CSCI-UA 0480-042 Computer Vision

Homework 1

In this assignment, you will be introduced to few Python libraries that will be needed for this course. This assumes that you can write basic Python programs. If you do not know how to code in Python, this would be a good time for you to learn.

The main goals of this assignment are to introduce how you could:

1. Do basic vector operations.
2. Use Matplotlib to plot a function, and to also display a collection of images.
3. Summarize a neural network architecture.

You may have already worked with these libraries before, in which case we hope this could be a nice review.

Also accompanying each section below, there are a few questions (**4 questions in total**). Please give your answers in the space provided.

Part 1: Numpy

NumPy (https://numpy.org/) is a highly popular Python library within the scientific community. With NumPy, you can operate on n-dimensional arrays and perform a number of mathematical operations on them. For example, you can generate an array of random numbers (https://numpy.org/doc/stable/reference/random/index.html), compute element-wise sum/difference between 2 arrays (https://numpy.org/doc/stable/reference/ufuncs.html#available-ufuncs), find the L2 norm of an array (https://numpy.org/doc/stable/reference/generated/numpy.linalg.norm.html), etc.

NumPy is mostly C under the hood, and it's highly optimized. So it's highly recommended that you use NumPy whenever possible. We will show some basic operations here. This is by no means complete - NumPy is a huge library and it's impossible to cover everything.

First, let's import numpy:

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

You can convert a 2d list of numbers into a numpy array using:

In [2]:
```
nums = [[1, 2, 3, 4], [5, 6, 7, 8]]
np.array(nums)
```

Out[2]:
```
array([[1, 2, 3, 4],
       [5, 6, 7, 8]])
```

`linspace(start, end, n)` can be used to generate an array of `n` evenly spaced numbers from `start` to `end` (both inclusive).

In [3]:
```
np.linspace(0, 10, 21)
```

Out[3]:
```
array([ 0. ,  0.5,  1. ,  1.5,  2. ,  2.5,  3. ,  3.5,  4. ,  4.5,  5. ,
        5.5,  6. ,  6.5,  7. ,  7.5,  8. ,  8.5,  9. ,  9.5, 10. ])
```

You can multiply this array with a scalar:

In [4]:
```
2*np.linspace(0, 10, 21)
```

Out[4]:
```
array([ 0.,  1.,  2.,  3.,  4.,  5.,  6.,  7.,  8.,  9., 10., 11., 12.,
       13., 14., 15., 16., 17., 18., 19., 20.])
```

A 1d array can also be reshaped into a 2d array. To see the dimensions of a numpy array `arr`, use `arr.shape`.

In [5]:
```
arr = np.linspace(0, 99, 100)
new_arr = arr.reshape((10, 10))
print("Original shape", arr.shape)
print("Reshaped array shape", new_arr.shape)
print("Reshaped array:\n", new_arr)
```

```
Original shape (100,)
Reshaped array shape (10, 10)
Reshaped 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.]
 [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.]
 [60. 61. 62. 63. 64. 65. 66. 67. 68. 69.]
 [70. 71. 72. 73. 74. 75. 76. 77. 78. 79.]
 [80. 81. 82. 83. 84. 85. 86. 87. 88. 89.]
 [90. 91. 92. 93. 94. 95. 96. 97. 98. 99.]]
```

You can learn more about NumPy from [the quickstart page (https://numpy.org/doc/stable/user/quickstart.html)](https://numpy.org/doc/stable/user/quickstart.html).

