What is the difference between contiguous and non-contiguous arrays?

Asked 6 years, 8 months ago Active 4 years, 2 months ago Viewed 70k times

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In the numpy manual about the reshape() function, it says

```
>>> a = np.zeros((10, 2))
# A transpose make the array non-contiguous
>>> b = a.T
# Taking a view makes it possible to modify the shape without modifying the
# initial object.
>>> c = b.view()
>>> c.shape = (20)
AttributeError: incompatible shape for a non-contiguous array
```

My questions are:

1. What are continuous and noncontiguous arrays? Is it similar to the contiguous memory block in C like What is a contiguous memory block?
2. Is there any performance difference between these two? When should we use one or the other?
3. Why does transpose make the array non-contiguous?
4. Why does `c.shape = (20)` throws an error `incompatible shape for a non-contiguous array` ?

Thanks for your answer!

python arrays numpy memory

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edited May 23 '17 at 12:26
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1 1

asked Nov 18 '14 at 15:45

jdeng
2,406 3 17 17

2 Answers

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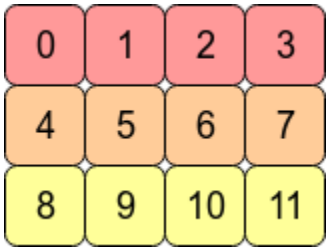
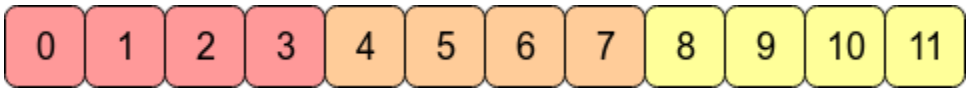
A contiguous array is just an array stored in an unbroken block of memory: to access the next value in the array, we just move to the next memory address.

Consider the 2D array `arr = np.arange(12).reshape(3,4)`. It looks like this:

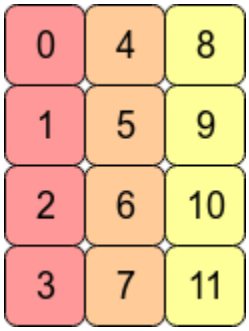


In the computer's memory, the values of `arr` are stored like this:



This means `arr` is a **C contiguous** array because the *rows* are stored as contiguous blocks of memory. The next memory address holds the next row value on that row. If we want to move down a column, we just need to jump over three blocks (e.g. to jump from 0 to 4 means we skip over 1,2 and 3).

Transposing the array with `arr.T` means that C contiguity is lost because adjacent row entries are no longer in adjacent memory addresses. However, `arr.T` is **Fortran contiguous** since the *columns* are in contiguous blocks of memory:



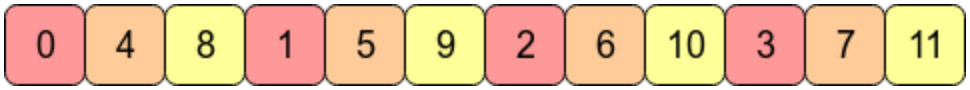
Performance-wise, accessing memory addresses which are next to each other is very often faster than accessing addresses which are more "spread out" (fetching a value from RAM could entail a number of neighbouring addresses being fetched and cached for the CPU.) This means that operations over contiguous arrays will often be quicker.

As a consequence of C contiguous memory layout, row-wise operations are usually faster

Finally, why can't we flatten the Fortran contiguous array by assigning a new shape?

```
>>> arr2 = arr.T
>>> arr2.shape = 12
AttributeError: incompatible shape for a non-contiguous array
```

In order for this to be possible NumPy would have to put the rows of `arr.T` together like this:



(Setting the `shape` attribute directly assumes C order - i.e. NumPy tries to perform the operation row-wise.)

This is impossible to do. For any axis, NumPy needs to have a *constant* stride length (the number of bytes to move) to get to the next element of the array. Flattening `arr.T` in this way would require skipping forwards and backwards in memory to retrieve consecutive values of the array.

