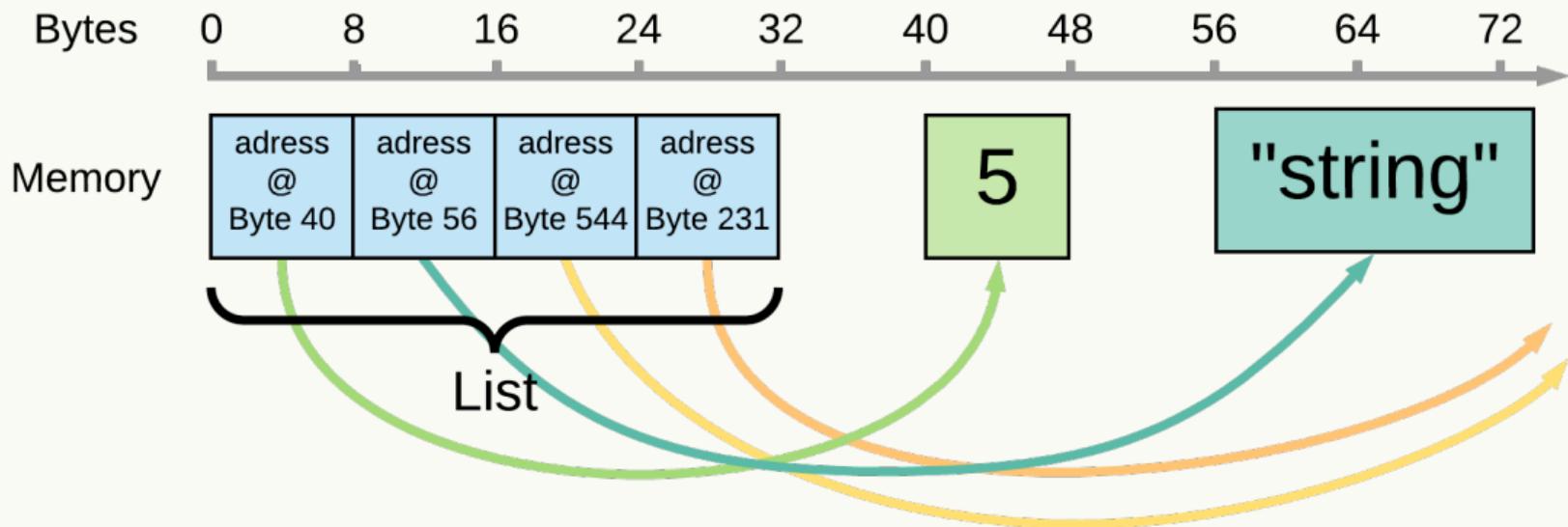
```
[In [2]: list = [5, "string", 3.5, ('tu', 'ple')]
```



Topic 1: Numpy Arrays

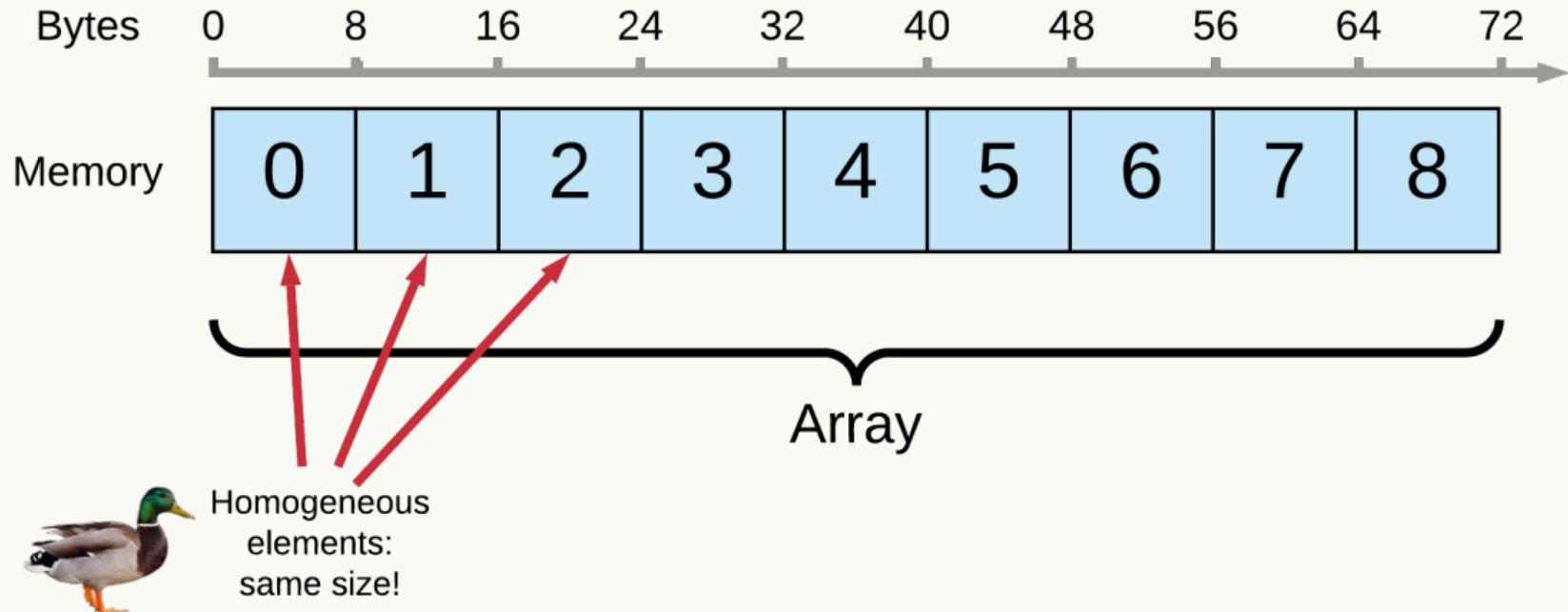
actually, what is a list?

```
[In [2]: list = [5, "string", 3.5, ('tu', 'ple')]
```



Topic 1: Numpy Arrays

This is an Array!



