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`ipython` is an enhanced python environment well suited for interactive use.

Let's see an example:

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Creating an 8 elements `array` arranged as a 1-D vector from a python list

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>>> ar4 = ar3.reshape(2,4)
>>> ar3
array([1, 2, 3, 4, 5, 6, 7, 8])
>>> ar4
array([[1, 2, 3, 4],
       [5, 6, 7, 8]])
>>> ar3[3] = 0
>>> ar3
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>>> ar4 = ar3.reshape(2,4)
>>> ar3
array([1, 2, 3, 4, 5, 6, 7, 8])
>>> ar4
array([[1, 2, 3, 4],
       [5, 6, 7, 8]])
>>> ar3[3] = 0
>>> ar3
array([1, 2, 3, 0, 5, 6, 7, 8])
>>> ar4
array([[1, 2, 3, 0],
       [5, 6, 7, 8]])
```

A vector of values [1..8]

`array` creation:

```
>>> import numpy as np

>>> ar1 = np.array([1, 2, 3, 4, 5, 6, 7, 8])
>>> ar2 = np.array([[1, 2, 3, 4],[5, 6, 7, 8]])

>>> ar1.size, ar2.size
(8, 8)
>>> ar1.shape, ar2.shape
((8,), (2, 4))
>>> ar1.dtype, ar2.dtype
(dtype('int64'), dtype('int64'))

>>> ar5 = np.zeros((2,4))
>>> ar6 = np.ones((2,4,3))

>>> ar7 = np.identity(10)

>>> ar8 = np.linspace(0, np.pi, 5)

>>> # ar9 = np.loadtxt("datafile.txt")
>>> # ar9 = np.fromfile("datafile.txt")
```

Creating an 8 elements

`ar2` has 8 elements too, but is arranged as a 2 by 4 matrix

`shape` shows the arrangement of arrays

`dtype` shows the type of `array` elements

A 2 by 4 array of zero's

A 2 by 4 by 3 array of one's

The i

A vector of 5 equally spaced values in [0, pi)

Simple ways to read data from files into `arrays`

“views” on arrays:

```
>>> ar3 = np.arange(1, 9)
>>> ar4 = ar3.reshape(2,4)
>>> ar3
array([1, 2, 3, 4, 5, 6, 7, 8])
>>> ar4
array([[1, 2, 3, 4],
       [5, 6, 7, 8]])
>>> ar3[3] = 0
>>> ar3
array([1, 2, 3, 0, 5, 6, 7, 8])
>>> ar4
array([[1, 2, 3, 0],
       [5, 6, 7, 8]])
```

The very same `array`, but “seen” as a 2 by 4 array

The `array` class - 1

package: numpy - 5

`array` creation:

```
>>> import numpy as np

>>> ar1 = np.array([1, 2, 3, 4, 5, 6, 7, 8])
>>> ar2 = np.array([[1, 2, 3, 4],[5, 6, 7, 8]])
```

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>>> ar1.size, ar2.size
(8, 8)
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(dtype('int64'), dtype('int64'))
```

`shape` shows the arrangement of arrays

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>>> ar5 = np.zeros((2,4))
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```

A 2 by 4 array of zero's

A 2 by 4 by 3 array of one's

```
>>> ar7 = np.identity(10)
```

The i

```
>>> ar8 = np.linspace(0, np.pi, 5)
```

A vector of 5 equally spa

```
>>> # ar9 = np.loadtxt("datafile.txt")
>>> # ar9 = np.fromfile("datafile.txt")
```

Simple ways to read data from files into `arrays`

“views” on arrays:

```
>>> ar3 = np.arange(1, 9)
>>> ar4 = ar3.reshape(2,4)
>>> ar3
array([1, 2, 3, 4, 5, 6, 7, 8])
>>> ar4
array([[1, 2, 3, 4],
       [5, 6, 7, 8]])
>>> ar3[3] = 0
>>> ar3
array([1, 2, 3, 0, 5, 6, 7, 8])
>>> ar4
array([[1, 2, 3, 0],
       [5, 6, 7, 8]])
```

The very same `array`, but “seen” as a 2 by 4 array

If we change one element of `ar3` ...

The array class - 1

array creation:

```
>>> import numpy as np

>>> ar1 = np.array([1, 2, 3, 4, 5, 6, 7, 8])
>>> ar2 = np.array([[1, 2, 3, 4],[5, 6, 7, 8]])

>>> ar1.size, ar2.size
(8, 8)
>>> ar1.shape, ar2.shape
((8,), (2, 4))
>>> ar1.dtype, ar2.dtype
(dtype('int64'), dtype('int64'))

>>> ar5 = np.zeros((2,4))
>>> ar6 = np.ones((2,4,3))

>>> ar7 = np.identity(10)

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>>> # ar9 = np.loadtxt("datafile.txt")
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```

Creating an 8 elements

`ar2` has 8 elements too, but is arranged as a 2 by 4 matrix

`shape` shows the arrangement of arrays

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Simple ways to read data from files into `arrays`

"views" on arrays:

```
>>> ar3 = np.arange(1, 9)
>>> ar4 = ar3.reshape(2,4)
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array([1, 2, 3, 4, 5, 6, 7, 8])
>>> ar4
array([[1, 2, 3, 4],
       [5, 6, 7, 8]])
>>> ar3[3] = 0
>>> ar3
array([1, 2, 3, 0, 5, 6
>>> ar4
array([[1, 2, 3, 0],
       [5, 6, 7, 8]])
```

The very same `array`, but "seen" as a 2 by 4 array

If we change one element of `ar3` ...

... the same element is changed in `ar4`

Slices and selection of sub-arrays:

```
>>> a=np.arange(150).reshape(10,5,3)
>>> a
array([[[ 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]],
   ...

>>> a[1,:,:]
array([[15, 16, 17],
       [18, 19, 20],
       [21, 22, 23],
       [24, 25, 26],
       [27, 28, 29]])

>>> a[2:4,:,:]
array([[[30, 31, 32],
        [33, 34, 35],
        [36, 37, 38],
        [39, 40, 41],
        [42, 43, 44]],

       [[45, 46, 47],
        [48, 49, 50],
        [51, 52, 53],
        [54, 55, 56],
        [57, 58, 59]]])
>>> a[:,1,1]
array([ 4,  19,  34,  49,  64,  79,  94, 109, 124, 139])
```

Slices and selection of sub-arrays:

Make a 10 by 5 by 3 array ⟸

```
>>> a=np.arange(150).reshape(10,5,3)
>>> a
array([[[ 0,   1,   2],
        [ 3,   4,   5],
        [ 6,   7,   8],
        [ 9,  10,  11],
        [ 12,  13,  14]],

       [[ 15,  16,  17],
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   ...