If we wrote `arr2.reshape(12)` instead, NumPy would copy the values of arr2 into a new block of memory (since it can't return a view on to the original data for this shape).

Share Improve this answer Follow edited May 5 '17 at 20:42

answered Nov 18 '14 at 16:25

Alex Riley
136k 39 225 211

1 I am having difficulty understanding this, can you please elaborate a little? In the latest graphical representation of the impossible ordering in the memory actually the strides are constant in my opinion. For example to go from 0 to 1 the stride is 1 byte (let's say each element is a byte) and it is the same for each column. Likewise the stride is 4 bytes for to go from one element in the row to the next one and it is also constant. – Vesnog Apr 12 '20 at 1:29

4 @Vesnog the failed reshape of the 2D `arr2` to the 1D shape `(12,)` uses C order, meaning that that axis 1 is unwound before axis 0 (i.e. each of the four rows needs to be placed next to each other to create desired the 1D array). It is impossible to read this sequence of integers (0, 4, 8, 1, 5, 9, 2, 6, 10,

14

Maybe this example with 12 different array values will help:

```
In [207]: x=np.arange(12).reshape(3,4).copy()

In [208]: x.flags
Out[208]:
  C_CONTIGUOUS : True
  F_CONTIGUOUS : False
  OWNDATA : True
  ...
In [209]: x.T.flags
Out[209]:
  C_CONTIGUOUS : False
  F_CONTIGUOUS : True
  OWNDATA : False
  ...
```

The `C order` values are in the order that they were generated in. The transposed ones are not

```
In [212]: x.reshape(12,)   # same as x.ravel()
Out[212]: array([ 0,  1,  2,  3,  4,  5,  6,  7,  8,  9, 10, 11])

In [213]: x.T.reshape(12,)
Out[213]: array([ 0,  4,  8,  1,  5,  9,  2,  6, 10,  3,  7, 11])
```

You can get 1d views of both

```
In [214]: x1=x.T

In [217]: x.shape=(12,)
```

the shape of `x` can also be changed.

```
In [220]: x1.shape=(12,)
---------------------------------------------------------------------------
AttributeError                            Traceback (most recent call last)
<ipython-input-220-cf2b1a308253> in <module>()
----> 1 x1.shape=(12,)

AttributeError: incompatible shape for a non-contiguous array
```

But the shape of the transpose cannot be changed. The `data` is still in the `0,1,2,3,4...` order, which can't be accessed accessed as `0,4,8...` in a 1d array.

Looking at `strides` might also help. A strides is how far (in bytes) it has to step to get to the next value. For a 2d array, there will be be 2 stride values:

```
In [233]: x=np.arange(12).reshape(3,4).copy()

In [234]: x.strides
Out[234]: (16, 4)
```

To get to the next row, step 16 bytes, next column only 4.

```
In [235]: x1.strides
Out[235]: (4, 16)
```

Transpose just switches the order of the strides. The next row is only 4 bytes- i.e. the next number.

```
In [236]: x.shape=(12,)

In [237]: x.strides
Out[237]: (4,)
```

Changing the shape also changes the strides - just step through the buffer 4 bytes at a time.

```
In [238]: x2=x1.copy()

In [239]: x2.strides
Out[239]: (12, 4)
```

Even though `x2` looks just like `x1`, it has its own data buffer, with the values in a different order. The next column is now 4 bytes over, while the next row is 12 (3*4).

```
In [240]: x2.shape=(12,)

In [241]: x2.strides
Out[241]: (4,)
```

And as with `x`, changing the shape to 1d reduces the strides to `(4,)`.

For `x1`, with data in the `0,1,2,...` order, there isn't a 1d stride that would give `0,4,8...`.

different buffer address.

You could also experiment with adding a `order='F'` parameter to the `copy` and `reshape` commands.

Share Improve this answer Follow edited Nov 19 '14 at 1:22

answered Nov 18 '14 at 21:01

hpaulj

179k 13 176 285