Topic 1: Numpy Arrays

so what's the difference?

	Python List	Numpy Array
Dimensions	1	n
Elements	can be different types	must be homogeneous
Memory Layout	Stores addresses at which the element data is located	One contiguous block of memory
Memory Access	Access address, then access data	direct data access
Size	Expandable	Not expandable
Contents	Mutable	Mutable
Good for...	variable sequences	large amounts of data; data that will be operated on; vectorization

> Exercise 2

1. Make a random 10x10 numpy array. Print the element in the fourth column and the fifth row.
2. Print the entire fifth row.

see file `Exercises_Notebook_1.py`

Topic 2: Indexing

Numpy arrays can have multiple dimensions

```
1 a = np.random.randint(1, 10, (5,5))  
2 print(a)
```

```
>>> array([[8, 2, 3, 1, 7],  
>>>          [2, 8, 1, 8, 2],  
>>>          [5, 6, 3, 2, 4],  
>>>          [5, 2, 8, 2, 2],  
>>>          [6, 9, 5, 5, 9]])
```

Topic 2: Indexing

Ways to index a numpy array

1. field access indexing 'a[1][2][3]'
2. regular indexing 'a[1,2,3]'
3. slicing 'a[1:3, 1:3]'
4. fancy indexing 'a[[1,2], [1,2]]'

The first three are sometimes called "Orthogonal Indexing".

if you want more:

Check out the `indexing.ipynb`. It shows off all the different kinds of indexing and combinations!

Topic 2: Indexing

Ways to index a numpy array

1. field access indexing 'a[1][2][3]'
2. regular indexing 'a[1,2,3]'
3. slicing 'a[1:3, 1:3]'
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Ways to index a numpy array

1. field access indexing 'a[1][2][3]'
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Topic 2: Indexing

Ways to index a numpy array

1. field access indexing 'a[1][2][3]'
2. regular indexing 'a[1,2,3]'
3. slicing 'a[1:3, 1:3]'
4. fancy indexing 'a[[1,2], [1,2]]'

The first three are sometimes called "Orthogonal Indexing".

if you want more:

Check out the indexing.ipynb. It shows off all the different kinds of indexing and combinations!

Topic 2: Indexing

Field Access Indexing

Numpy arrays are compatible with lists of lists in pure python and they can be accessed like this:

```
1 # 3-dimensional array
2 a = zeros(3,3,3)
3 z = x = y = 1
4 a[z][x][y]
```

Topic 2: Indexing

Regular Indexing

The more common usage is with just one set of square brackets:

Dimensions are represented by commas. To index explicitly, you need as many values separated by commas as dimensions.

```
1 a = np.random.randint(1, 10, (5,5))  
2 row = 2  
3 col = 3  
4 a[row, col]
```

```
>>> 2
```

Topic 2: Indexing

Common pitfall: don't think of the index as coordinates (x and y): They are interpreted in the reverse order!

```
1 a = np.random.randint(1, 10, (2, 3, 4))  
2 print(a)
```

```
>>> array([[[8, 2, 6, 7],  
>>>           [7, 5, 6, 2],  
>>>           [1, 8, 6, 1]],  
>>>  
>>>           [[[7, 3, 7, 9],  
>>>             [2, 4, 2, 1],  
>>>             [1, 1, 8, 3]]])
```

```
1 >>> x = y = z = 1  
2 >>> print(a[z, y, x])
```

```
>>> 4
```

Topic 2: Indexing

Numpy Slice

- ▶ Numpy slicing expands the slice syntax into n dimensions
- ▶ you pass one slice object per dimension in the array
- ▶ There are three big differences to base python slicing:
 1. slicing can be done over multiple dimensions
 2. exactly one ellipsis object "..." can be used to indicate several dimensions at once,
 3. slicing cannot be used to expand the size of an array (unlike lists).

Topic 2: Indexing

Slicing Shorthands

There are some convenient shorthands/default expansions like:

- ▶ If you want all indexes from a dimension use ":"
- ▶ Ellipses [...] can be used to replace zero or more ":" terms
- ▶ If you give fewer comma-separated values than dimensions, it assumes you provided the first dimension's indexes.

```
1 # 3-dimensional array
2 a = zeros(3,3,3)
3 # access the second element of the first dimension
4 a[1, :, :] # explicit
5 a[1, ...] # equivalent
6 a[1] # equivalent
```

Topic 2: Indexing

What Dimensionality is my output?

When slicing Dimensionality of the output is determined by the combined dimensionality of the indexes

```
1 a = np.zeros((5,5,5))  
2 a[1, ::2, ::2].shape
```

Topic 2: Indexing

What Dimensionality is my output?

When slicing Dimensionality of the output is determined by the combined dimensionality of the indexes

```
1 a = np.zeros((5,5,5))  
2 a[1, ::2, ::2].shape
```

```
>>> (3,3)
```

Topic 2: Indexing

What Dimensionality is my output?

Single element dimensions disappear

```
1 a = np.zeros((3,3))  
2 a[1,:,:].shape
```

```
>>> (3,)
```

Topic 2: Indexing

What Dimensionality is my output?

What if I can't use slices, because I want some irregular subset of the data?

```
1 a = np.zeros((5,5))
```

I want every second row and the second and third column!

Topic 2: Indexing

What Dimensionality is my output?

What if I can't use slices, because I want some irregular subset of the data?

```
1 a = np.zeros((5,5))
```

I want every second row and the second and third column!

```
1 a[::-2, [2,3]].shape
```

Answer: using a list of indices also works

Topic 2: Indexing

What Dimensionality is my output?

