Memory layout

This lesson explains the memory layout using NumPy.

We'll cover the following

The NumPy documentation defines the ndarray class very clearly:

> *An instance of class **ndarray** consists of a contiguous one-dimensional segment of computer memory (owned by the array, or by some other object), combined with an indexing scheme that maps N integers into the location of an item in the block.*

Said differently, an array is mostly a contiguous block of memory whose parts can be accessed using an indexing scheme. Such indexing scheme is in turn defined by a shape and a data type and this is precisely what is needed when you define a new array:

```
import numpy as np
Z = np.arange(9).reshape(3,3).astype(np.int16)
print(Z)
```

```
print(Z.itemsize)# returns size of Z in bytes
print(Z.shape)# returns the x dimension and y dimension of Z
print(Z.ndim)# dimension in Z i.e (2 in this case) since the array is 2D
```

Here, we know that itemsize is 2 bytes (`int16`), the shape is (3,3) and the number of dimensions is 2.

> To calculate the dimension we can also use `len(Z.shape)`.

Furthermore, we can deduce the strides of the array that define the number of bytes to step in each dimension when traversing the array.

```
import numpy as np
Z = np.arange(9).reshape(3,3).astype(np.int16)
stride = Z.shape[1]*Z.itemsize, Z.itemsize # store stride of Z
print("Stride(as np.int16):",stride)
print("Z.stride(np.16):",Z.strides)
Z = np.arange(9).reshape(3,3).astype(np.int32)
stride= Z.shape[1]*Z.itemsize, Z.itemsize  #stores stride of Z
print("Stride(as np.int32):",stride)
print("Z.stride(np.32):",Z.strides)
```

Here in this example, we have to skip 2 bytes (1 value) to move to the next column, but 6 bytes (3 values) to get to the same position in the next row. As such, the **strides** for the array `Z` will be **(6, 2)**.

With all this information, we know how to access a specific item (designed by an index tuple) and more precisely, how to compute the start and end offsets:

```
import numpy as np
Z = np.arange(9).reshape(3,3).astype(np.int16)
offset_start = 0
for i in range(Z.ndim):
  offset_start += Z.strides[i] * i #compute the start offset of Z
  offset_end = offset_start + Z.itemsize #compute the end offset of Z

print("Starting offset:", offset_start)
print("Ending offset:", offset_end)
```

Let’s see if this is correct using the tobytes conversion method that construct Python bytes containing the raw data bytes in the array:

```
import numpy as np
Z = np.arange(9).reshape(3, 3).astype(np.int16)
index = 1, 1
print(Z[index].tobytes())
   #b'\x04\x00'
offset_start = 0
for i in range(Z.ndim):
  offset_start += Z.strides[i] * index[i]
  offset_end = offset_start + Z.itemsize

print(Z.tobytes()[offset_start:offset_end])#b'\x04\x00'
```

Layouts

This array can be actually considered from different perspectives (i.e. layouts):

Item layout

Consider item layout as a 2-Dimensional Matrix with x rows and y columns.

Example 1

Consider the following example:

```
Z = np.arange(9).reshape(3, 3)
```

Here takes 9 values from 0-8 and is reshaped in 2-D matrix format having dimensions (3 * 3).

Z has the following item layout:

```
               shape[1]
                 (=3)

            ┌───────────┐

         ┌  ┌───┬───┬───┐  ┐
         │  │ 0 │ 1 │ 2 │  │
```

```
          │  ┬───┬───┬───┬  │
shape[0]  │  │ 3 │ 4 │ 5 │  │ len(Z)
          │  │   │   │   │  │
   (=3)   │  ├───┼───┼───┤  │  (=3)
          │  │ 6 │ 7 │ 8 │  │
          └  └───┴───┴───┘  ┘
```

Example 2

Consider the following example

```
Z = np.arange(9).reshape(3,3)
V= Z[::2,::2])
```

Here Z takes up 9 values from 0-8 and arranges them in a 3 * 3 matrix V takes values from corners from the grid. i.e V has 4 values.

V has the following item layout:

```
                  shape[1]
                    (=2)

               ┌───────────┐

            ┌  ┌───┬┄┄┄┬───┐  ┐
            │  │ 0 │   │ 2 │  │
            │  ├───┼┄┄┄┼───┤  │          ┌───┬───┐
            │  ┊   ┊   ┊   ┊  │          │ 0 │ 2 │
   shape[0] │  ┊   ┊   ┊   ┊  │ len(V) → ├───┼───┤
     (=2)   │  ├───┼┄┄┄┼───┤  │  (=2)    │ 6 │ 8 │
            │  │ 6 │   │ 8 │  │          └───┴───┘
            └  └───┴┄┄┄┴───┘  ┘
```

Flattened item layout

Consider flattened item layout as 1-Dimensional Matrix with 1 row and n columns.

Example 1

Consider the following example:

```
Z = np.arange(9)
```

It makes 9 indices in the computer’s memory and places values from 0 to 8.