Question 1

Find the dot product of these 2 arrays using NumPy:

$$A = \begin{bmatrix} 19 & 7 & -15 \\ 12 & 59 & 27 \end{bmatrix}$$

$$B = \begin{bmatrix} 3 \\ -7 \\ -13 \end{bmatrix}$$

In [6]:
```
A = [[19, 7, -15], [12, 59, 27]]
B = [[3], [-7], [-13]]
output = np.dot (A, B)
print (output)
```

```
[[ 203]
 [-728]]
```

Question 2

Create 2 matrices:

1. C: [[1, 2, 3], [4, 5, 6]]
2. D: [[10, 11, 12], [13, 14, 15]]

and concatenate them to get this matrix:

[[1, 2, 3], [4, 5, 6], [10, 11, 12], [13, 14, 15]]

In [7]:
```
C = [[1, 2, 3], [4, 5, 6]]
D = [[10, 11, 12], [13, 14, 15]]
concatenation = np.concatenate((C,D), axis=0)
print (concatenation)
```

```
[[ 1  2  3]
 [ 4  5  6]
 [10 11 12]
 [13 14 15]]
```

Part 2: Plotting in Python

Matplotlib is the most commonly used plotting Python library. There are other libraries out there (such as seaborn, bokeh, etc.), but we will focus on Matplotlib.

Our first step would be to plot the sigmoid activation function:

$$\sigma(x) = \frac{1}{1 + e^{-x}}$$

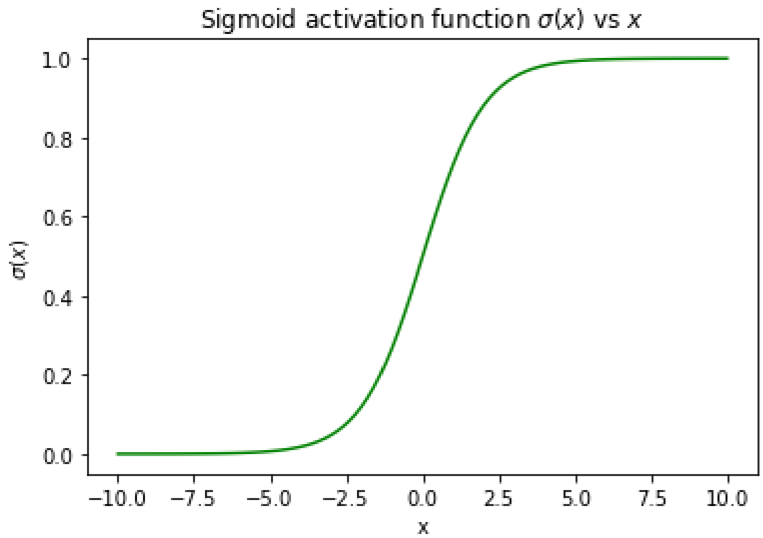
In [8]:
```
x = np.linspace(-10, 10, 101) # get 101 data points
sigma = 1/(1+ np.exp(-x))     # get f(x)
```

In [9]:
```
print(x.shape, sigma.shape)
```

```
(101,) (101,)
```

In [10]:
```
import matplotlib.pyplot as plt

fig, ax = plt.subplots()
ax.plot(x, sigma, 'g-') # plot x, f(x)
ax.set_xlabel('x')
ax.set_ylabel('$\sigma(x)$')
ax.set_title('Sigmoid activation function $\sigma(x)$ vs $x$')
plt.show()
```



Question 3

On the same graph:

1. Plot the `tanh` activation function (using a blue line). For reference,
$$\tanh x = \frac{e^x - e^{-x}}{e^x + e^{-x}}$$
2. Draw a vertical dotted line at $x = 0$.
3. Add a legend indicating what the different lines are.