What if I can't use slices, because I want some irregular subset of the data?

```
1 a = np.zeros((5,5))
```

I want every second row and the second and third column!

```
1 a[::-2, [2,3]].shape
```

Answer: using a list of indices also works

```
>>> (3,2)
```

Topic 2: Indexing

What Dimensionality is my output?

Before we indexed with a slice and a list. Now how about two lists?
What do you think happens here?

```
1 a = np.zeros((5,5))  
2 a[[2,3], [2,3]].shape
```

Topic 2: Indexing

What Dimensionality is my output?

Before we indexed with a slice and a list. Now how about two lists?

What do you think happens here?

```
1 a = np.zeros((5,5))  
2 a[[2,3], [2,3]].shape
```

```
>>> (2,)
```



Topic 2: Indexing

Fancy Indexing

When indexing with multiple lists, they are interpreted as coordinates to look up.

... actually that's just a useful lie to believe for now. Let's talk about it later!

```
1 a = np.array(list("ABCDEFGHIJKLM NOPQRSTUVWXYZ")).reshape(4,6)
2 print(a)
```

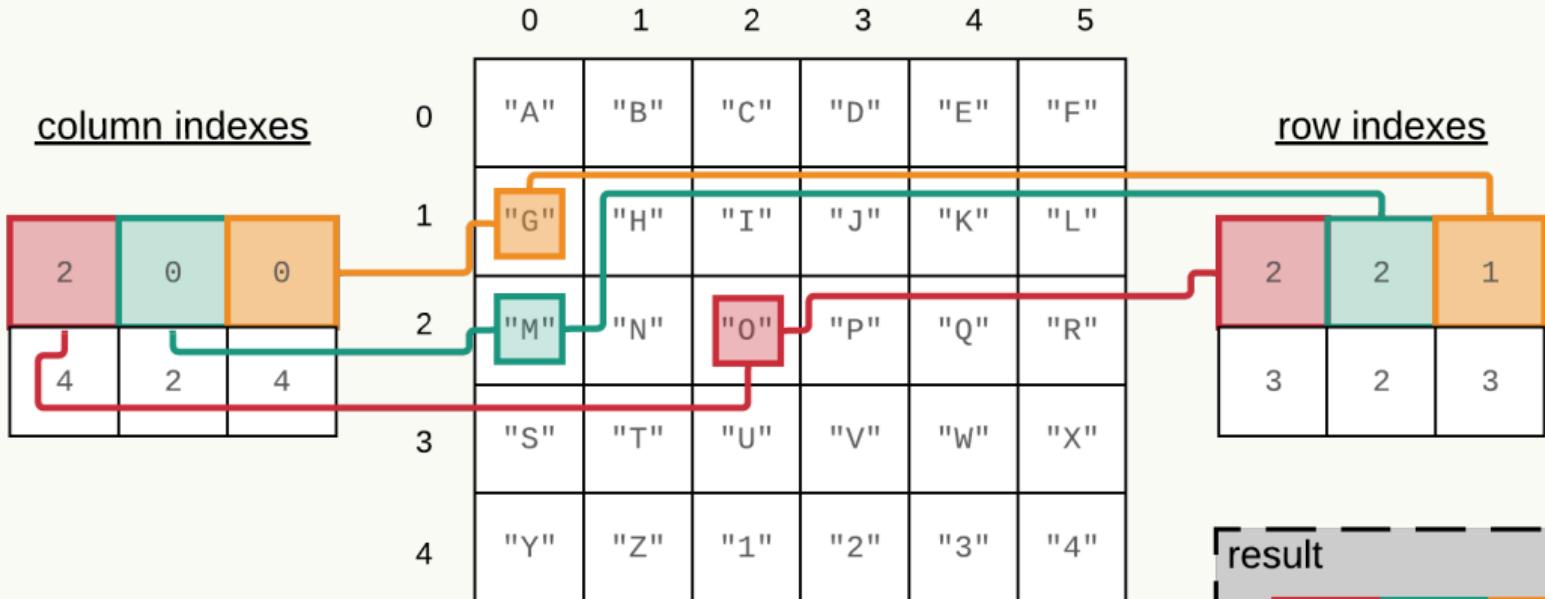
```
>>> array([[ 'A', 'B', 'C', 'D', 'E', 'F'],
>>>          [ 'G', 'H', 'I', 'J', 'K', 'L'],
>>>          [ 'M', 'N', 'O', 'P', 'Q', 'R'],
>>>          [ 'S', 'T', 'U', 'V', 'W', 'X']], dtype='<U1')
```

```
1 print(a[[3,3,0],[4,1,5]])
```

```
>>> array(['W', 'T', 'F'], dtype='<U1')
```

TOPIC 3: at the heart of Numpy

Fancy Indexing



result

"O"	"M"	"G"
"W"	"O"	"W"

Topic 2: Indexing

Fancy Indexing with Bools

If you pass an array of booleans, Numpy will return the values at the True positions.

```
1 a = np.random.randint(1, 10, (3,3))  
2 print(a)
```

```
>>> array([[9, 2, 7],  
>>>          [2, 6, 9],  
>>>          [1, 7, 3]])
```

Topic 2: Indexing

Fancy Indexing with Bools

If you pass an array of booleans, Numpy will return the values at the True positions.

```
1 a = np.random.randint(1, 10, (3,3))  
2 print(a)
```

```
>>> array([[9, 2, 7],  
>>>         [2, 6, 9],  
>>>         [1, 7, 3]])
```

```
1 print(a<5)
```

```
>>> array([[False,  True, False],  
>>>         [ True, False, False],  
>>>         [ True, False,  True]])
```

Topic 2: Indexing

Fancy Indexing with Bools

If you pass an array of booleans, Numpy will return the values at the True positions.

```
1 a = np.random.randint(1, 10, (3,3))  
2 print(a)
```

```
>>> array([[9, 2, 7],  
>>>      [2, 6, 9],  
>>>      [1, 7, 3]])
```

```
1 print(a[a<5])
```

```
>>> array([2, 2, 1, 3])
```