Z has the following flattened item layout:

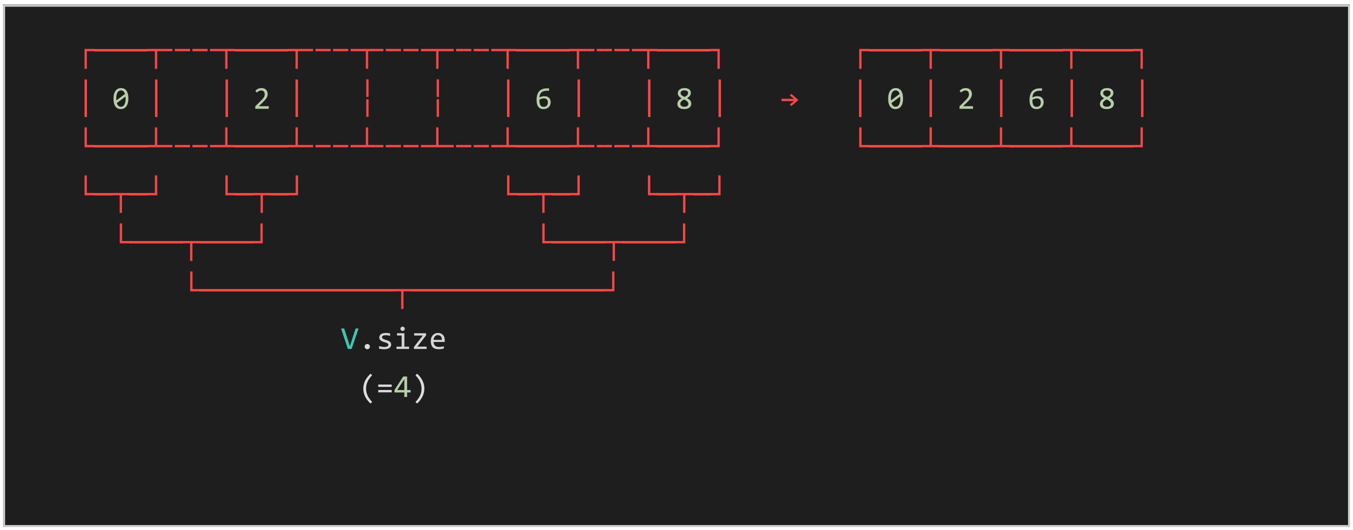
Z has the following flattened item layout:

Example 2

Consider the following example

```
Z = np.arange(9).reshape(3,3).astype(np.int16)
V = Z[::2,::2]
V=V.reshape(1,4)
```

Here Z takes up 9 values from 0-8 and arranges them in a 3 * 3 matrix V takes values from corners from the grid. i.e V has 4 values. V has the following flattened item layout:



Memory layout (C order, big endian)

Consider memory layout with rows equal to the number of bytes and columns equal to the number of bytes divided by 8 (i.e Z.itemsize).

Example 1

Consider the following example:

```
Z = np.arange(9).reshape(3, 3).astype(np.int16)
```

Here, the number of rows is 16 and the number of columns is 2. The total number of bytes is 3 * 3 * 2 where 3 * 3 is the size of the grid and each cell takes 2 bytes, so total 18 bytes. Z has the following memory layout:

```
                         strides[1]
                           (=2)
                    ┌─────────────────────┐

          ┌         ┌──────────┬──────────┐ ┐
          │ p+00:   │ 00000000 │ 00000000 │ │
          │         ├──────────┼──────────┤ │
          │ p+02:   │ 00000000 │ 00000001 │ │ strides[0]
          │         ├──────────┼──────────┤ │   (=2x3)
          │ p+04    │ 00000000 │ 00000010 │ │
          │         ├──────────┼──────────┤ ┘
          │ p+06    │ 00000000 │ 00000011 │
          │         ├──────────┼──────────┤
Z.nbytes  │ p+08:   │ 00000000 │ 00000100 │
(=3x3x2)  │         ├──────────┼──────────┤
          │ p+10:   │ 00000000 │ 00000101 │
          │         ├──────────┼──────────┤
          │ p+12:   │ 00000000 │ 00000110 │
          │         ├──────────┼──────────┤
          │ p+14:   │ 00000000 │ 00000111 │
          │         ├──────────┼──────────┤
          │ p+16:   │ 00000000 │ 00001000 │
          └         └──────────┴──────────┘

                    └─────────────────────┘
                         Z.itemsize
                      Z.dtype.itemsize
                           (=2)
```

Example 2

Consider the following example

```
Z = np.arange(9).reshape(3,3).astype(np.int16)
V = Z[::2,::2]
```

Here we take a slice of `Z`, the result is a view of the base array `Z`. In the memory layout below, since the array takes up only 4 value. and each value is

2 bytes so the total bytes are 2 * 4 = 8 bytes. V has the following memory layout:

```
                   ┌        ┌─────────┬─────────┐  ┐              ┐
                 ┌─┤  p+00: │ 00000000│ 00000000│  │              │
                 │ └        ├─────────┼─────────┤  │ strides[1]   │
               ┌─┤    p+02: │         │         │  │   (=4)       │
               │ │ ┌        ├─────────┼─────────┤  ┘              │
               │ └─┤  p+04  │ 00000000│ 00000010│                 │
               │   └        ├─────────┼─────────┤                 │ strides[
0]
               │      p+06: │         │         │                 │   (=12)
               │            ├─────────┼─────────┤                 │
    V.nbytes  ─┤      p+08: │         │         │                 │
      (=8)     │            ├─────────┼─────────┤                 │
               │      p+10: │         │         │                 │
               │   ┌        ├─────────┼─────────┤                 ┘
               │ ┌─┤  p+12: │ 00000000│ 00000110│
               │ │ └        ├─────────┼─────────┤
               └─┤    p+14: │         │         │
                 │ ┌        ├─────────┼─────────┤
                 └─┤  p+16: │ 00000000│ 00001000│
                   └        └─────────┴─────────┘

                            └─────────┬─────────┘
                                 Z.itemsize
                              Z.dtype.itemsize
                                    (=2)
```

Such a view is specified using a shape, a dtype and strides because strides cannot be deduced anymore from the dtype and shape only.

Solve this Quiz!

1 What is the output of the following code?

```
Z = np.arange(9).reshape(3,3).astype(np.int32)
```

```
print(Z.itemsize())
```

A) 2

B) 4

COMPLETED 0%

1 of 2

Now, that we have viewed memory layouts, we'll look at views and copies in the next lesson.