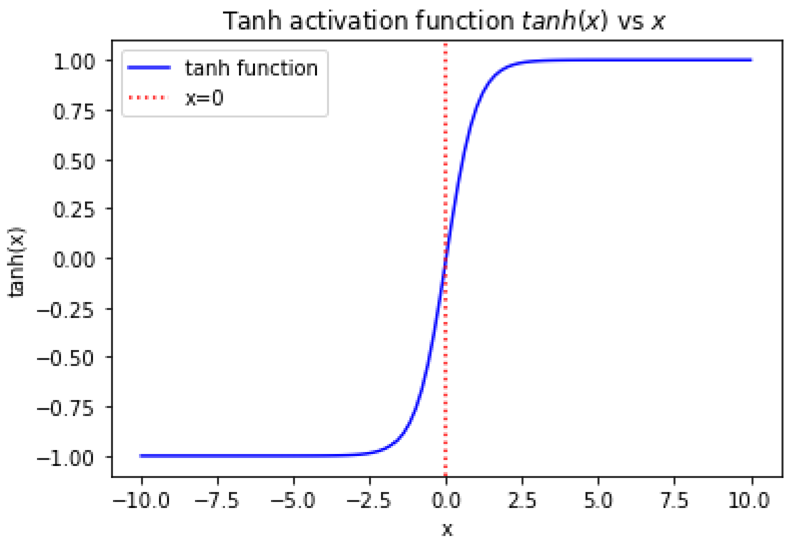
Here's an excellent article (although slightly advanced) that gives a quick intro to Matplotlib: [https://pbpython.com/effective-matplotlib.html (https://pbpython.com/effective-matplotlib.html)](https://pbpython.com/effective-matplotlib.html). Some sections use Pandas, which is another Python library used by the data science community. You don't need to understand how it works, but just know that in Pandas, you can visualize data by calling a plot method on the data object (known as a dataframe in Pandas vernacular). This effectively calls matplotlib in the background.

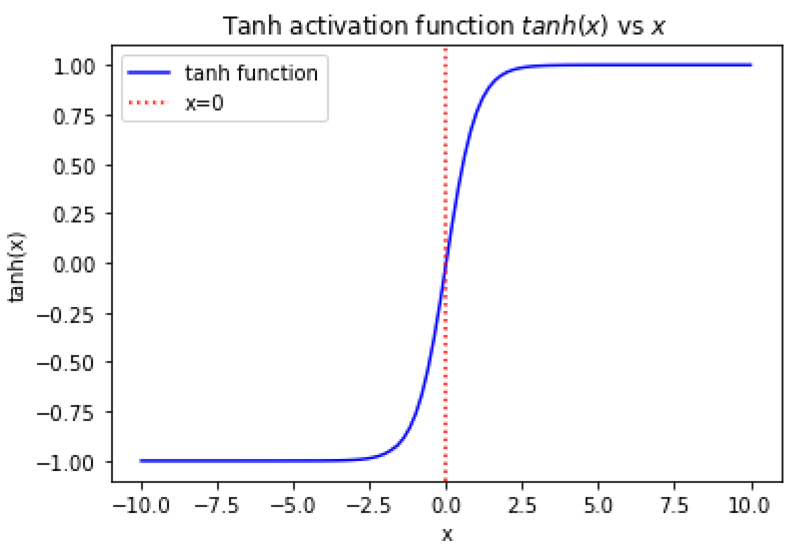
Matplotlib documentation: [https://matplotlib.org/3.3.3/contents.html (https://matplotlib.org/3.3.3/contents.html)](https://matplotlib.org/3.3.3/contents.html).

In [11]:

```
fig, ax = plt.subplots()
tanh = (np.exp(x)-np.exp(-x))/(np.exp(x)+np.exp(-x))
vertical = 0
ax.plot (x, tanh, 'b-', label = "tanh function")
ax.axvline (x=0, color='r', linestyle=':', label = "x=0")
ax.set_xlabel ('x')
ax.set_ylabel ('tanh(x)')
ax.set_title ('Tanh activation function $tanh(x)$ vs $x$')
plt.legend()
# Uncomment the line below to redraw the figure and display it:
fig
```

Out[11]:





Now let's try to display a group of images using Matplotlib. We have provided some sample images from Imagenet dataset in the `img` folder. This dataset is mainly used to train neural nets for object recognition task. For this, we will need a library called `PIL` (Python Imaging Library).