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array([[15, 16, 17],
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array([[[30, 31, 32],
        [33, 34, 35],
        [36, 37, 38],
        [39, 40, 41],
        [42, 43, 44]],

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        [48, 49, 50],
        [51, 52, 53],
        [54, 55, 56],
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>>> a[:,1,1]
array([ 4, 19, 34, 49, 64, 79, 94, 109, 124, 139])
```

Slices and selection of sub-arrays:

Make a 10 by 5 by 3 array

You may think of it as a sequence of ten 5 by 3 arrays

```
>>> a=np.arange(150).reshap
>>> a
array([[[ 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]],
   ...

>>> a[1,:,:]
array([[15, 16, 17],
       [18, 19, 20],
       [21, 22, 23],
       [24, 25, 26],
       [27, 28, 29]])

>>> a[2:4,:,:]
array([[[30, 31, 32],
        [33, 34, 35],
        [36, 37, 38],
        [39, 40, 41],
        [42, 43, 44]],

       [[45, 46, 47],
        [48, 49, 50],
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        [57, 58, 59]]])
>>> a[:,1,1]
array([ 4, 19, 34, 49, 64, 79, 94, 109, 124, 139])
```

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       [[ 15, 16, 17],
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>>> a[:,1,1]
array([ 4, 19, 34, 49, 64, 79, 94, 109, 124, 139])
```

Make a 10 by 5 by 3 array

You may think of it as a sequence of ten 5 by 3 arrays

This is the second element of the 10 elements sequence (remember: the first element has index 0)

Slices and selection of sub-arrays:

Make a 10 by 5 by 3 array

You may think of it as a sequence of ten 5 by 3 arrays

```
>>> a=np.arange(150).reshap
>>> a
array([[[ 0,  1,  2],
        [ 3,  4,  5],
        [ 6,  7,  8],
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       [[ 15, 16, 17],
        [ 18, 19, 20],
        [ 21, 22, 23],
        [ 24, 25, 26],
        [ 27, 28,
   ...
```

This is the second element of the 10 elements sequence (remember: the first element has index 0)

```
>>> a[1,:,:]
array([[15, 16, 17],
       [18, 19, 20],
       [21, 22, 23],
       [24, 25, 26],
       [27, 28, 29]
```

The third and fourth elements of the 10 elements sequence

```
>>> a[2:4,:,:]
array([[[30, 31, 32],
        [33, 34, 35],
        [36, 37, 38],
        [39, 40, 41],
        [42, 43, 44]],

       [[45, 46, 47],
        [48, 49, 50],
        [51, 52, 53],
        [54, 55, 56],
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>>> a[:,1,1]
array([ 4, 19, 34, 49, 64, 79, 94, 109, 124, 139])
```

Slices and selection of sub-arrays:

Make a 10 by 5 by 3 array

You may think of it as a sequence of ten 5 by 3 arrays

```
>>> a=np.arange(150).reshap
>>> a
array([[[ 0,   1,   2],
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       [[ 15, 16,  17],
        [ 18, 19,  20],
        [ 21, 22,  23],
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   ...
```

This is the second element of the 10 elements sequence (remember: the first element has index 0)

```
>>> a[1,:,:]
array([[15, 16, 17],
       [18, 19, 20],
       [21, 22, 23],
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       [27, 28, 29]
```

The third and fourth elements of the 10 elements sequence

```
>>> a[2:4,:,:]
array([[[30, 31, 32],
        [33, 34, 35],
        [36, 37, 38],
        [39, 40, 41],
        [42, 43, 44]],

       [[45, 46, 47],
        [48, 49, 50],
        [51, 52, 53],
        [54, 55, 5
        [57, 58, 5
```

A vector of all the elements of index [1,1] of the 10 elements sequence

```
>>> a[:,1,1]
array([ 4, 19, 34, 49, 64, 79, 94, 109, 124, 139])
```

Slices and selection of sub-arrays:

```
>>> a=np.arange(150).reshap
>>> a
array([[[ 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,
   ...

>>> a[1,:,:]
array([[15, 16, 17],
       [18, 19, 20],
       [21, 22, 23],
       [24, 25, 26],
       [27, 28, 29]

>>> a[2:4,:,:]
array([[[30, 31, 32],
        [33, 34, 35],
        [36, 37, 38],
        [39, 40, 41],
        [42, 43, 44]],

       [[45, 46, 47],
        [48, 49, 50],
        [51, 52, 53],
        [54, 55, 5
        [57, 58, 5
>>> a[:,1,1]
array([ 4, 19, 34, 49, 64, 79, 94, 109, 124, 139])
```

Make a 10 by 5 by 3 array

You may think of it as a sequence of ten 5 by 3 arrays

This is the second element of the 10 elements sequence (remember: the first element has index 0)

The third and fourth elements of the 10 elements sequence

A vector of all the elements of index [1,1] of the 10 elements sequence

→

Simple array operations

array <op> scalar:

```
>>> a = np.arange(0., 10, 0.3)
>>> a
array([ 0. , 0.3, 0.6, 0.9, 1.2, 1.5, 1.8, 2.1, 2.4, 2.7, 3. ,
        3.3, 3.6, 3.9, 4.2, 4.5, 4.8, 5.1, 5.4, 5.7, 6. , 6.3,
        6.6, 6.9, 7.2, 7.5, 7.8, 8.1, 8.4, 8.7, 9. , 9.3, 9.6,
        9.9])
>>> a*3
array([ 0. ,  0.9,  1.8,  2.7,  3.6,  4.5,  5.4,  6.3,  7.2,
         8.1,  9. ,  9.9, 10.8, 11.7, 12.6, 13.5, 14.4, 15.3,
        16.2, 17.1, 18. , 18.9, 19.8, 20.7, 21.6, 22.5, 23.4,
        24.3, 25.2, 26.1, 27. , 27.9, 28.8, 29.7])
```

array <op> scalar:

```
>>> a = np.arange(0., 10, 0.3)
>>> a
array([ 0. , 0.3, 0.6, 0.9,
       3.3, 3.6, 3.9, 4.2, 4
       6.6, 6.9, 7.2, 7.5, 7
       9.9])
>>> a*3
array([ 0. ,  0.9,  1.8,  2.7,  3.6,  4.5,  5.4,  6.3,  7.2,
        8.1,  9. ,  9.9, 10.8, 11.7, 12.6, 13.5, 14.4, 15.3,
       16.2, 17.1, 18. , 18.9, 19.8, 20.7, 21.6, 22.5, 23.4,
       24.3, 25.2, 26.1, 27. , 27.9, 28.8, 29.7])
```

The operation (**+**, **-**, *, /, ...) is performed on each element of the array

Simple array operations

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array([ 0. ,  0.9,  1.8,  2.7,  3.6,  4.5,  5.4,  6.3,  7.2,
         8.1,  9. ,  9.9, 10.8, 11.7, 12.6, 13.5, 14.4, 15.3,
        16.2, 17.1, 18. , 18.9, 19.8, 20.7, 21.6, 22.5, 23.4,
        24.3, 25.2, 26.1, 27. , 27.9, 28.8, 29.7])
```

The operation (**+**, **-**, *, /, ...) is performed on each element of the array

array <op> array:

```
>>> b = np.arange(10., 0, -0.3)
>>> b
array([ 10. , 9.7,  9.4,  9.1,  8.8,  8.5,  8.2,  7.9,  7.6,
         7.3,  7. ,  6.7,  6.4,  6.1,  5.8,  5.5,  5.2,  4.9,
         4.6,  4.3,  4. ,  3.7,  3.4,  3.1,  2.8,  2.5,  2.2,
         1.9,  1.6,  1.3,  1. ,  0.7,  0.4,  0.1])
>>> a+b
array([ 10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
        10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
        10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
        10.])
```

Simple array operations

array <op> scalar:

```
>>> a = np.arange(0., 10, 0.3)
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array([ 0. , 0.3, 0.6, 0.9,
       3.3, 3.6, 3.9, 4.2, 4
       6.6, 6.9, 7.2, 7.5, 7
       9.9])
>>> a*3
array([ 0. ,  0.9,  1.8,  2.7,  3.6,  4.5,  5.4,  6.3,  7.2,
        8.1,  9. ,  9.9, 10.8, 11.7, 12.6, 13.5, 14.4, 15.3,
       16.2, 17.1, 18. , 18.9, 19.8, 20.7, 21.6, 22.5, 23.4,
       24.3, 25.2, 26.1, 27. , 27.9, 28.8, 29.7])
```

The operation (**+**, **-**, *, /, ...) is performed on each element of the array

array <op> array:

```
>>> b = np.arange(10., 0, -0.3)
>>> b
array([ 10. , 9.7,  9.4,  9.
        7.3,  7. ,  6.7,  6.
        4.6,  4.3,  4. ,  3.
        1.9,  1.6,  1.3,  1.
>>> a+b
array([ 10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
       10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
       10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
       10.])
```

The operation is performed element by element. The operands must be of the same size and shape

Simple array operations

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>>> a = np.arange(0., 10, 0.3)
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array([ 0. , 0.3, 0.6, 0.9,
        3.3, 3.6, 3.9, 4.2, 4
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        8.1,  9. ,  9.9, 10.8, 11.7, 12.6, 13.5, 14.4, 15.3,
       16.2, 17.1, 18. , 18.9, 19.8, 20.7, 21.6, 22.5, 23.4,
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The operation (**+**, **-**, *, /, ...) is performed on each element of the array

array <op> array:

```
>>> b = np.arange(10., 0, -0.3)
>>> b
array([ 10. , 9.7,  9.4,  9.
        7.3,  7. ,  6.7,  6.4
        4.6,  4.3,  4. ,  3.7
        1.9,  1.6,  1.3,  1.
>>> a+b
array([ 10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
       10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
       10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
       10.])
```

The operation is performed element by element. The operands must be of the same size and shape

Dot product ($\sum a_i b_i$):

```
>>> np.dot(a,b)
555.38999999999726
```

Vector product:

```
>>> prod = np.outer(a,b)
>>> prod.shape
(34, 34)
```

array <op> scalar:

```
>>> a = np.arange(0., 10, 0.3)
>>> a
array([ 0.  , 0.3, 0.6, 0.9,
        3.3, 3.6, 3.9, 4.2, 4
        6.6, 6.9, 7.2, 7.5, 7
        9.9])
>>> a*3
array([ 0.  ,  0.9,  1.8,  2.7,  3.6,  4.5,  5.4,  6.3,  7.2,
         8.1,  9.  ,  9.9, 10.8, 11.7, 12.6, 13.5, 14.4, 15.3,
        16.2, 17.1, 18.  , 18.9, 19.8, 20.7, 21.6, 22.5, 23.4,
        24.3, 25.2, 26.1, 27.  , 27.9, 28.8, 29.7])
```

The operation (**+**, **-**, *, /, ...) is performed on each element of the array

array <op> array:

```
>>> b = np.arange(10., 0, -0.3)
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array([ 10.  , 9.7,  9.4,  9.
         7.3,  7.  ,  6.7,  6.
         4.6,  4.3,  4.  ,  3.
         1.9,  1.6,  1.3,  1.
>>> a+b
array([ 10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
        10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
        10., 10., 10., 10., 10., 10., 10., 10., 10., 10., 10.,
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Function operating on arrays

All functions defined in `numpy` operate usually element by element

- Trigonometric functions

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Function operating on arrays

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Function operating on arrays

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- Exponential, logarithms, bessel functions
- Floating point functions
- Arithmetic functions

Function operating on arrays

All functions defined in `numpy` operate usually element by element

- Trigonometric functions
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- Rounding (round(), floor(), ceil(), ...)
- Sum, product, difference, division
- Exponential, logarithms, bessel functions
- Floating point functions
- Arithmetic functions
- Complex functions

Beware of function name conflicts:

```
>>> import numpy as np
>>> a=np.array([[1,2,3],[4,5,6]])
>>> max(a)
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Function operating on arrays

All functions defined in `numpy` operate usually element by element

- Trigonometric functions
- Hyperbolic functions
- Rounding (round(), floor(), ceil(), ...)
- Sum, product, difference, division
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Using **numpy** - 1

Problem: Verify whether there is significant correlation between number of births and moon phase.

Input data: Number of births for each day from 6/1/1978 to 11/15/1986 (From the civil registry of Firenze).

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import math

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MOON_MONTH = 29*86400 + 12*3600 + 43*60 + 11 # seconds
MOON_QUARTER = MOON_MONTH*0.25 # Duration of a moon quarter

# First new moon after 1/1/1970
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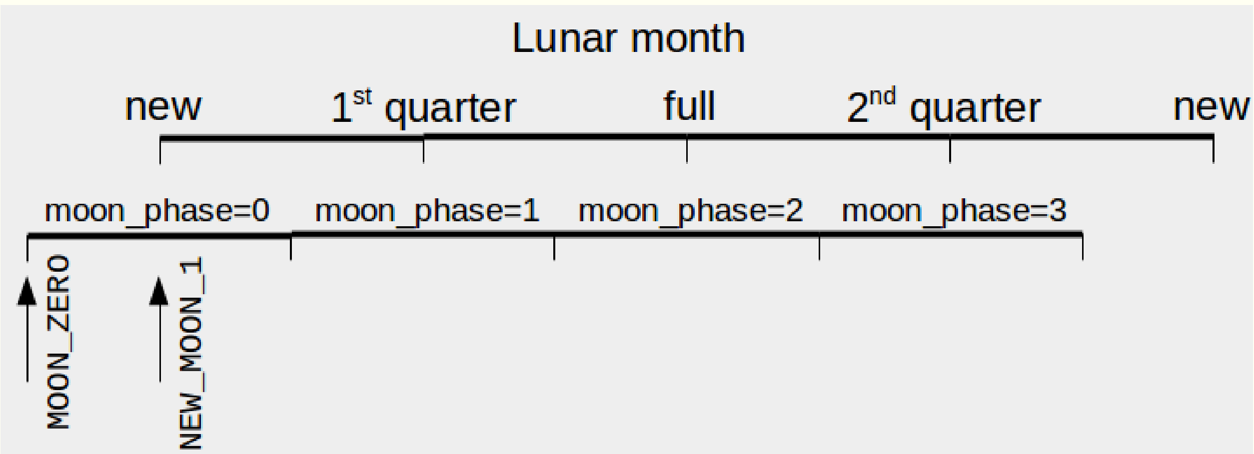

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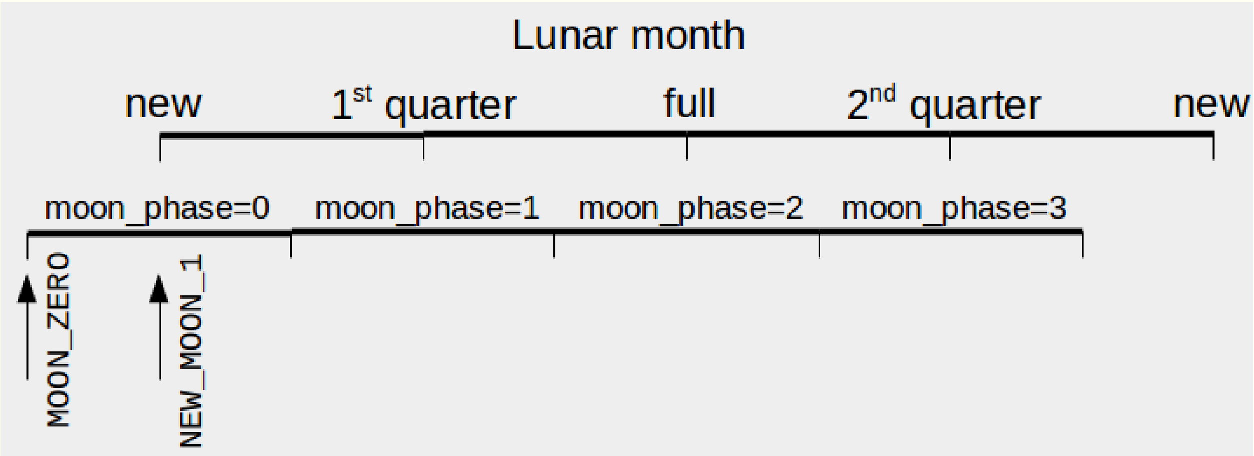

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import time

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    year = int(aammgg[:2])+1900
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Using **numpy** - 3

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see: np.loadtxt
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Measured and expected number of births in the four moon phases

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    day = int(aammgg[4:6])
    tt = (year, month, day, 12, 0
    return time.mktime(tt)
```

see: time.mktime

... let's go on with ipython:

```
In [1]: import tt, moon
In [2]: filename = "dati_nascite.dat"
In [3]: data = np.loadtxt(filename, dtype=np.int_,
   ...: converters={0: tt.toseconds}, unpack=True)
In [4]: cvt_moon = np.vectorize(moon.moon_phase)
In [5]: moonphase = cvt_moon(data[0])

In [6]: m0 = np.array([1 if x==0 else
In [7]: m1 = np.array([1 if x==1 else
In [8]: m2 = np.array([1 if x==2 else
In [9]: m3 = np.array([1 if x==3 else

In [10]: births0 = np.dot(m0,data[3])
In [11]: births1 = np.dot(m1,data[3
In [12]: births2 = np.dot(m2,data[3
In [13]: births3 = np.dot(m3,data[3

In [14]: births = births0+births1+births2+births3
In [15]: births_dd = births/len(moonphase)

In [16]: n_births = [births0, births1,
In [17]: n_expect = [np.sum(m0)*births
    ...: np.sum(m2)*births_dd, np.sum(n
```

see: np.loadtxt
→ converters
→ unpack

see: np.vectorize

m0 has ones in dates when moon_phase is 0, m1 in dates when moon_phase is 1, etc.

births0 is the total number of births in dates when moon_phase is 0, etc.

Measured and expected number of births in the four moon phases

→

Here are the instructions shown in the previous slide, gathered into a file.

file: births.py

```
import numpy as np
import tt, moon

filename = "dati_nascite.dat"
data = np.loadtxt(filename, dtype=np.int_,
                  converters={0: tt.toseconds}, unpack=True)

cvt_moon = np.vectorize(moon.moon_phase)
moonphase = cvt_moon(data[0])

m0 = np.array([1 if x==0 else 0 for x in moonphase])
m1 = np.array([1 if x==1 else 0 for x in moonphase])
m2 = np.array([1 if x==2 else 0 for x in moonphase])
m3 = np.array([1 if x==3 else 0 for x in moonphase])

births0 = np.dot(m0,data[3])
births1 = np.dot(m1,data[3])
births2 = np.dot(m2,data[3])
births3 = np.dot(m3,data[3])

births = births0+births1+births2+births3

f_births = np.array([births0,births1,births2,births3])/births
f_expect = np.array([np.sum(m0),np.sum(m1),np.sum(m2),np.sum(m3)])/len(moonphase

chi_sq = sum([(x-y)**2/y for (x,y) in zip(f_births, f_expect)])
```

Using **numpy** - 4

Here are the instructions shown in the previous slide, gathered into a file.

file: births.py

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import numpy as np
import tt, moon

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births = births0+births1+bir

f_births = np.array([births0
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chi_sq = sum([(x-y)**2/y for (x,y) in zip(f_births, f_expect)])
```

We also compute the expected and observed frequencies of births and the χ^2 statistics

Using **numpy** - 4

Here are the instructions shown in the previous slide, gathered into a file.

file: `births.py`

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⇑

The `zip()` function converts two lists: $[a_0, a_1, a_2, ...]$, $[b_0, b_1, b_2, ...]$

into a list of two element tuples:

$[(a_0, b_0), (a_1, b_1), (a_2, b_2), ...]$

Let's proceed with `ipython`:

```
$ ipython --pylab
 ....
In [1]: %run births.py

In [2]: plt.bar(np.arange(0.6, 4.5, 1), f_births, width=0.4, color="blue")

In [3]: plt.bar(np.arange(1, 4.5, 1), f_expect, width=0.4, color="green")
```

Let's proceed with

> The *magic* command `%run` executes the content of file `births.py` in the ipython environment, as if lines were written at the prompt

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Using **numpy** - 5

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Let's plot observed (blue) and expected (green) frequency of births in each moon phase

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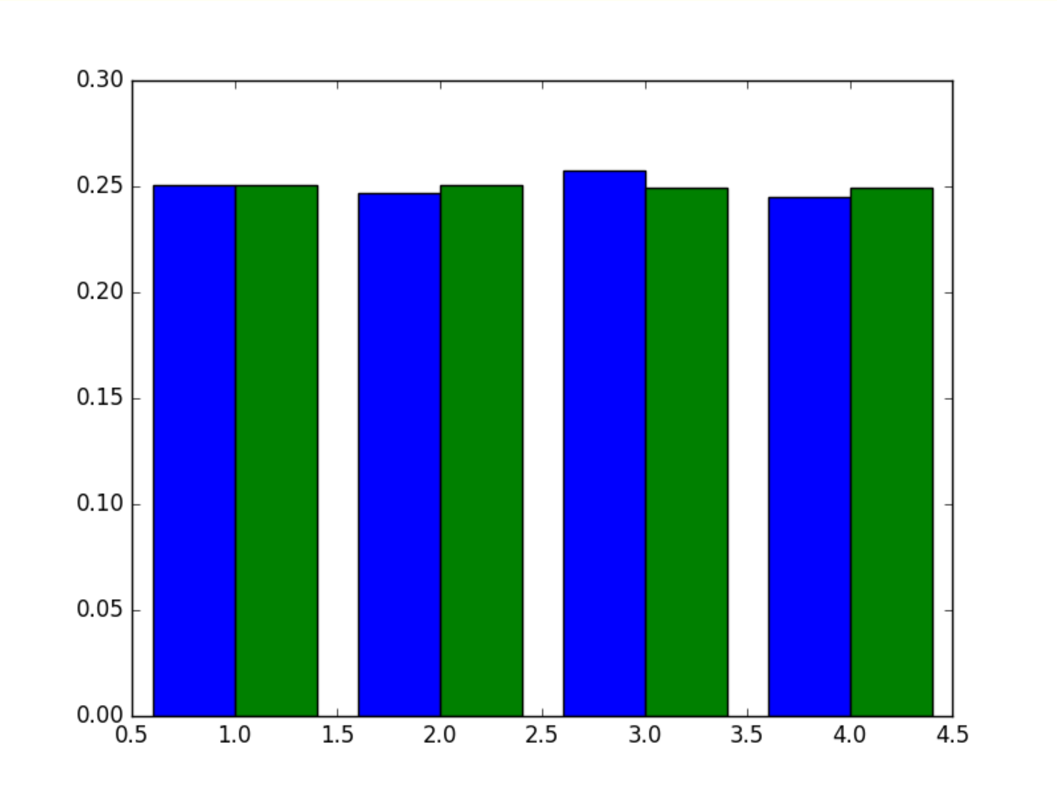

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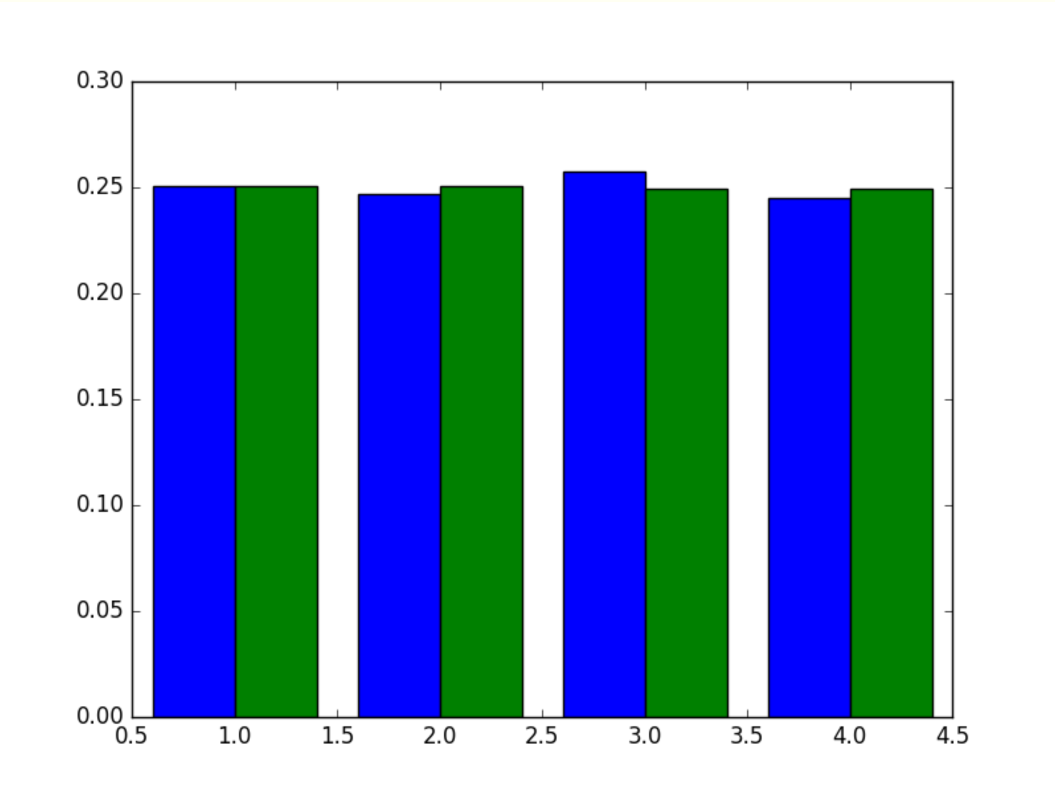

Are differences meaningful?

```
In [5]: chi_sq
Out[5]: 0.00038396010576387837
```

	P										
DF	**0.995**	**0.975**	**0.20**	**0.10**	**0.05**	**0.025**	**0.02**	**0.01**	**0.005**	**0.002**	**0.001**
1	0.0000393	0.000982	1.642	2.706	3.841	5.024	5.412	6.635	7.879	9.550	10.828
2	0.0100	0.0506	3.219	4.605	5.991	7.378	7.824	9.210	10.597	12.429	13.816
3	0.0717	0.216	4.642	6.251	7.815	9.348	9.837	11.345	12.838	14.796	16.266
4	0.207	0.484	5.989	7.779	9.488	11.143	11.668	13.277	14.860	16.924	18.467

matplotlib - 1

matplotlib is a graphic 2D package to be used in `python` programs and particularly suited for the `ipython` environment.

- Generates “publication quality” drawings

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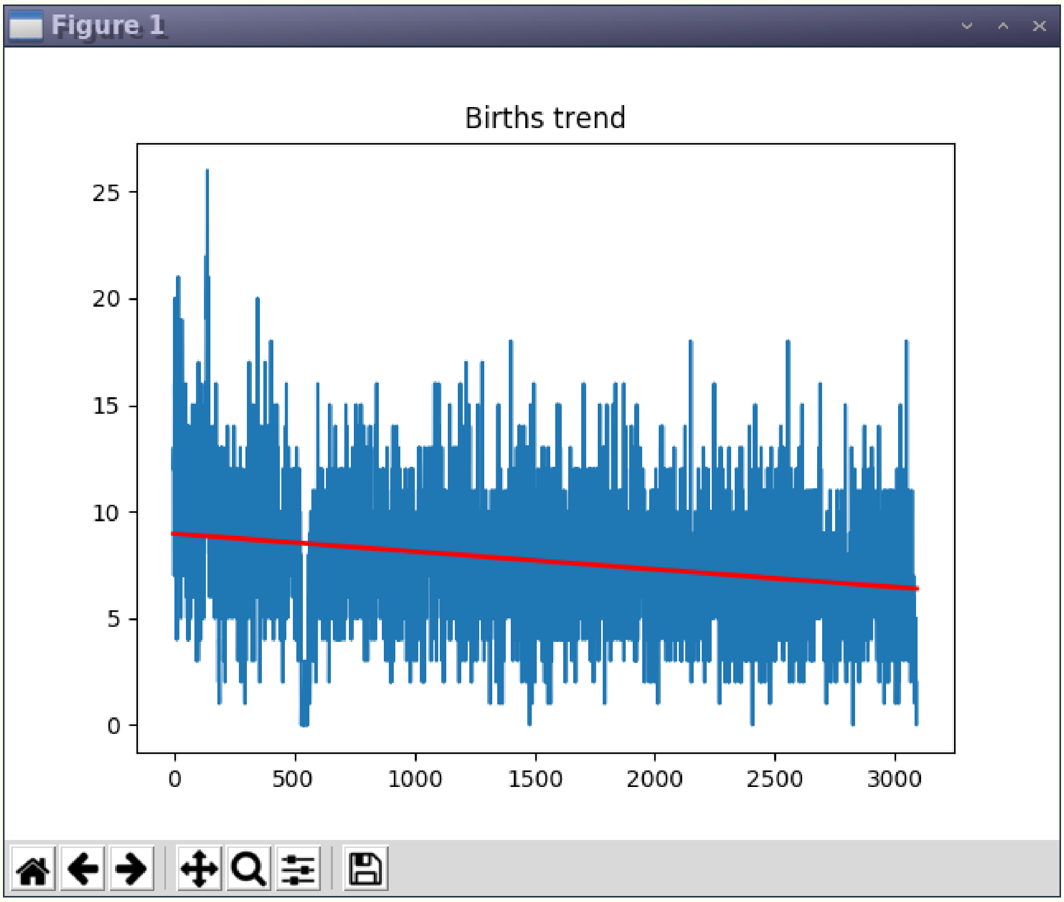

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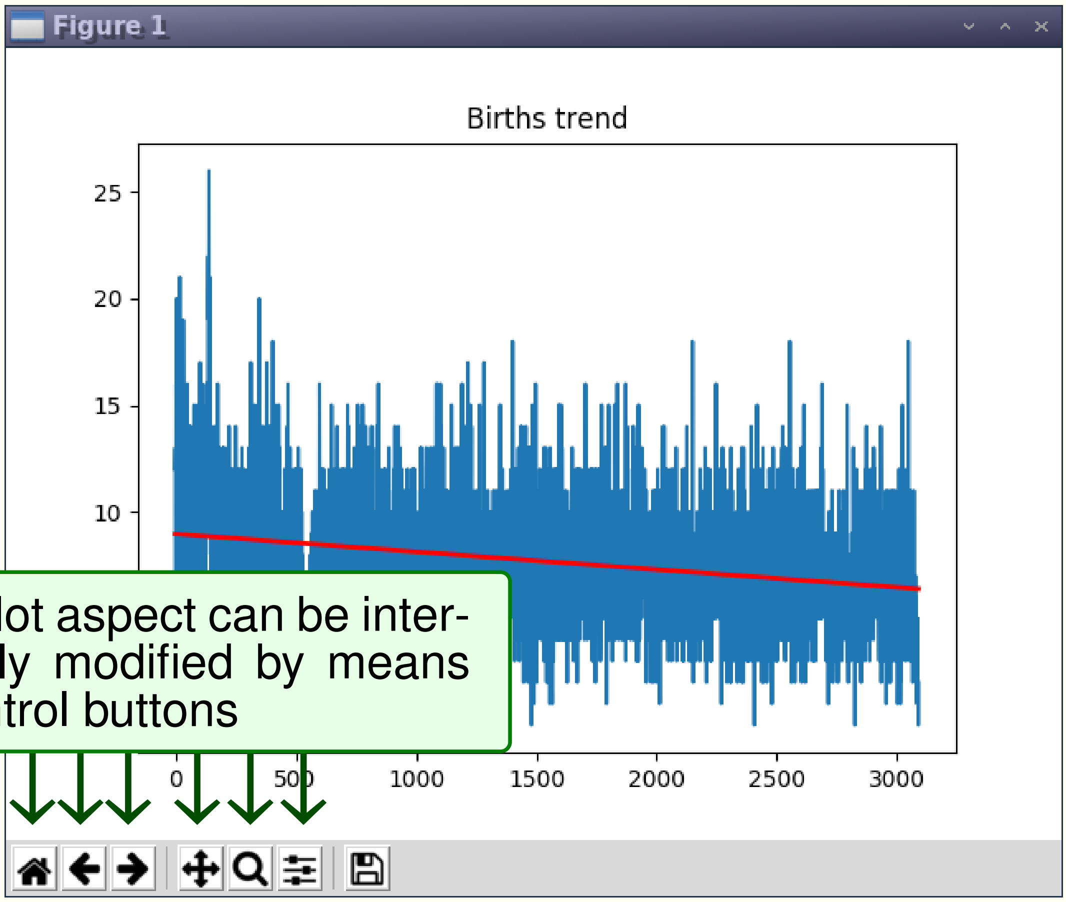

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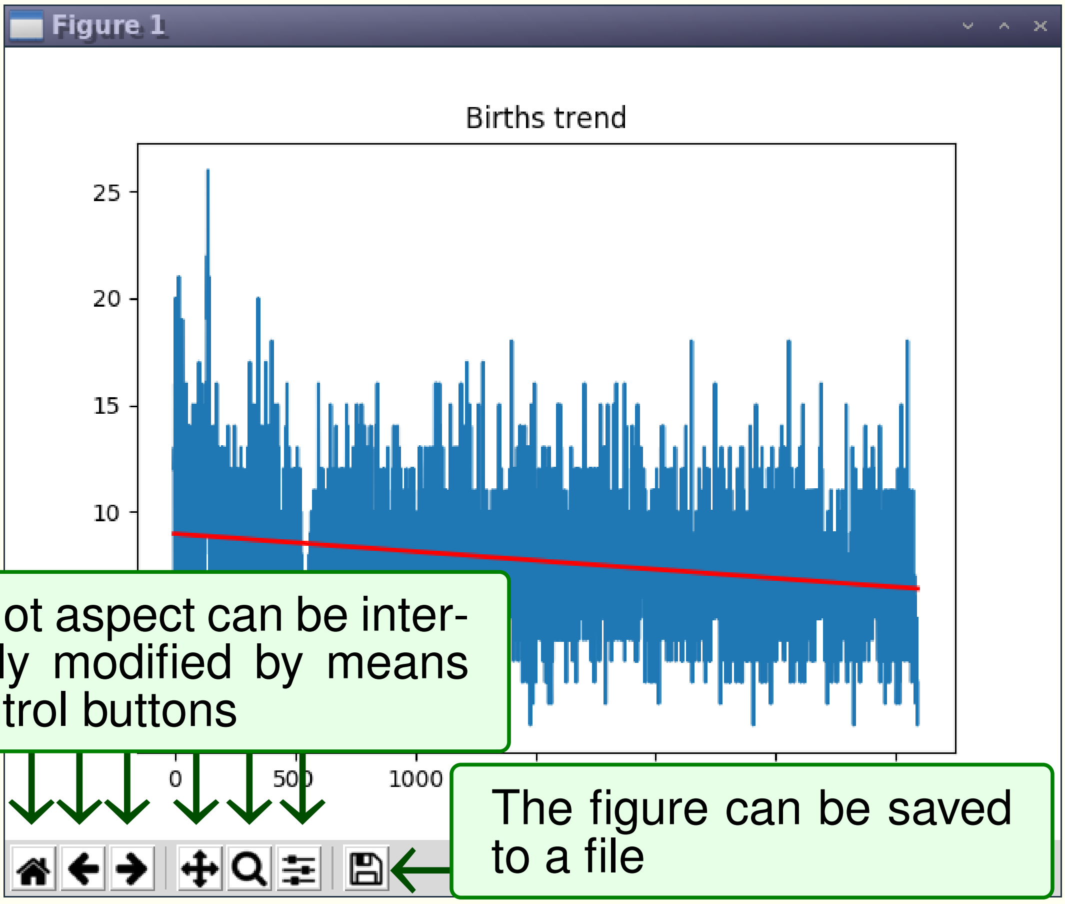

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The figure can be saved to a file

Some examples:

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Point plotting

```
>>> import matplotlib.pyplot as plt
>>> import numpy as np
>>> a = np.linspace(0,10,100)
>>> b = np.exp(-a)
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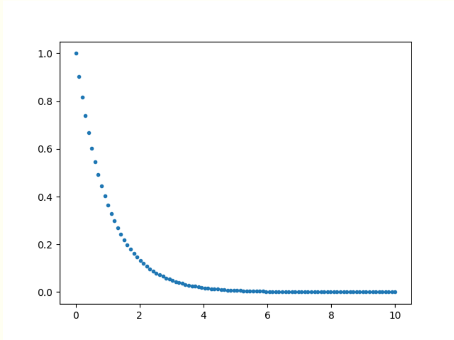
>>> plt.show()
```



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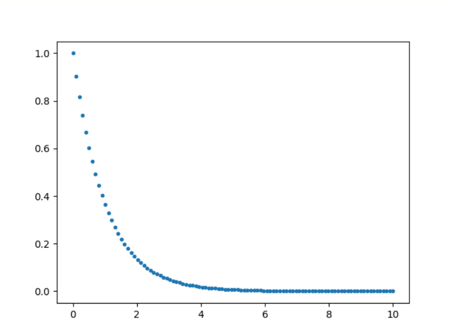

Histogram

```
>>> from numpy.random import normal
>>> x = normal(size=200)
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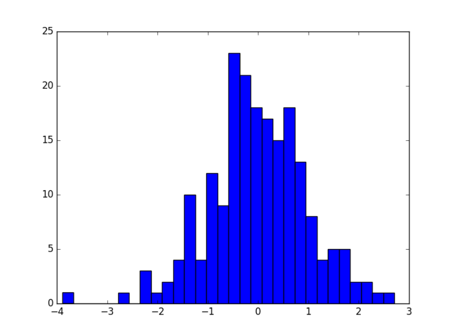

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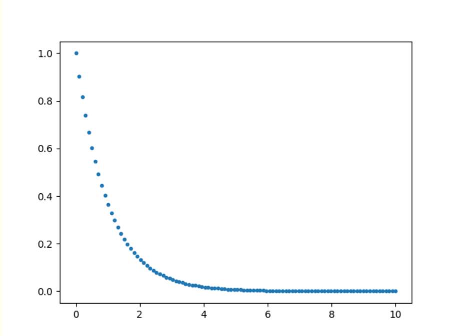

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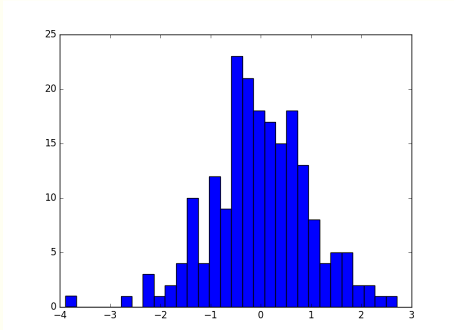
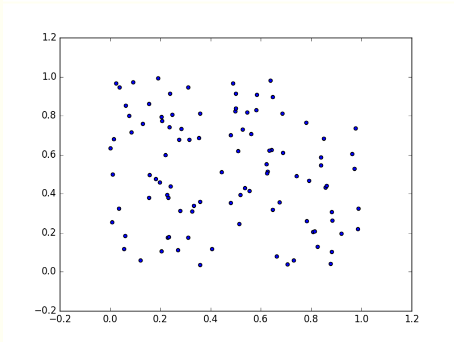


Scatter plot

```
>>> from numpy.random import rand
>>> a = rand(100)
>>> b = rand(100)
>>> plt.scatter(a,b)
>>> plt.show()
```



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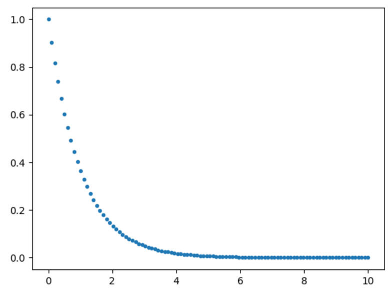

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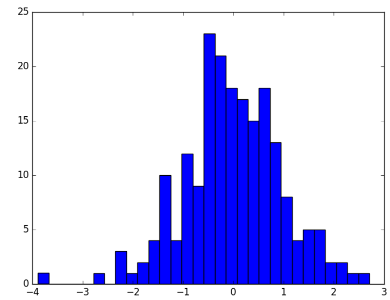

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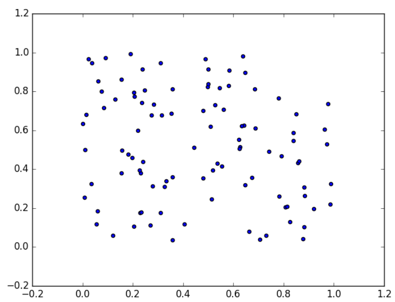
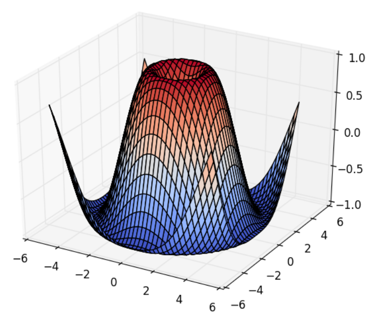


3D surface

```
>>> from matplotlib import cm
>>> from mpl_toolkits.mplot3d import Axes3D
>>> fig = plt.figure()
>>> ax = fig.gca(projection="3d")
>>> X = np.arange(-5, 5, 0.25)
>>> Y = np.arange(-5, 5, 0.25)
>>> X, Y = np.meshgrid(X, Y)
>>> R = np.sqrt(X**2 + Y**2)
>>> Z = np.sin(R)
>>> surf = ax.plot_surface(X, Y, Z, rstride=1,
                 cstride=1, cmap=cm.coolwarm)
>>> plt.show()
```



We have a map of wind data (speed and direction) around LBTO at Mt. Graham, to be properly plotted.

File: wind_2d.stat:

```
### GRID SIZE X, GRID SIZE Y, START EXIT, END EXIT, EXIT NUM, MIN WIND, MAX WIND
        100      100       4      10     7  1.4624E-02  5.78828
#  I   J    XLAT    XLON     ZS     W.MOD. W.ANG. W.X (UT) W.Y(VT)
   2   2   32.656 -109.941 1912.875 1.7029 62.383 -1.5089 -0.78941
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   2   4   32.658 -109.941 1924.812 1.4617 76.891 -1.4236 -0.33153
   2   5   32.659 -109.941 1935.500 1.4756 85.017 -1.4700 -0.12814
  .......
```

File: plot_wind_2d.py:

```
import numpy as np
import matplotlib.cm as cm
import matplotlib.pyplot as plt

DELTAX=0.1               # Spatial resolution
SYMX=51-1                # Center position, X
SYMY=51-1                # Center position, Y
filename="wind_2d.stat"

data = np.loadtxt(filename, skiprows=3, unpack=True)

ipoints = int(np.max(data[0])-np.min(data[0])+1)
jpoints = int(np.max(data[1])-np.min(data[1])+1)

ZS = data[4].reshape(ipoints, -1).transpose() # Convert into maps
WM = data[5].reshape(ipoints, -1).transpose()
WUT = data[7].reshape(ipoints, -1).transpose()
WVT = data[8].reshape(ipoints, -1).transpose()

arrayI = np.arange(0, ipoints)*DELTAX # Spatial scales
arrayJ = np.arange(0, jpoints)*DELTAX
maxI = np.max(arrayI)
maxJ = np.max(arrayJ)
```

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  .......
```

File: plot_wind_2d.py:

```
import numpy as np
import matplotlib.cm as cm
import matplotlib.pyplot as plt

DELTAX=0.1             # Spatial resolution
SYMX=51-1              # Center position, X
SYMY=51-1              # Center position, Y
filename="wind_2d.stat"

data = np.loadtxt(filename, skiprows=3, unpack=True)

ipoints = int(np.max(data[0])-np.min(data[0])+1)
jpoints = int(np.max(data[1])-np.min(data[1])+1)

ZS = data[4].reshape(ipoints, -1).transpose() # Convert into maps
WM = data[5].reshape(ipoints, -1).transpose()
WUT = data[7].reshape(ipoints, -1).transpose()
WVT = data[8].reshape(ipoints, -1).transpose()

arrayI = np.arange(0, ipoints)*DELTAX # Spatial scales
arrayJ = np.arange(0, jpoints)*DELTAX
maxI = np.max(arrayI)
maxJ = np.max(arrayJ)
```

We have a map of wind data (speed and direction) around LBTO at Mt. Graham, to be properly plotted.

File: wind_2d.stat:

```
### GRID SIZE X, GRID SIZE Y, START EXIT, END EXIT, EXIT NUM, MIN WIND, MAX WIND
        100      100       4      10    7  1.4624E-02  5.78828
#  I   J    XLAT    XLON     ZS      W.MOD.  W.ANG.  W.X (UT) W.Y(VT)
   2   2   32.656 -109.941 1912.875 1.7029 62.383 -1.5089 -0.78941
   2   3   32.657 -109.941 1916.125 1.5125 71.936 -1.4380 -0.46900
   2   4   32.658 -109.941 1924.812 1.4617 76.891 -1.4236 -0.33153
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  .......
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Read data from file. Note:
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Read data from file. Note:
→ `skiprows`
→ `unpack`

Convert data columns into 2D arrays

We have a map of wind data (speed and direction) around LBTO at Mt. Graham, to be properly plotted.

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Read data from file. Note:
→ skiprows
→ unpack

Convert data columns into 2D arrays

X and Y axes

File: plot_wind_2d.py - contd.:

```
im = plt.imshow(WM, interpolation='bilinear', origin='lower', # Show image
              extent=[0, maxI, 0, maxJ], cmap=cm.hot_r)

cbar = plt.colorbar(im, orientation='vertical')
cbar.set_label("Wind speed (m/s)")

maxzs = np.max(ZS)
minzs = np.min(ZS)
levels = np.linspace(minzs, maxzs, 25) # Set contour levels

plt.contour(arrayI,arrayJ,ZS,levels,colors='k',origin='lower',linewidths=0.5)

plt.plot([arrayI[SYMX]],[arrayJ[SYMY]],"o",color='black', ms=8)

plt.quiver(arrayI[::5],arrayJ[::5],WUT[::5,::5],WVT[::5,::5], # Arrows
         headwidth=6,headlength=6)

plt.title("Wind speed - hour 007 or hour 000 MST")
plt.xlabel('Km')
plt.ylabel('Km')
plt.tight_layout()
plt.show()
plotfile = 'wind_speed.png'
plt.savefig(plotfile, dpi=200)
print("Created file:", plotfile)
```

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Show the image. Note:
- → interpolation
- → origin
- → extent
- → cmap

File: plot_wind_2d.py - contd.:

```
im = plt.imshow(WM, interpolation='bilinear', or
              extent=[0, maxI, 0, maxJ], cmap=cm

cbar = plt.colorbar(im, orientation='vertical')
cbar.set_label("Wind speed (m/s)")

maxzs = np.max(ZS)
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im = plt.imshow(WM, interpolation='bilinear', or
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cbar = plt.colorbar(im, orientation='vertica
cbar.set_label("Wind speed (m/s)")

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Add the colorbar at a side of image

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Add the colorbar at a side of image

Set the desired levels for contours

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Show the image. Note:
- → `interpolation`
- → `origin`
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Add the colorbar at a side of image

Set the desired levels for contours

Plot the contours

File: plot_wind_2d.py - contd.:

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Show the image. Note:
→ interpolation
→ origin
→ extent
→ cmap

Add the colorbar at a side of image

Set the desired levels for contours

Plot the contours

Plot the arrows

File: plot_wind_2d.py - contd.:

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Show the image. Note:
- → interpolation
- → origin
- → extent
- → cmap

Add the colorbar at a side of image

Set the desired levels for contours

Plot the contours

Plot the arrows

Save the image onto a file, with desired quality

File: plot_wind_2d.py - contd.:

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im = plt.imshow(WM, interpolation='bilinear', or
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Add the colorbar at a side of image

Set the desired levels for contours

Plot the contours

Plot the arrows

Save the image onto a file, with desired quality