> Exercises 3

Recreate these plots

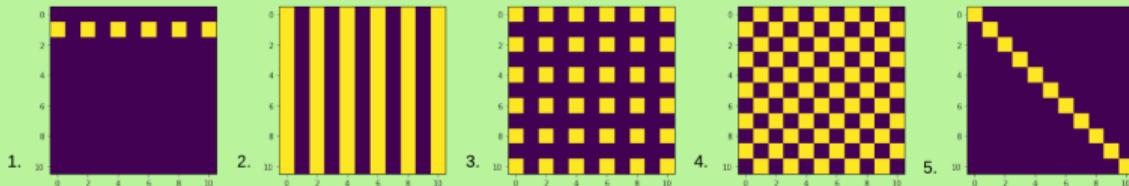
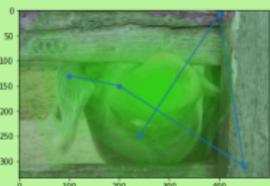


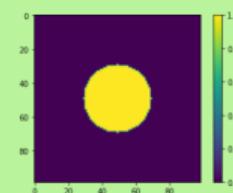
Image processing



Saliency map evaluation



Recreate this plot



see file `Exercises_Notebook_2.py`

TOPIC 3: at the heart of Numpy

Views and Copies

[...] a regular indexing expression on an ndarray can always produce an ndarray object **without copying any data**. This is sometimes referred to as the “**view**” feature of array indexing

— Guide to Numpy, pg. 30

- ▶ Slicing gives a view
- ▶ In-place operations can be done on views
- ▶ All fancy indexing returns a copy
- ▶ the `a.copy()` command gives a copy when specifically requested

TOPIC 3: at the heart of Numpy

Views and Copies

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

TOPIC 3: at the heart of Numpy

Views and Copies

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

```
>>> [3 4 5]
```

TOPIC 3: at the heart of Numpy

Views and Copies

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

```
>>> [3 4 5]
```

```
1 v[1] = 999
2 print(v)
```

TOPIC 3: at the heart of Numpy

Views and Copies

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

```
>>> [3 4 5]
```

```
1 v[1] = 999
2 print(v)
```

```
>>> [3 999 5]
```

TOPIC 3: at the heart of Numpy

Views and Copies

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

```
>>> [3 4 5]
```

```
1 v[1] = 999
2 print(v)
```

```
>>> [3 999 5]
```

```
1 print(a)
```

TOPIC 3: at the heart of Numpy

Views and Copies

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

```
>>> [3 4 5]
```

```
1 v[1] = 999
2 print(v)
```

```
>>> [3 999 5]
```

```
1 print(a)
```

```
>>> [1 2 3 999 5 6]
```

TOPIC 3: at the heart of Numpy

Views and Copies

```
1 a = np.zeros([4,4])  
2 print(a)
```

```
>>> [[0.  0.  0.  0.]  
>>> [0.  0.  0.  0.]  
>>> [0.  0.  0.  0.]  
>>> [0.  0.  0.  0.]
```

```
1 v = a[2:4, 2]  
2 v[1] = 9  
3 print(a)
```

```
1 v = a[[2,3], 2]  
2 v[1] = 9  
3 print(a)
```

```
>>> [[0.  0.  0.  0.]  
>>> [0.  0.  0.  0.]  
>>> [0.  0.  0.  0.]  
>>> [0.  0.  9.  0.]
```

```
>>> [[0.  0.  0.  0.]  
>>> [0.  0.  0.  0.]  
>>> [0.  0.  0.  0.]  
>>> [0.  0.  0.  0.]
```

TOPIC 3: at the heart of Numpy **ndarray**

An N-dimensional array is a **homogeneous** collection of “items” indexed using N integers.
There are two essential pieces of information that define an N-dimensional array:

1. the shape of the array
2. the kind of item the array is composed of

— Guide to Numpy, pg. 18

TOPIC 3: at the heart of Numpy ndarray

An N-dimensional array is a **homogeneous** collection of “items” indexed using N integers. There are two essential pieces of information that define an N-dimensional array:

1. the shape of the array
2. the kind of item the array is composed of

— Guide to Numpy, pg. 18

homogeneous: all elements in the array are of the same **type**. Therefore each item takes the same amount of memory (fixed number of bytes).



TOPIC 3: at the heart of Numpy ndarray

An N-dimensional array is a **homogeneous** collection of “items” indexed using N integers.
There are two essential pieces of information that define an N-dimensional array:

1. the shape of the array
2. the kind of item the array is composed of

— Guide to Numpy, pg. 18

homogeneous: all elements in the array are of the same **type**. Therefore each item takes the same amount of memory (fixed number of bytes).

type: typically one of the inbuilt types but it could be self-defined

TOPIC 3: at the heart of Numpy

ndarray

```
1 a = np.random.randint(1, 10, (3,3))  
2 print(a.shape)  
3 print(a.dtype)
```

```
>>> (3, 3)  
>>> dtype('int64')
```

TOPIC 3: at the heart of Numpy ndarray properties

```
>>> a = np.arange(0,9).reshape((3,3))
>>> tools.info(a)

Interface (item)
  shape:      (3, 3)
  dtype:      int64
  length:     3
  size:       9
  endianness: native (little)
  order:      ☐ C ☐ Fortran

Memory (byte)
  item size:   8
  array size: 72
  strides:    (24, 8)

Properties
  own data:   ☐ Yes ☐ No
  writeable:  ☐ Yes ☐ No
  contiguous: ☐ Yes ☐ No
  aligned:    ☐ Yes ☐ No

>>> a.data
<memory at 0x11b3d21e0>
```

Which information does the ndarray need?