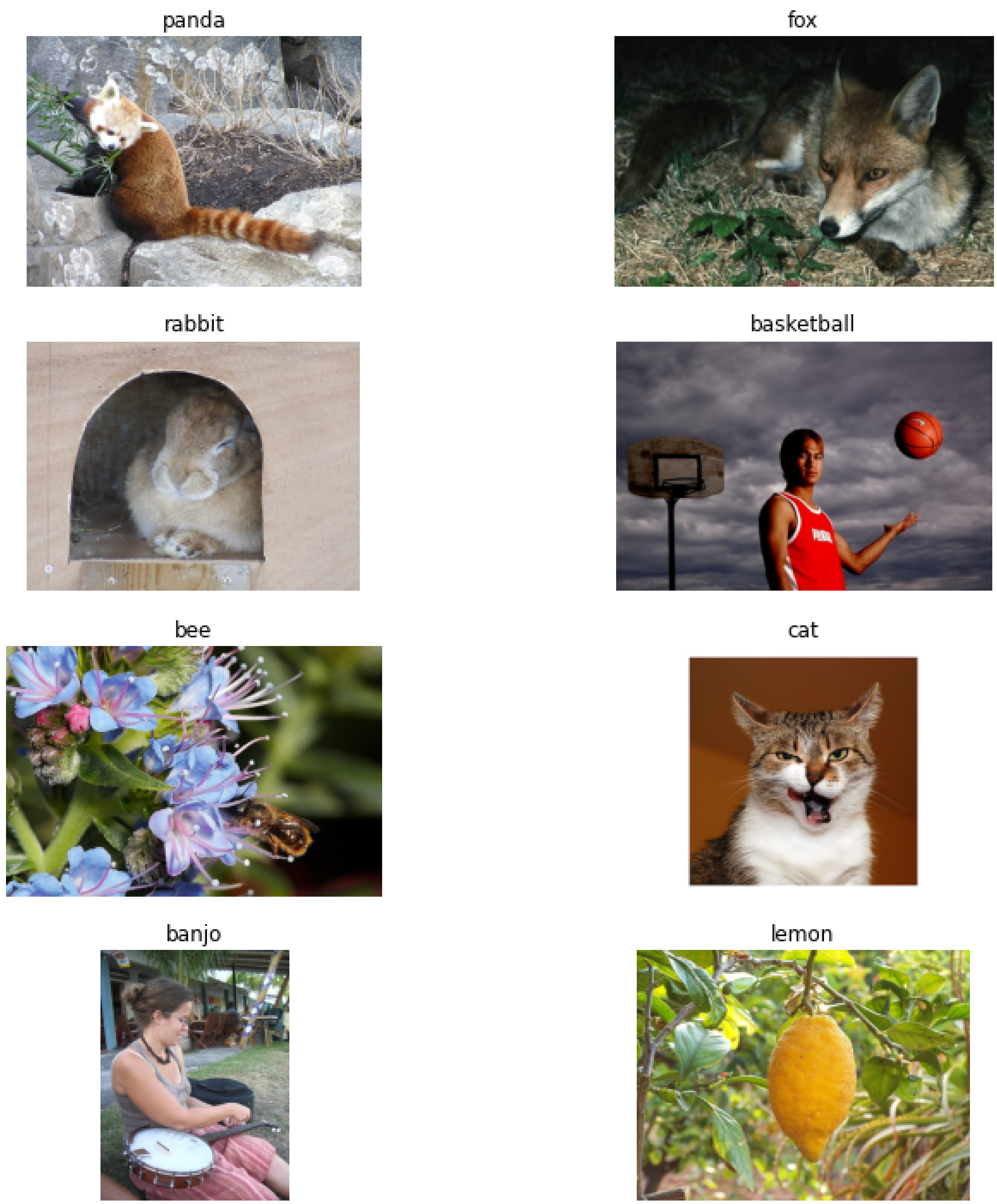
In [12]:
```
from PIL import Image # Reference: https://pillow.readthedocs.io/en/3.0.x/refe
rence/Image.html
import glob     # Reference: https://docs.python.org/3/library/glob.html
img_paths = glob.glob('img/**.jpg')
n_images = len(img_paths)
```