- ▶ data: where to start reading
- ▶ strides/item size: by how many bits to move
- ▶ size: when to stop reading
- ▶ data type: how to interpret the bits
- ▶ order: which reading convention to use

TOPIC 3: at the heart of Numpy ndarray properties



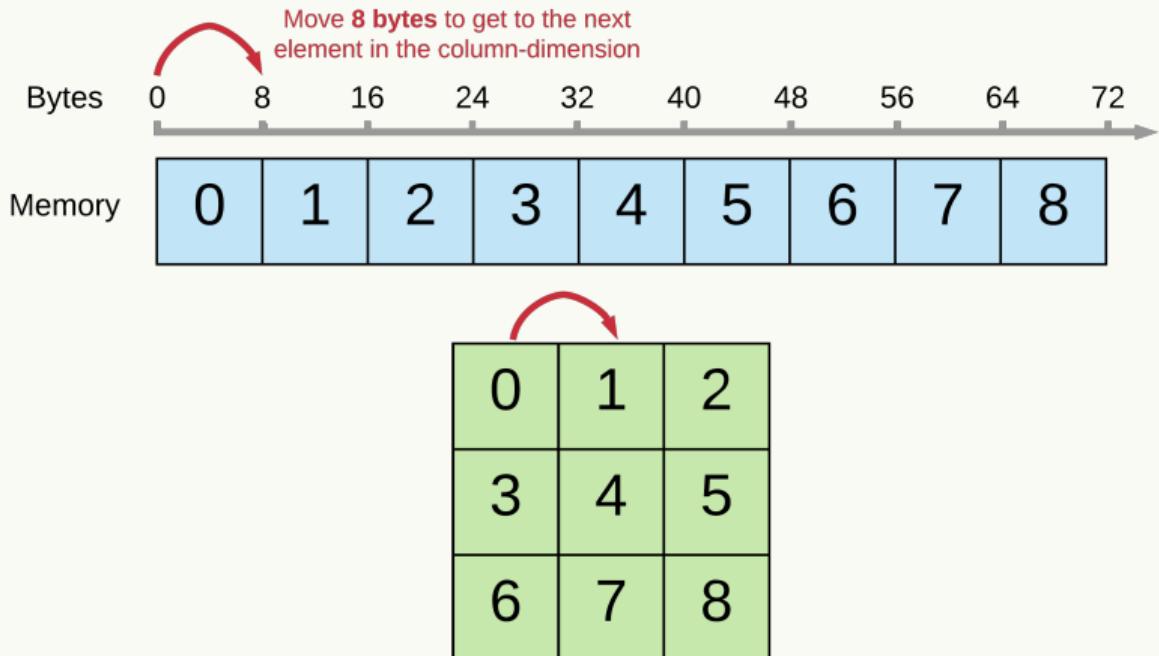
```
>>> a = np.random.rand(3,3)  
>>> a.strides  
(24, 8)
```

0	1	2
3	4	5
6	7	8

TOPIC 3: at the heart of Numpy

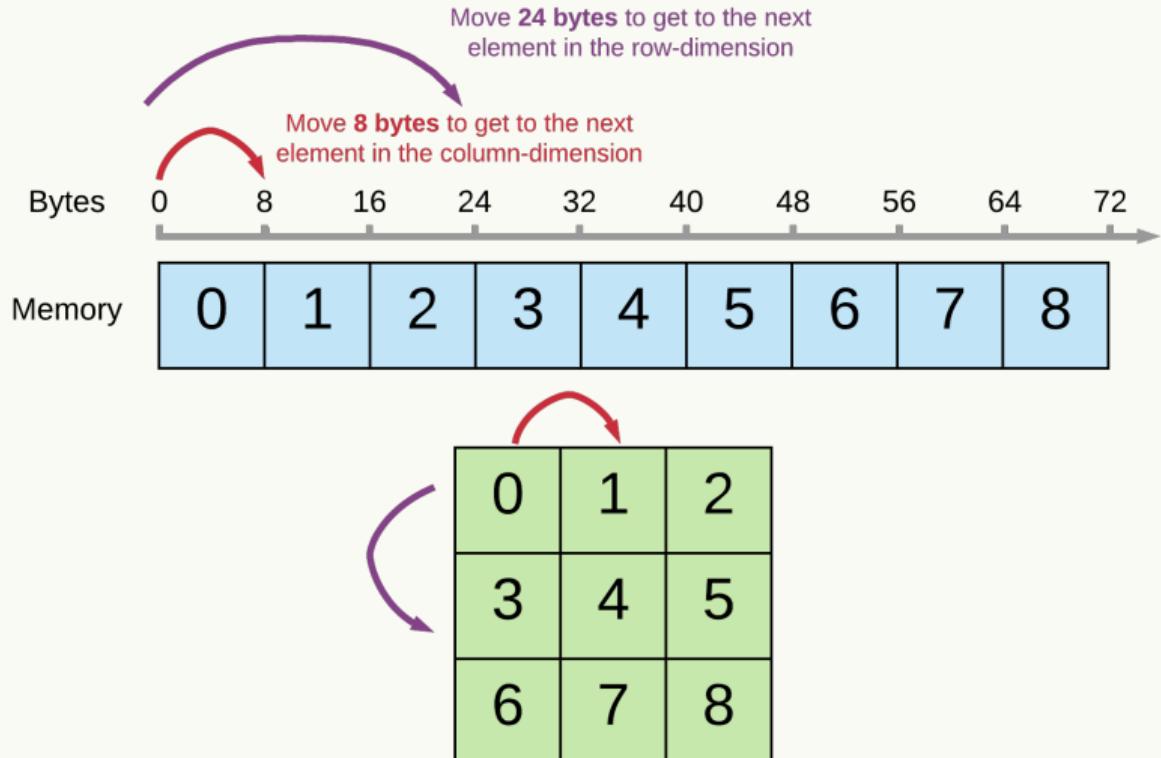
ndarray properties

```
>>> a = np.random.rand(3,3)  
>>> a.strides  
(24, 8)
```



TOPIC 3: at the heart of Numpy

ndarray properties



```
>>> a = np.random.rand(3,3)
>>> a.strides
(24, 8)
```

TOPIC 3: at the heart of Numpy

Question

Views and Copies

Why does fancy indexing return copies and slices return views?

Stride operations

What kind of operations are strides useful for?

TOPIC 3: at the heart of Numpy

ndarray properties

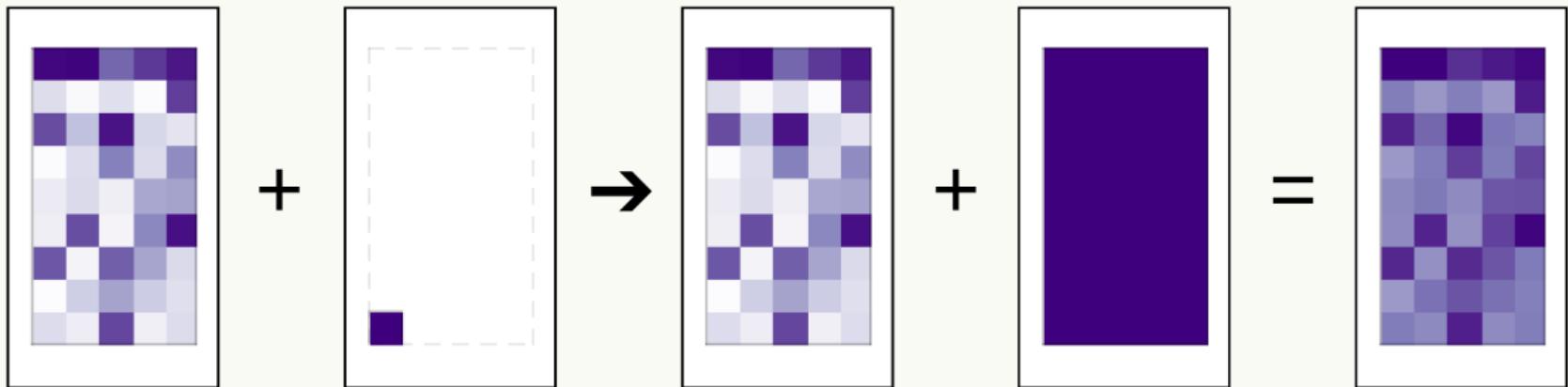
Attribute	Settable	Description
flags	No	special array-connected dictionary-like object with attributes showing the state of flags in this array; only the flags WRITEABLE, ALIGNED, and UPDATEIFCOPY can be modified by setting attributes of this object
shape	Yes	tuple showing the array shape; setting this attribute re-shapes the array
strides	Yes	tuple showing how many <i>bytes</i> must be jumped in the data segment to get from one entry to the next
ndim	No	number of dimensions in array
data	Yes	buffer object loosely wrapping the array data (only works for single-segment arrays)
size	No	total number of elements
itemsize	No	size (in bytes) of each element
nbytes	No	total number of bytes used
base	No	object this array is using for its data buffer, or None if it owns its own memory
dtype	Yes	data-type object for this array
real	Yes	real part of the array; setting copies data to real part of current array
imag	Yes	imaginary part, or read-only zero array if type is not complex; setting works only if type is complex
flat	Yes	one-dimensional, indexable iterator object that acts somewhat like a 1-d array
ctypes	No	object to simplify the interaction of this array with the ctypes module
<code>__array_interface__</code>	No	dictionary with keys (data, typestr, descr, shape, strides) for compliance with Python side of array protocol
<code>__array_struct__</code>	No	array interface on C-level
<code>__array_priority__</code>	No	always 0.0 for base type <code>ndarray</code>



TOPIC 3: at the heart of Numpy

Broadcasting

... allows ufuncs to deal with inputs that do not have exactly the same shape.

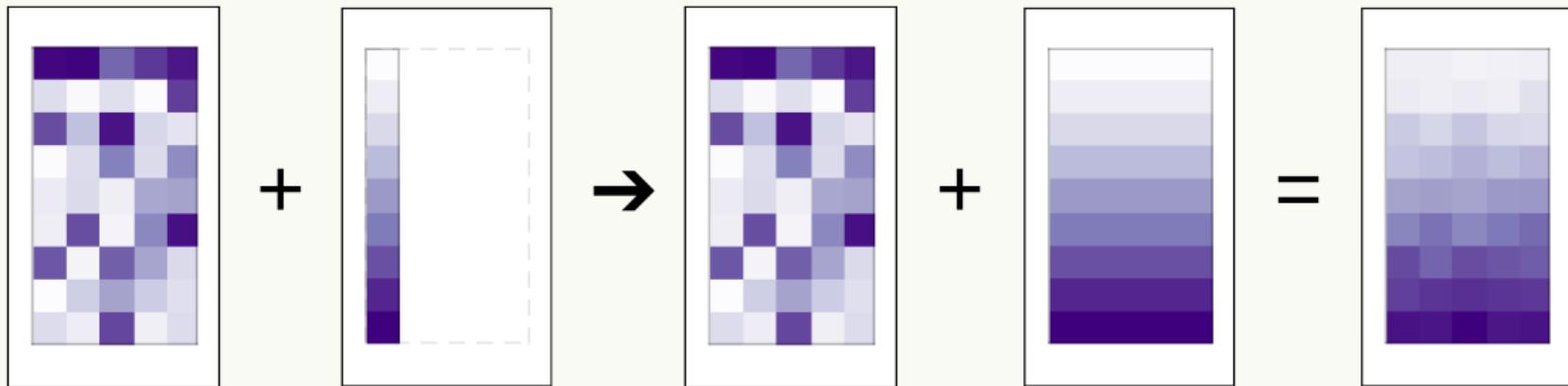


— plots: <https://github.com/rougier/numpy-tutorial>

TOPIC 3: at the heart of Numpy

Broadcasting

... allows ufuncs to deal with inputs that do not have exactly the same shape.

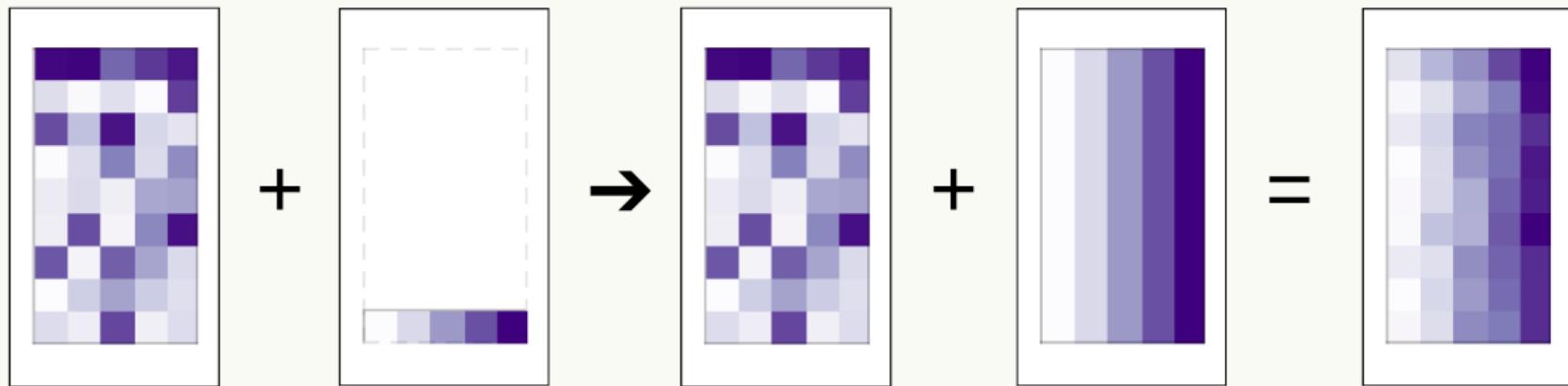


— plots: <https://github.com/rougier/numpy-tutorial>

TOPIC 3: at the heart of Numpy

Broadcasting

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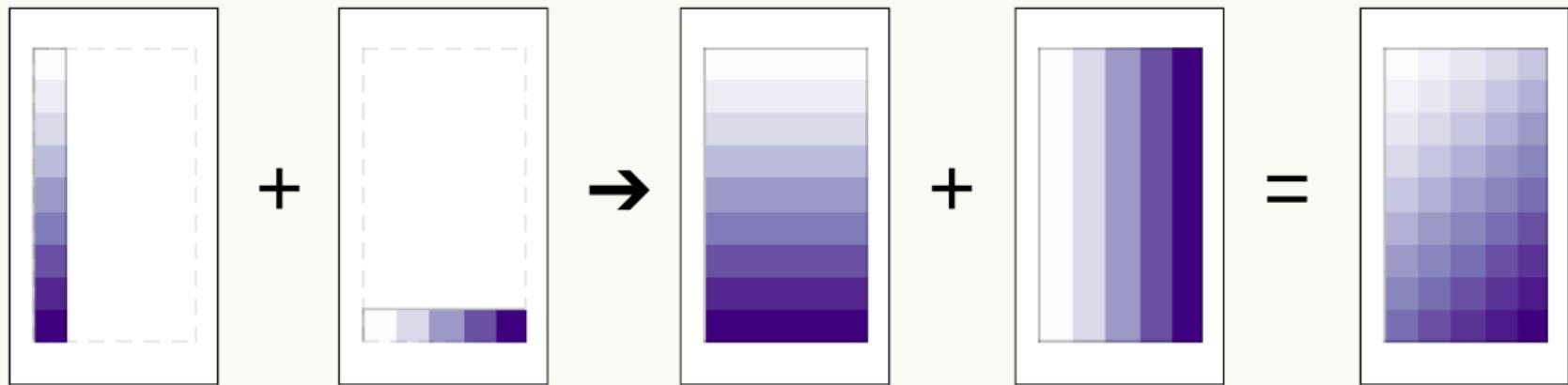


— plots: <https://github.com/rougier/numpy-tutorial>

TOPIC 3: at the heart of Numpy

Broadcasting

... allows ufuncs to deal with inputs that do not have exactly the same shape.



— plots: <https://github.com/rougier/numpy-tutorial>

TOPIC 3: at the heart of Numpy Broadcasting

Broadcasting can be understood by four rules:

1. All input arrays with ndim smaller than the input array of largest ndim have 1's prepended to their shapes.
2. The size in each dimension of the output shape is the maximum of all the input shapes in that dimension.
3. An input can be used in the calculation if its shape in a particular dimension either matches the output shape or has value exactly 1.
4. If an input has a dimension size of 1 in its shape, the first data entry in that dimension will be used for all calculations along that dimension.

— Guide to Numpy, pg. 154

TOPIC 3: at the heart of Numpy

Broadcasting

```
1 a = np.array([1,2,3]) #row vector  
2 b = np.array([[4],[5],[6]]) #column vector  
3 print(a.shape)  
4 print(b.shape)
```

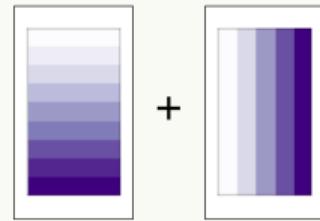
```
>>> (3,)  
>>> (3, 1)
```

```
1 np.broadcast_arrays(a, b)
```

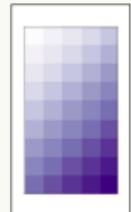
```
>>> [array([[1, 2, 3],  
>>> [1, 2, 3],  
>>> [1, 2, 3]]),  
>>> array([[4, 4, 4],  
>>> [5, 5, 5],  
>>> [6, 6, 6]])]
```



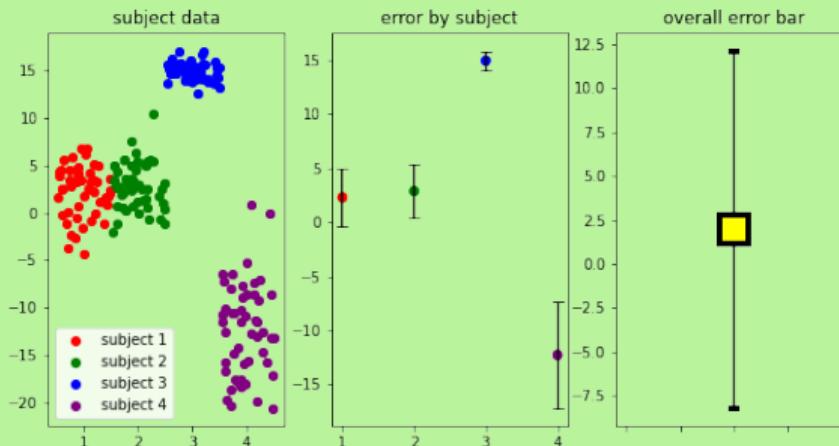
→



=



> Exercise 4



Calculate out the between subject variance, so that we can get a better estimate of the variance for each subject!

see file `Exercises_Notebook_3.ipynb`

TOPIC 4: Tricks, Conventions, and Applications

Save and Load

The .npy format is the standard binary file format in NumPy for persisting a **single** arbitrary NumPy array on disk.

- ▶ for one numpy array
- ▶ when called on something other than a pure np array, will use python pickle
- ▶ in that case the flag "allow_pickle" needs to be True

```
1 a = np.random.rand((5,5))
2 np.save(a, "my_file.npy")
3 b = np.load("my_file.npy")
```

TOPIC 4: Tricks, Conventions, and Applications

Errors

What happens when things go wrong?

```
1 >>> np.geterr()  
2 {'divide': 'warn',  
3  'over': 'warn',  
4  'under': 'ignore',  
5  'invalid': 'warn'}
```

When something goes wrong, but no error is raised, typically NaN is returned.

TOPIC 4: Tricks, Conventions, and Applications

Errors: divide

Division by zero: infinite result obtained from finite numbers.

```
1 a = np.divide(3,0)
```

```
>>> <stdin>:1: RuntimeWarning: divide by zero encountered in true_divide
```

```
1 a
```

```
>>> inf
```

Default consequence: Warning

TOPIC 4: Tricks, Conventions, and Applications

Errors: over

Overflow: result too large to be expressed.

```
1 np.exp(1234.1)
```

```
>>> <stdin>:1: RuntimeWarning: overflow encountered in exp
>>> inf
```

Default consequence: Warning

TOPIC 4: Tricks, Conventions, and Applications

Errors: under

Underflow: result so close to zero that some precision was lost.

```
1 a = np.exp(-(40)**2)
2 a
```

```
>>> 0.0
```

Default consequence: Ignore

TOPIC 4: Tricks, Conventions, and Applications

Errors: invalid

Invalid operation: result is not an expressible number, typically indicates that a NaN was produced.

```
1 a = np.arange(5)
2 b = np.array([4, 3, 2, np.NaN, 9])
3 b
```

```
>>> array([ 4.,  3.,  2., nan,  9.])
```

```
1 a<=b
```

```
>>> <stdin>:1: RuntimeWarning: invalid value encountered in less_equal
>>> array([ True,  True,  True, False,  True])
```

Default consequence: Warn

TOPIC 4: Tricks, Conventions, and Applications

Errors

You can configure your own safety net, by escalating particularly relevant errors

```
1 np.seterr(under='raise', over='ignore')
```

it can also be useful to use context managers

```
1 a = np.arange(5)
2 b = np.array([4, 3, 2, np.NaN, 9])
3 with np.errstate(invalid='ignore'):
4     c = a <= b
```

TOPIC 4: Tricks, Conventions, and Applications

Reshaping

```
1 np.arange(8).reshape(2,4)
```

```
>>> array([[0, 1, 2, 3],  
>>>      [4, 5, 6, 7]])
```

- ▶ reshaping is very fast (only changes string information)
- ▶ -1 means "just make it fit with the other dimensions"
- ▶ reshape gives a new view. resize is the same, but in place.

TOPIC 4: Tricks, Conventions, and Applications

Reshaping

- ▶ the corresponding opposites are flatten (copy) and ravel(in-place)
- ▶ also useful is squeeze(): return an array with all single dimensions squeezed out.

```
1 np.arange(8).reshape(2,4).flatten()
```

```
>>> array([0, 1, 2, 3, 4, 5, 6, 7])
```

> Exercises 5

1. Go insanity mode: switch off all the errors and do all the things you never thought you could!
2. Chose one of every two elements in a 1D array.

see file `Exercises_Notebook_4.ipynb`

In short Numpy introduces:

1. the Numpy array
 - ▶ at the core of Numpy functionality
 - ▶ it expands the Python List into n dimensions
 - ▶ it cleverly uses memory to avoid time-consuming copying and looping
 - ▶ is a homogeneous container for various datatypes
2. the ufunc
 - ▶ a standard class for functions
 - ▶ common interface to mathematical functions that operate on scalars
 - ▶ can be made to operate on arrays in an element-by-element fashion
 - ▶ uses broadcasting to deal with arrays that are not the same shape

Thank you