In [13]:
```
img_paths
```

Out[13]:
```
['img/n02509815_27612_red_panda.jpg',
 'img/n02118333_27_fox.jpg',
 'img/n02324045_3738_rabbit.jpg',
 'img/n02802426_12131_basketball.jpg',
 'img/n02206856_2865_bee.jpg',
 'img/n02121808_1421_domestic_cat.jpg',
 'img/n02787622_3030_banjo.jpg',
 'img/n07749582_16107_lemon.jpg']
```

In [14]:
```
fig, ax = plt.subplots(n_images//2, 2, figsize=(10, 10))
fig.tight_layout()

for i in range(n_images):
    img_path = img_paths[i]
    img_data = Image.open(img_path)
    row, col = i//2, i%2
    label = img_path.split('_')[-1].split('.')[0]
    ax[row][col].imshow(img_data)
    ax[row][col].set_title(label)
    ax[row][col].axis('off')
```



Part 3: ResNet

In this course, we will use PyTorch to build and train neural networks. Although PyTorch will be introduced in a later assignment, we want to show here how you can see important model details.

PyTorch folks also maintain a separate module called `torchvision` (https://pytorch.org/vision/stable/index.html), which contains popular datasets, pretrained models relevant to computer vision. We will use ResNet-18 model from this module to demonstrate this. You don't need to know any details about ResNet, this is just for demonstration purposes. Here's a link to the paper in case you're interested: https://arxiv.org/pdf/1512.03385.pdf (https://arxiv.org/pdf/1512.03385.pdf)

There is a library called `torchsummary` (https://github.com/sksq96/pytorch-summary) that can be used to print model summary (this was created by an NYU student!). With this, we can see all the layers inside the model, the type of each layer, etc. In addition, it also prints overall statistics such as model size, number of parameters in the model, etc.

In [15]:
```
from torchvision import models
from torchsummary import summary

resnet18 = models.resnet18().cpu()

# Summary method requires the input image size. ResNet has been trained
# on image size (3, 224, 224)
print(summary(resnet18, (3, 224, 224)))
```

```
/opt/conda/envs/cv_sp21/lib/python3.8/site-packages/torch/cuda/__init__.py:5
2: UserWarning: CUDA initialization: Found no NVIDIA driver on your system. P
lease check that you have an NVIDIA GPU and installed a driver from http://ww
w.nvidia.com/Download/index.aspx (Triggered internally at  /opt/conda/conda-b
ld/pytorch_1607370117127/work/c10/cuda/CUDAFunctions.cpp:100.)
  return torch._C._cuda_getDeviceCount() > 0
```

```
----------------------------------------------------------------
        Layer (type)               Output Shape         Param #
================================================================
            Conv2d-1         [-1, 64, 112, 112]           9,408
       BatchNorm2d-2         [-1, 64, 112, 112]             128
              ReLU-3         [-1, 64, 112, 112]               0
         MaxPool2d-4           [-1, 64, 56, 56]               0
            Conv2d-5           [-1, 64, 56, 56]          36,864
       BatchNorm2d-6           [-1, 64, 56, 56]             128
              ReLU-7           [-1, 64, 56, 56]               0
            Conv2d-8           [-1, 64, 56, 56]          36,864
       BatchNorm2d-9           [-1, 64, 56, 56]             128
             ReLU-10           [-1, 64, 56, 56]               0
       BasicBlock-11           [-1, 64, 56, 56]               0
           Conv2d-12           [-1, 64, 56, 56]          36,864
      BatchNorm2d-13           [-1, 64, 56, 56]             128
             ReLU-14           [-1, 64, 56, 56]               0
           Conv2d-15           [-1, 64, 56, 56]          36,864
      BatchNorm2d-16           [-1, 64, 56, 56]             128
             ReLU-17           [-1, 64, 56, 56]               0
       BasicBlock-18           [-1, 64, 56, 56]               0
           Conv2d-19          [-1, 128, 28, 28]          73,728
      BatchNorm2d-20          [-1, 128, 28, 28]             256
             ReLU-21          [-1, 128, 28, 28]               0
           Conv2d-22          [-1, 128, 28, 28]         147,456
      BatchNorm2d-23          [-1, 128, 28, 28]             256
           Conv2d-24          [-1, 128, 28, 28]           8,192
      BatchNorm2d-25          [-1, 128, 28, 28]             256
             ReLU-26          [-1, 128, 28, 28]               0
       BasicBlock-27          [-1, 128, 28, 28]               0
           Conv2d-28          [-1, 128, 28, 28]         147,456
      BatchNorm2d-29          [-1, 128, 28, 28]             256
             ReLU-30          [-1, 128, 28, 28]               0
           Conv2d-31          [-1, 128, 28, 28]         147,456
      BatchNorm2d-32          [-1, 128, 28, 28]             256
             ReLU-33          [-1, 128, 28, 28]               0
       BasicBlock-34          [-1, 128, 28, 28]               0
           Conv2d-35          [-1, 256, 14, 14]         294,912
      BatchNorm2d-36          [-1, 256, 14, 14]             512
             ReLU-37          [-1, 256, 14, 14]               0
           Conv2d-38          [-1, 256, 14, 14]         589,824
      BatchNorm2d-39          [-1, 256, 14, 14]             512
           Conv2d-40          [-1, 256, 14, 14]          32,768
      BatchNorm2d-41          [-1, 256, 14, 14]             512
             ReLU-42          [-1, 256, 14, 14]               0
       BasicBlock-43          [-1, 256, 14, 14]               0
           Conv2d-44          [-1, 256, 14, 14]         589,824
      BatchNorm2d-45          [-1, 256, 14, 14]             512
             ReLU-46          [-1, 256, 14, 14]               0
           Conv2d-47          [-1, 256, 14, 14]         589,824
      BatchNorm2d-48          [-1, 256, 14, 14]             512
             ReLU-49          [-1, 256, 14, 14]               0
       BasicBlock-50          [-1, 256, 14, 14]               0
           Conv2d-51            [-1, 512, 7, 7]       1,179,648
      BatchNorm2d-52            [-1, 512, 7, 7]           1,024
             ReLU-53            [-1, 512, 7, 7]               0
           Conv2d-54            [-1, 512, 7, 7]       2,359,296
```

```
      BatchNorm2d-55            [-1, 512, 7, 7]           1,024
           Conv2d-56            [-1, 512, 7, 7]         131,072
      BatchNorm2d-57            [-1, 512, 7, 7]           1,024
             ReLU-58            [-1, 512, 7, 7]               0
       BasicBlock-59            [-1, 512, 7, 7]               0
           Conv2d-60            [-1, 512, 7, 7]       2,359,296
      BatchNorm2d-61            [-1, 512, 7, 7]           1,024
             ReLU-62            [-1, 512, 7, 7]               0
           Conv2d-63            [-1, 512, 7, 7]       2,359,296
      BatchNorm2d-64            [-1, 512, 7, 7]           1,024
             ReLU-65            [-1, 512, 7, 7]               0
       BasicBlock-66            [-1, 512, 7, 7]               0
AdaptiveAvgPool2d-67            [-1, 512, 1, 1]               0
           Linear-68                 [-1, 1000]         513,000
================================================================
Total params: 11,689,512
Trainable params: 11,689,512
Non-trainable params: 0
----------------------------------------------------------------
Input size (MB): 0.57
Forward/backward pass size (MB): 62.79
Params size (MB): 44.59
Estimated Total Size (MB): 107.96
----------------------------------------------------------------
None
```

Question 4

There are other ResNet architectures - ResNet-34, ResNet-50, ResNet-101 and ResNet-152. These models mainly differ in the number of layers. They are available in the torchvision module. Using the example code above, find the model size (i.e. params size) and number of parameters for each of the **first three** models. Provide your answers in a tabular format.

Use the input image size (3, 224, 224).

Models	Model Size	# of params
ResNet34	83.15MB	21,797,672
ResNet50	97.49MB	25,557,032
ResNet101	169.94MB	44,549,160

In [ ]: