COMP SCI 1400
AI Technologies – Image Classification

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Outline

- What & Why
- Deep Neural Network
  - Convolution
  - Activation
  - Max-pooling
  - Full connection

What is image classification?

Image classification is a task to predict the label of a given image from predefined classes or categories:

$$\hat{y} = f(I), I \text{ is the input image.}$$

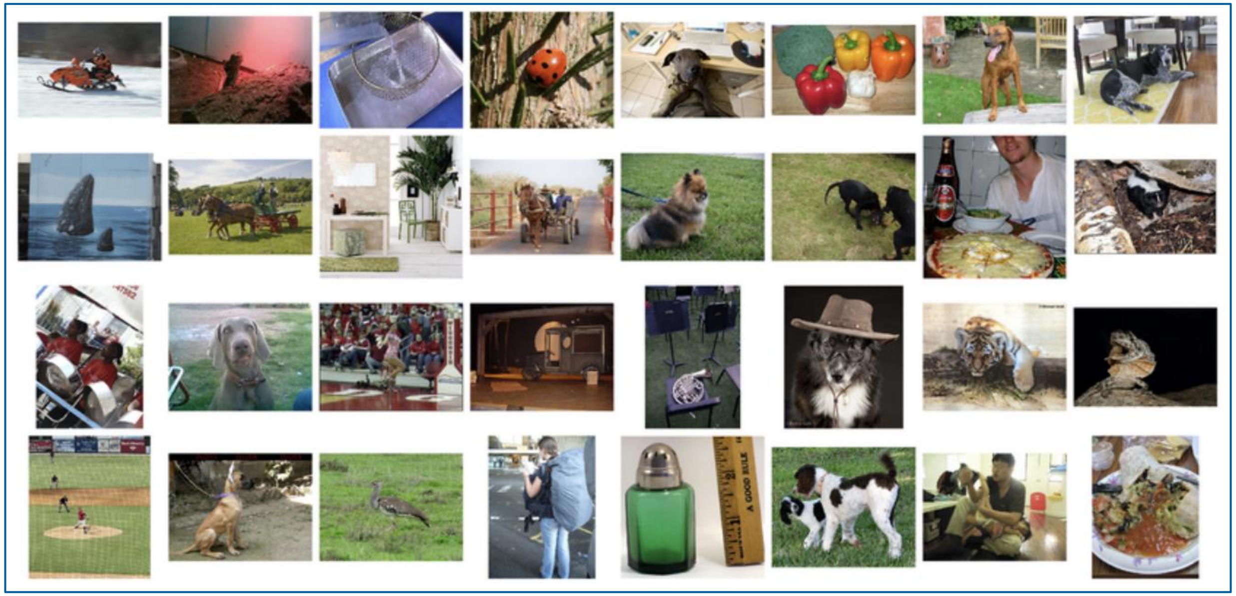
Predefined classes: dog, table, bird, bike, cat, apple, …

Image:		
Prediction $\hat{y}$:	bird	dog
Ground truth y:	bird	dog

ImageNet Large Scale Visual Recognition Challenge

1000 classes, 1.2M training images, 50K validation images, 100K test images

Predict 5 classes, each associated with a bounding box



https://www.image-net.org/challenges/LSVRC/

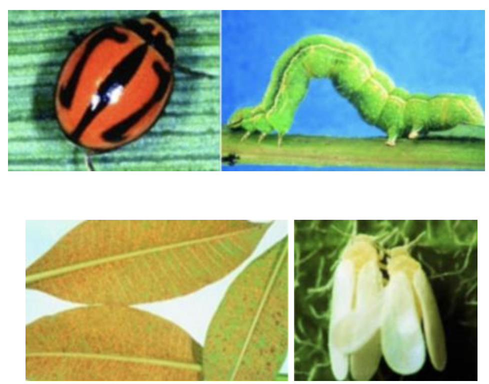
Why learn image classification?

It has wide applications.

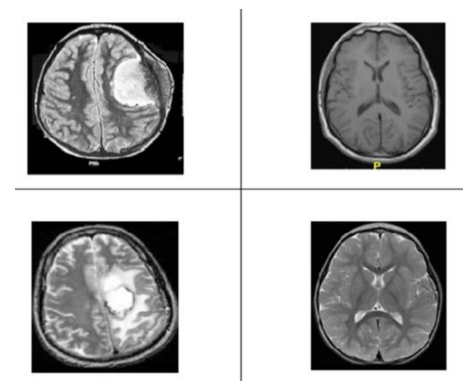
Security

Stranger?

Pest Identification



Medical Image Analysis



Brain Tumor

Brain Non-Tumor

What are the challenges in image classification?

Intense illumination variation

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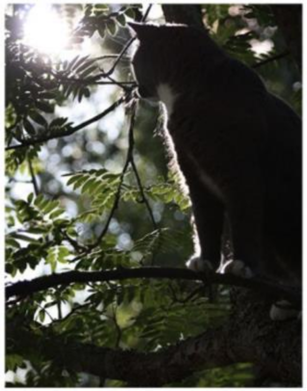

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What are the challenges?

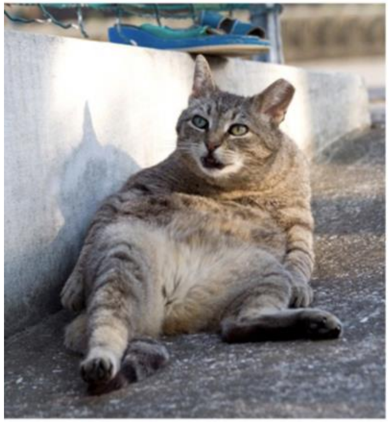
Background clutter

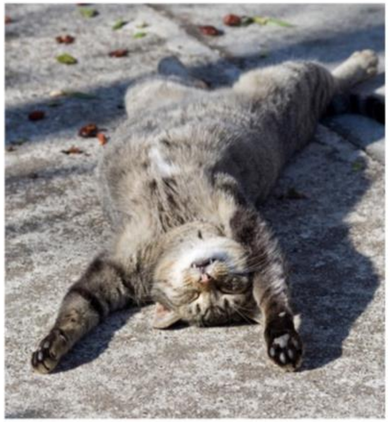
What are the challenges?

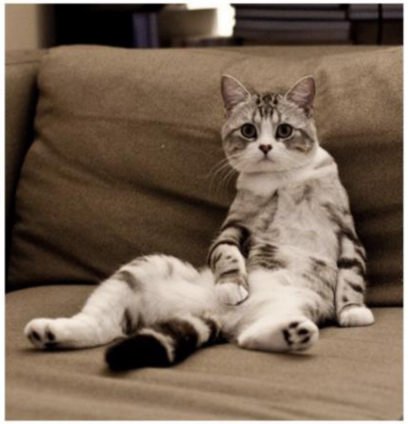
Occlusion

What are the challenges?

Pose / Deformation







Deep Neural Network

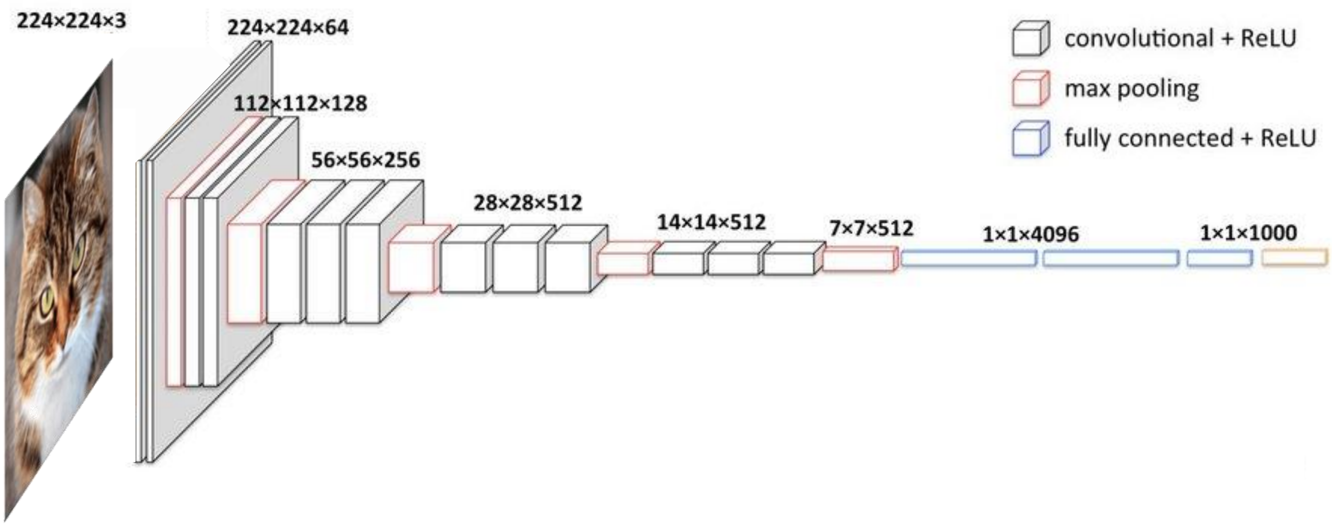
The winner of ILSVRC 2014: VGGNet

in terms of localization error

Localization Error	Classification Error
25.3%	7.4%

Deep Neural Network - VGG

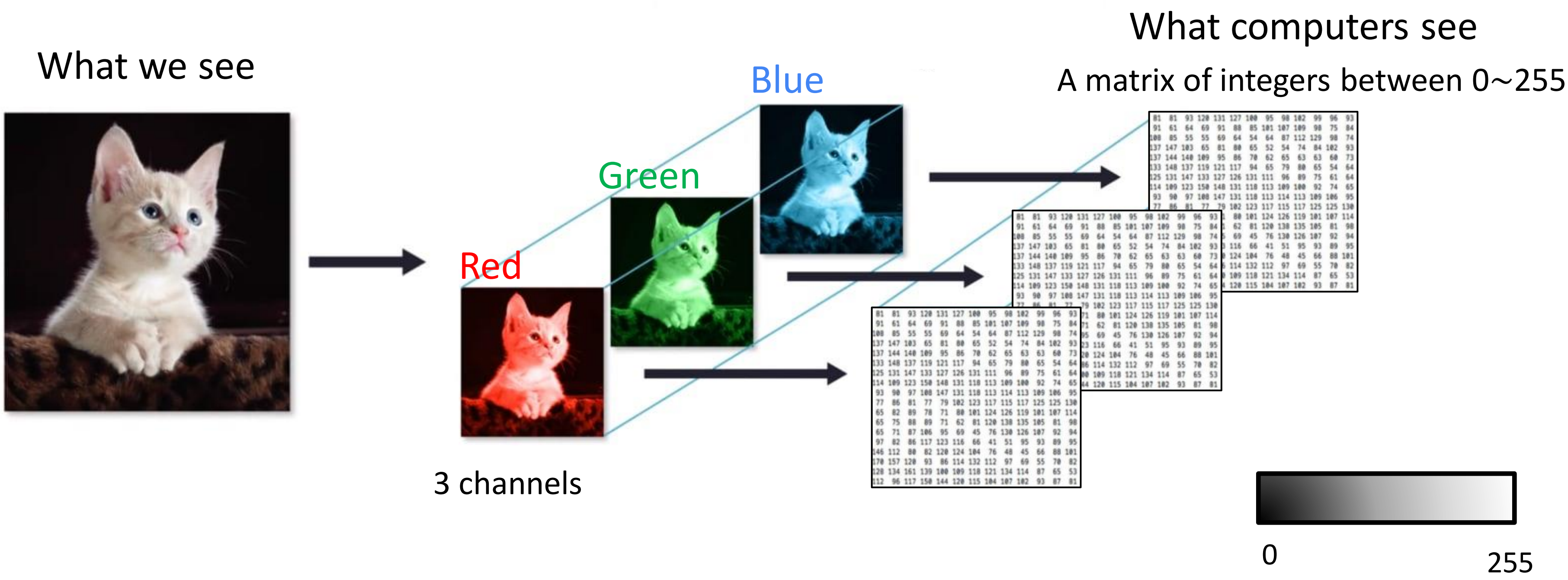
VGGNet architecture



https://arxiv.org/pdf/1409.1556.pdf

Deep Neural Network - VGG

- Image Representation



Deep Neural Network - VGG

- Convolution

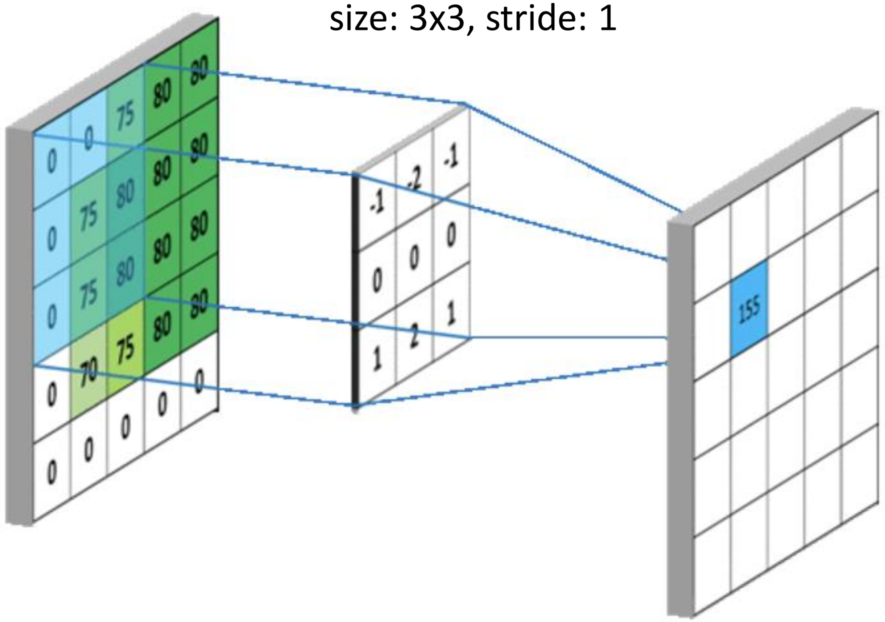
Element-wise multiplication

$$\begin{array}{|c|c|c|}\hline 0 & 0 & 75 \\ \hline 0 & 75 & 80 \\ \hline 0 & 75 & 80 \\ \hline \end{array} * \begin{array}{|c|c|c|}\hline -1 & -2 & -1 \\ \hline 0 & 0 & 0 \\ \hline 1 & 2 & 1 \\ \hline \end{array}$$

$$155 = 0 \times (-1) + 0 \times (-2) + 75 \times (-1) +$$
$$0 \times 0 + 75 \times 0 + 80 \times 0 +$$

Input (one channel) kernel Output

size: 3x3, stride: 1



Deep Neural Network - VGG

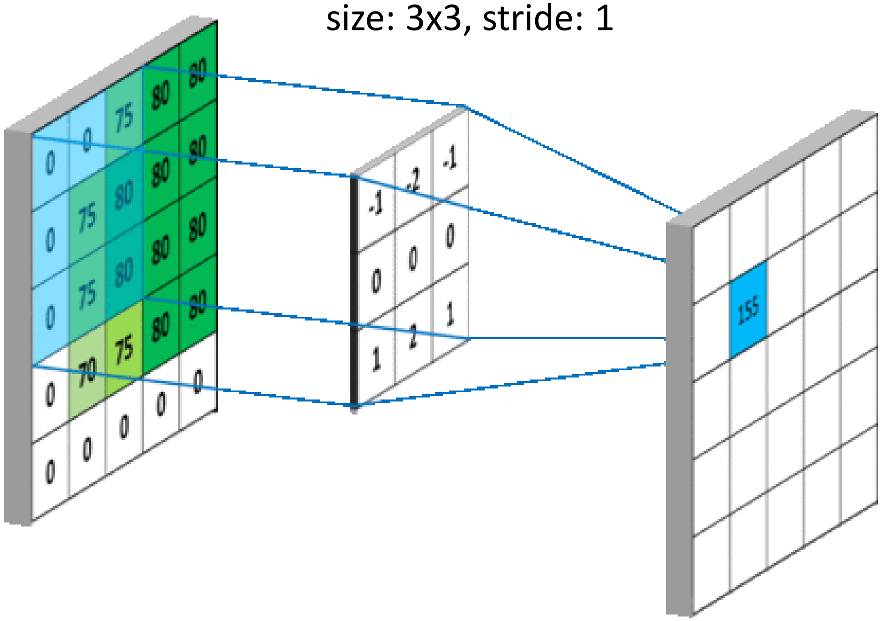
- Convolution

Input (one channel)

kernel

size: 3x3, stride: 1

Output



Element-wise multiplication

0	0	75			-1	-2	-1
0	75	80		*	0	0	0
0	75	80			1	2	1

$$155 = 0 \times (-1) + 0 \times (-2) + 75 \times (-1) + \\ 0 \times 0 + 75 \times 0 + 80 \times 0 + \\ 0 \times 1 + 75 \times 2 + 80 \times 1$$

Output size:

$$1 + floor(\text{ (input\_size} - \text{kernel\_size)/stride })$$

$$floor(\, 3.8 \,) = 3$$

Change the kernel size and stride to get different output size

Deep Neural Network - VGG

- Convolution

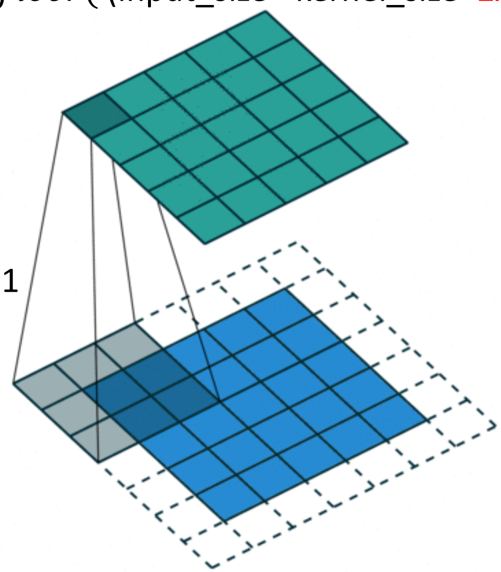
What if we want to keep the output size the same as the input?

1+$floor$((input_size−kernel_size+2xpadding_size)/stride)

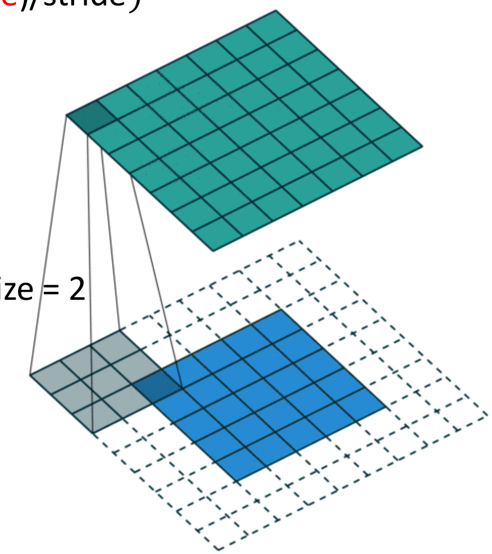
Padding

padding value is usually 0

Padding size = 1

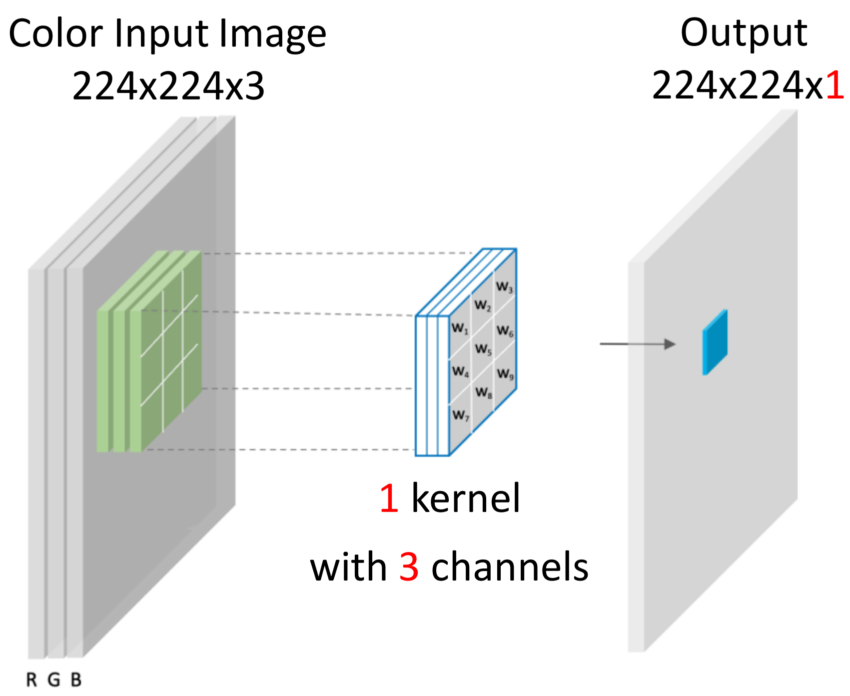


Padding size = 2



Deep Neural Network - VGG

- Convolution



One kernel produces 1 channel

If we hope the output has N channels,
we need to use N kernels

Deep Neural Network - VGG

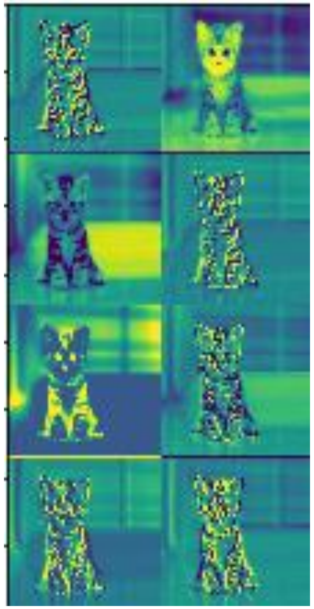
- What can convolution learn?

Input image

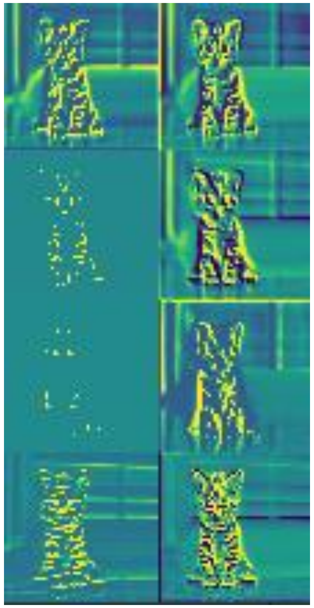
Deep Neural Network - VGG

- What can convolution learn?

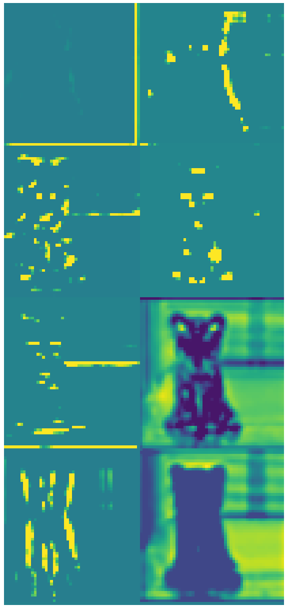
Conv1



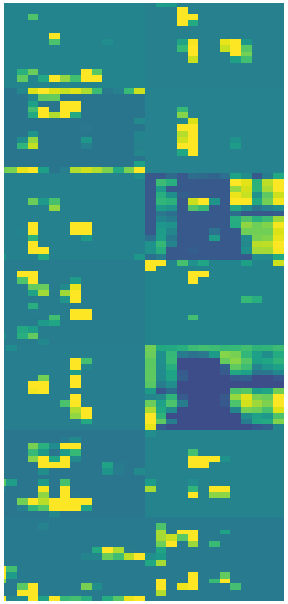
Conv2



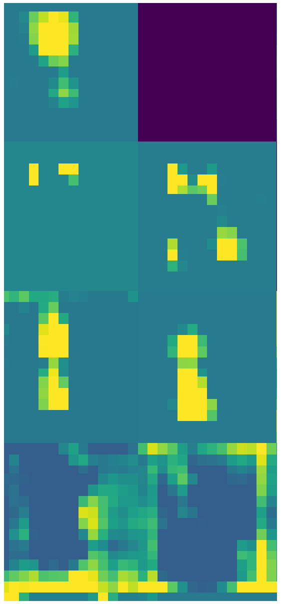
Conv3



Conv4

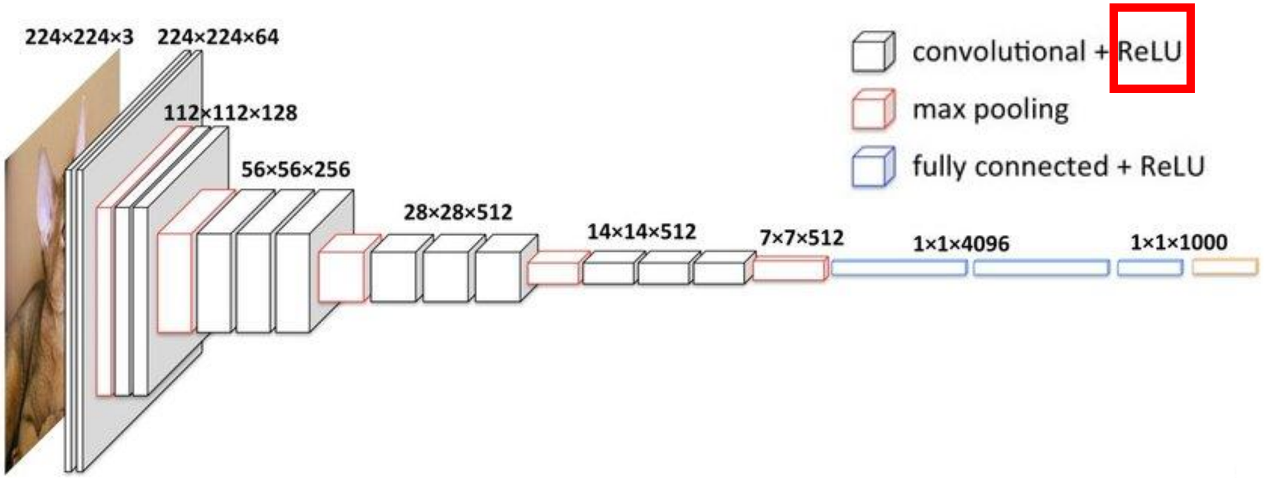


Conv5



Deep Neural Network - VGG

What is “ReLU”?

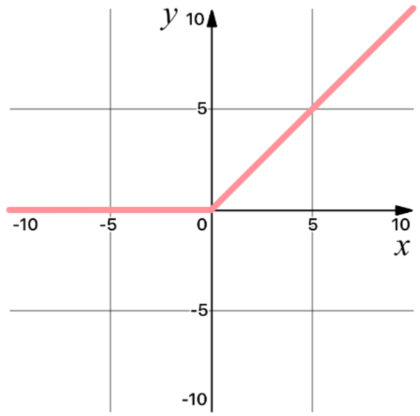


Deep Neural Network - VGG

- Activation function

ReLU: Rectified Linear activation Unit

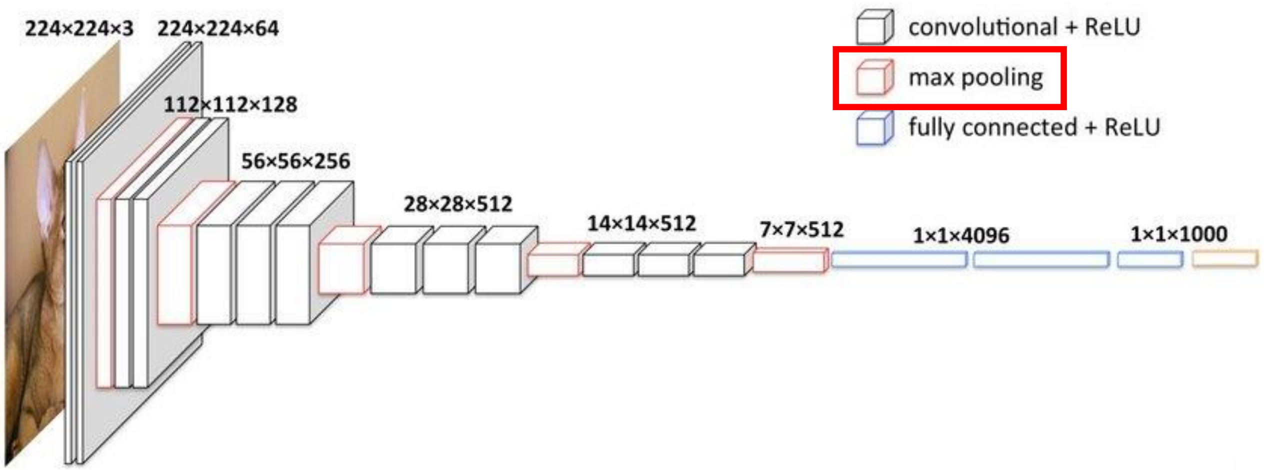
$$\mathrm{ReLU}(x) = \max(0, x)$$



Activation function introduces non-linear mapping, enhancing the capacity to learn complex data patterns and relationships

Deep Neural Network - VGG

- Max pooling



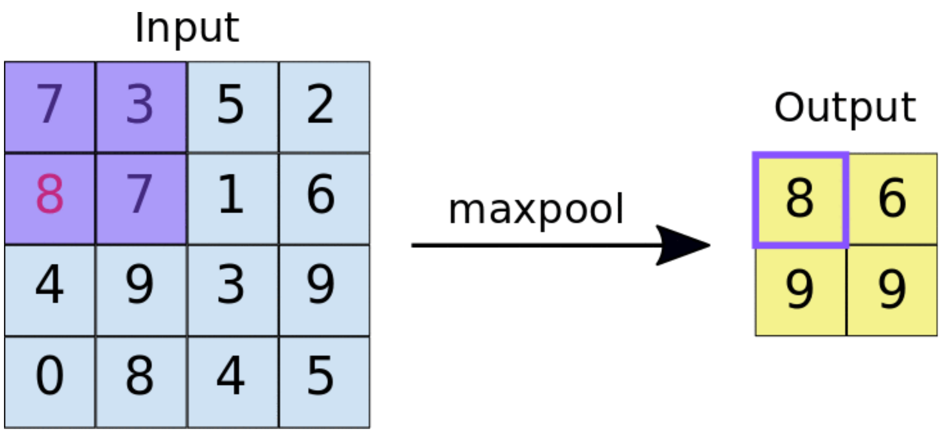
Deep Neural Network - VGG

- Max pooling

Two hype-parameters: size, stride

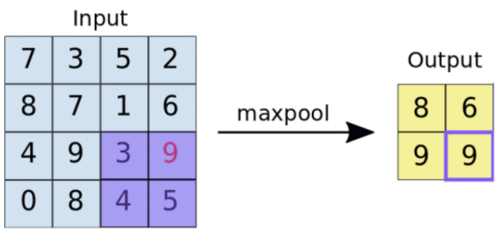
Output size: $1+floor((\text{input\_size}-\text{kernel\_size}+2\text{xpadding\_size})/\text{stride})$

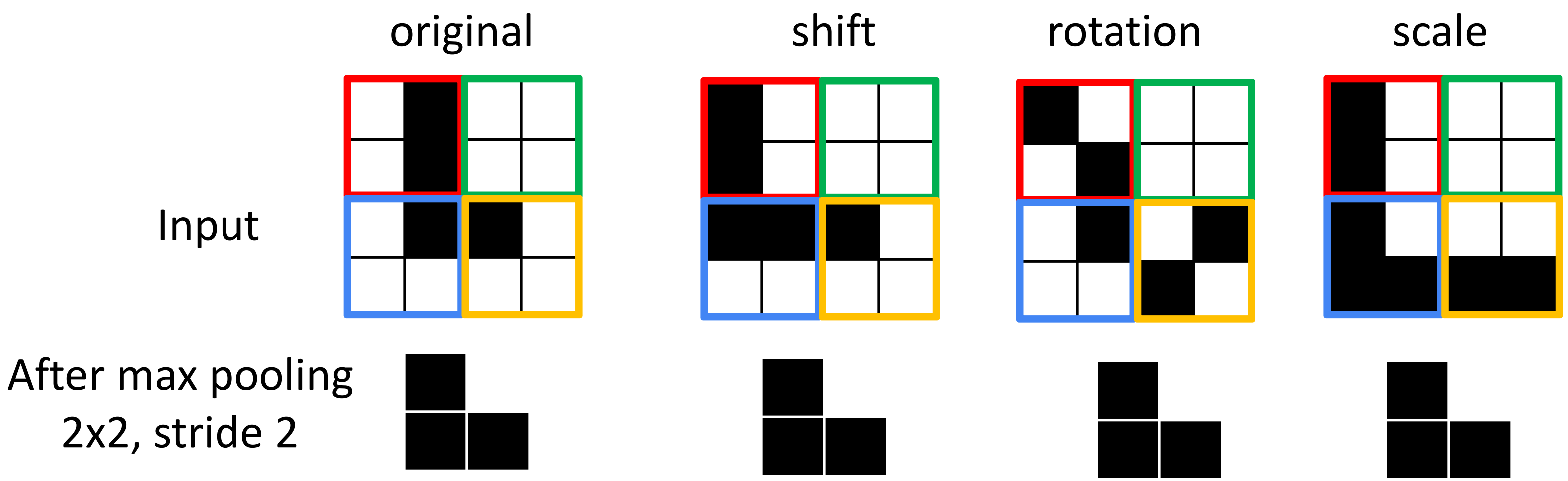
size: 2x2
stride: 2



Deep Neural Network - VGG

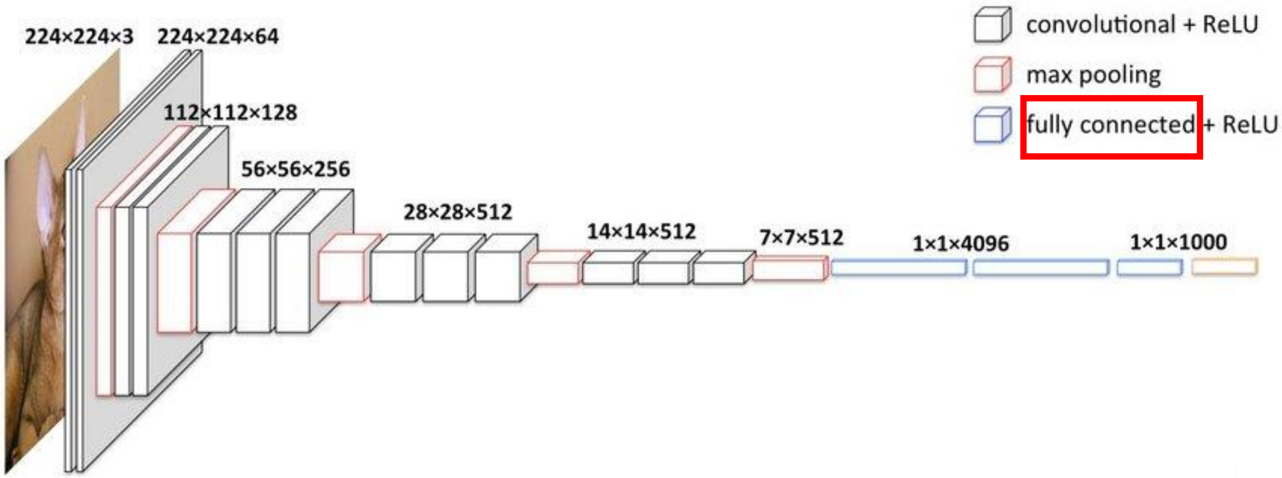
- Why do we use max pooling?
  - Downscaling input, reduce computation later layers
  - Introduce invariance to shift, rotation and scale





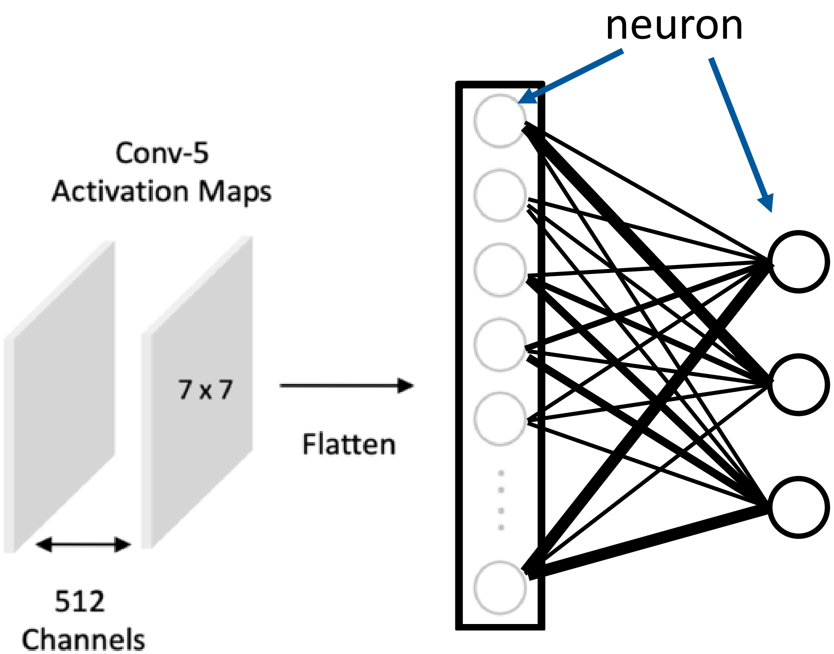
Deep Neural Network - VGG

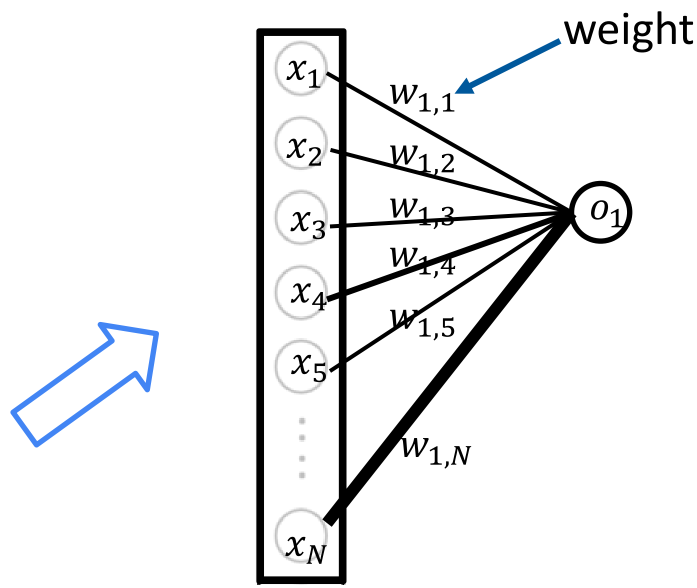
- Fully connected layer



Deep Neural Network - VGG

- Fully connected layer



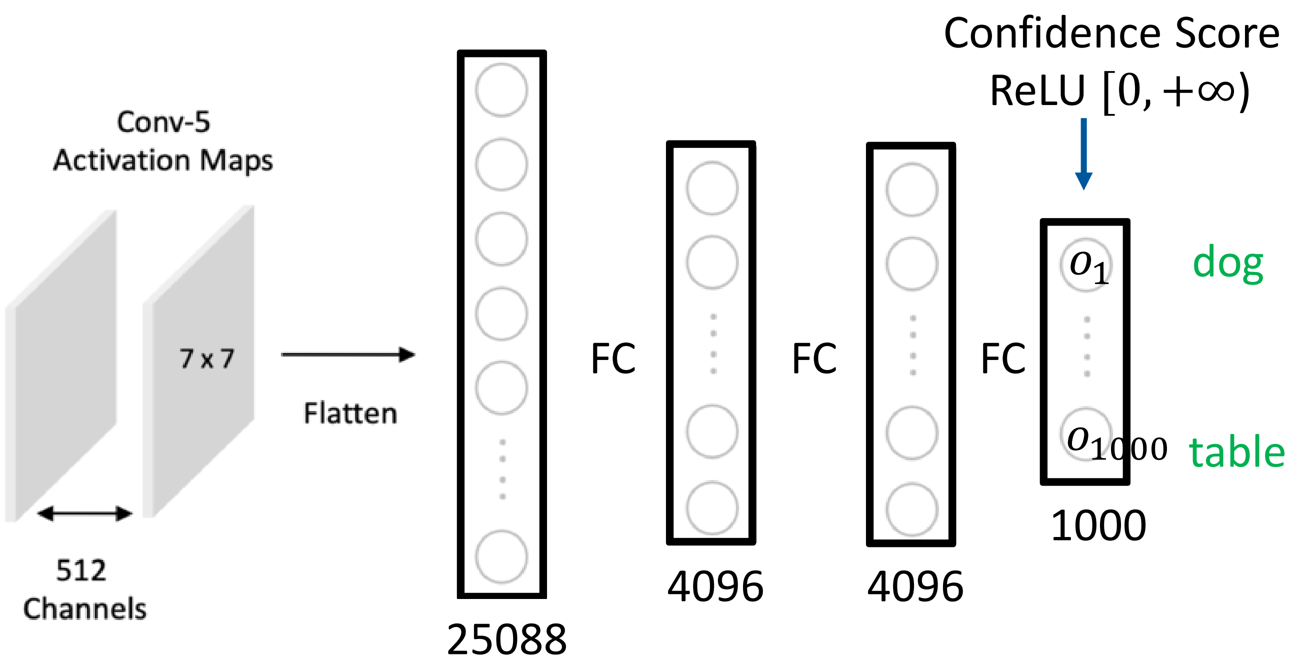


$$o_1 = \sigma(w_{1,1}x_1 + w_{1,2}x_2 + \cdots + w_{1,N}x_N + b_1)$$

$\sigma(\cdot)$ is an activation function, eg, ReLU

Deep Neural Network - VGG

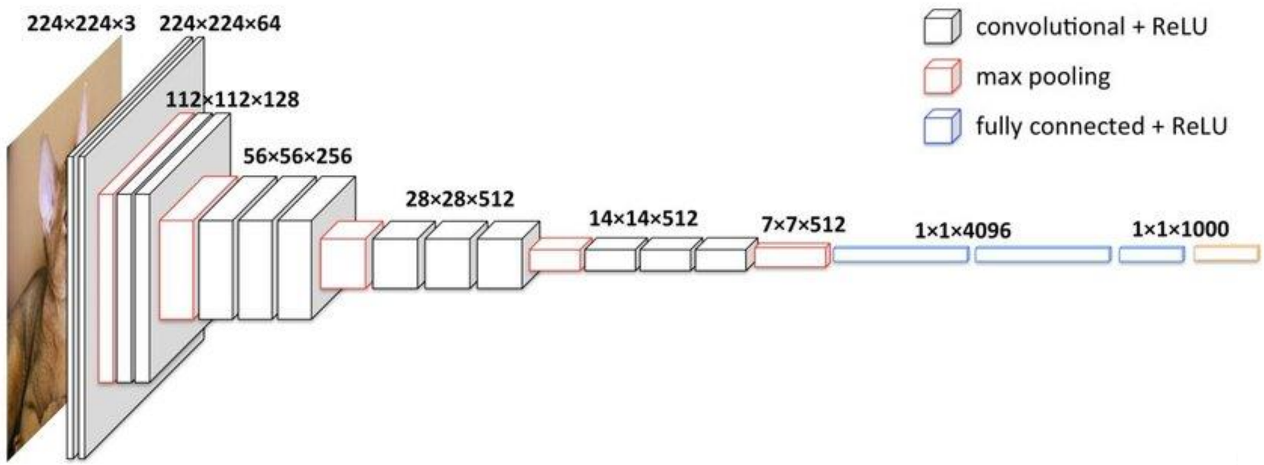
- Fully connected layer (FC) in VGG



$$p_i = \text{Softmax}(o_i) = \frac{e^{o_i}}{\sum_j e^{o_j}}$$

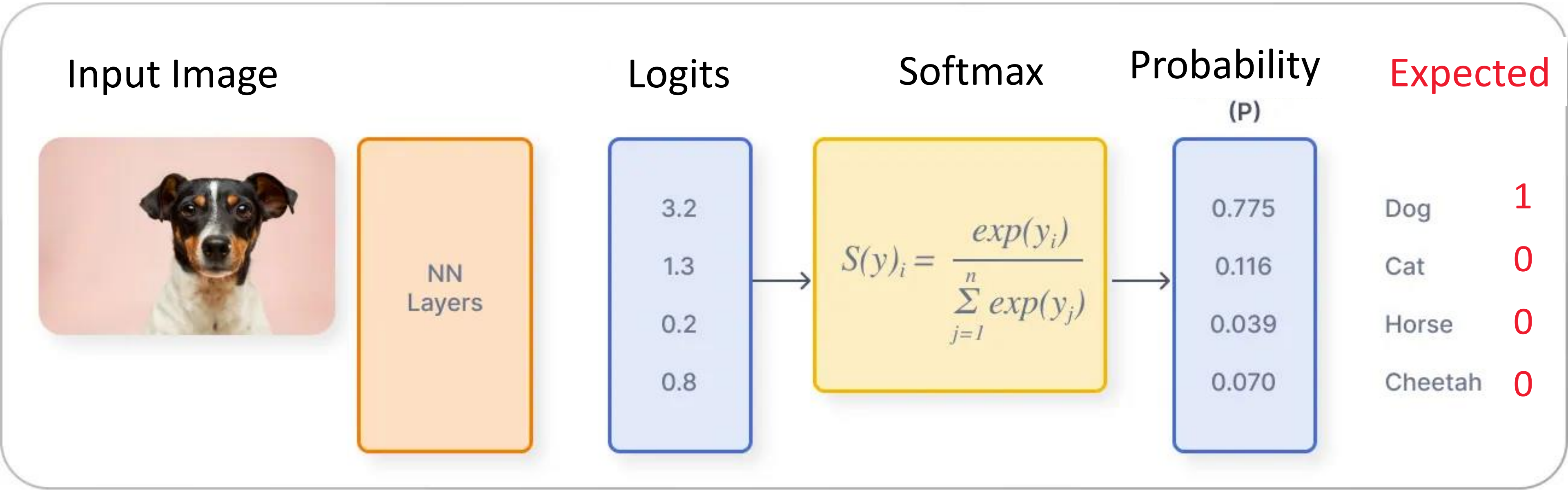
Deep Neural Network - VGG

- Build your own neural network



Deep Neural Network - VGG

- How to make the model predict expected values?



Cross-entropy loss: $-\log(p_i)$ $\quad\quad -\log(0.775) = 0.255$

i denotes the GT class $\quad\quad -\log(0.001) = 6.908$

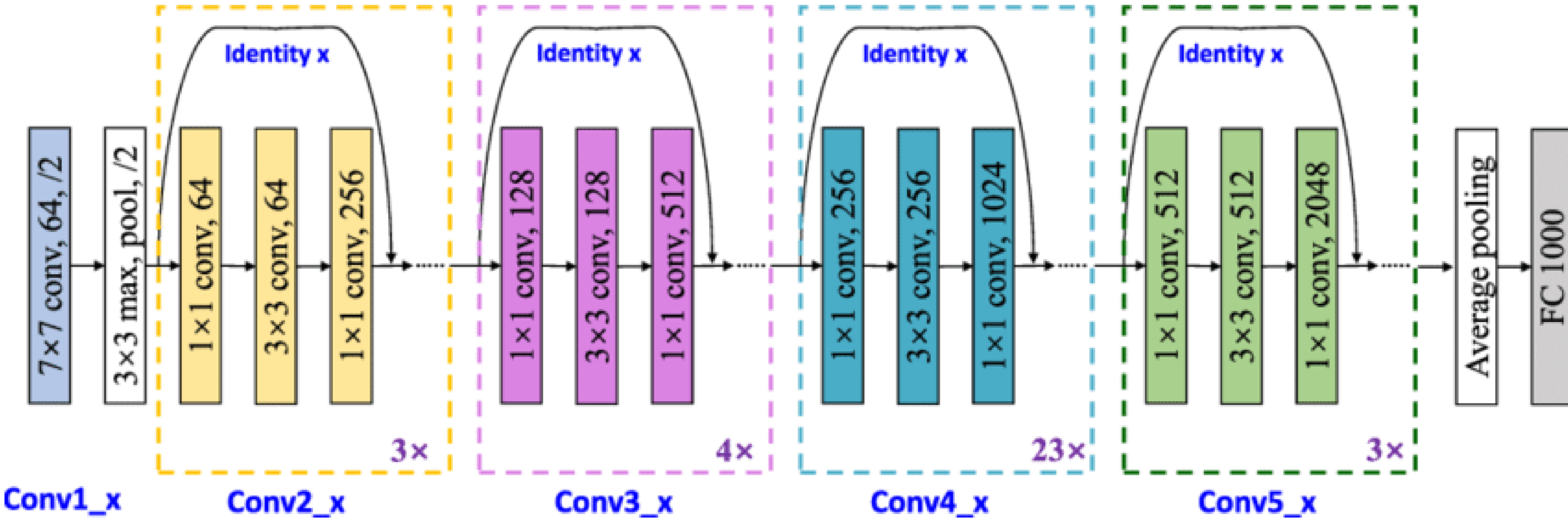
Use Stochastic Gradient Descent to minimize loss

ResNet

Winner of ILSVRC 2015

The 1st time outperforms humans

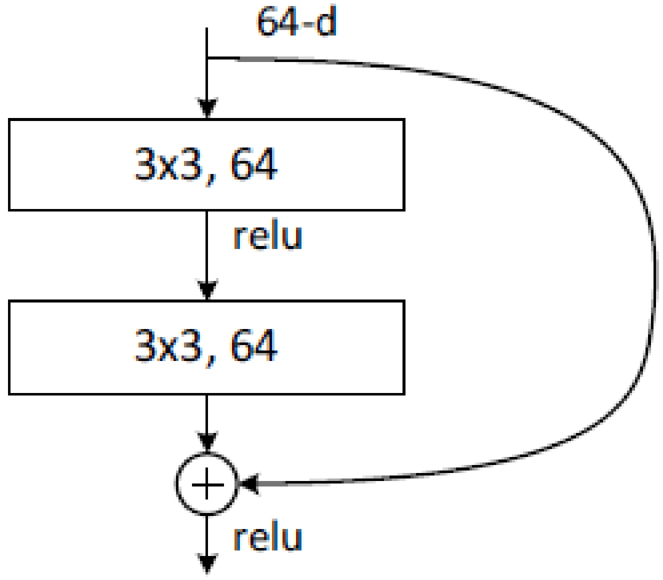
Deep Neural Network - ResNet

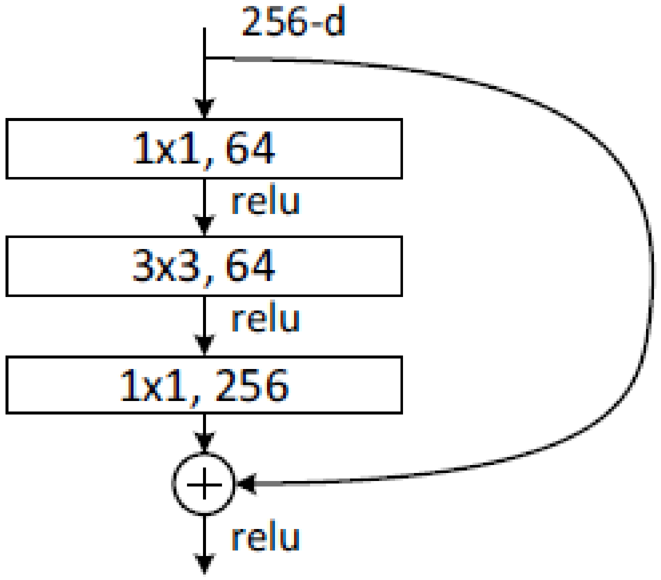


https://arxiv.org/pdf/1512.03385.pdf

Deep Neural Network - ResNet

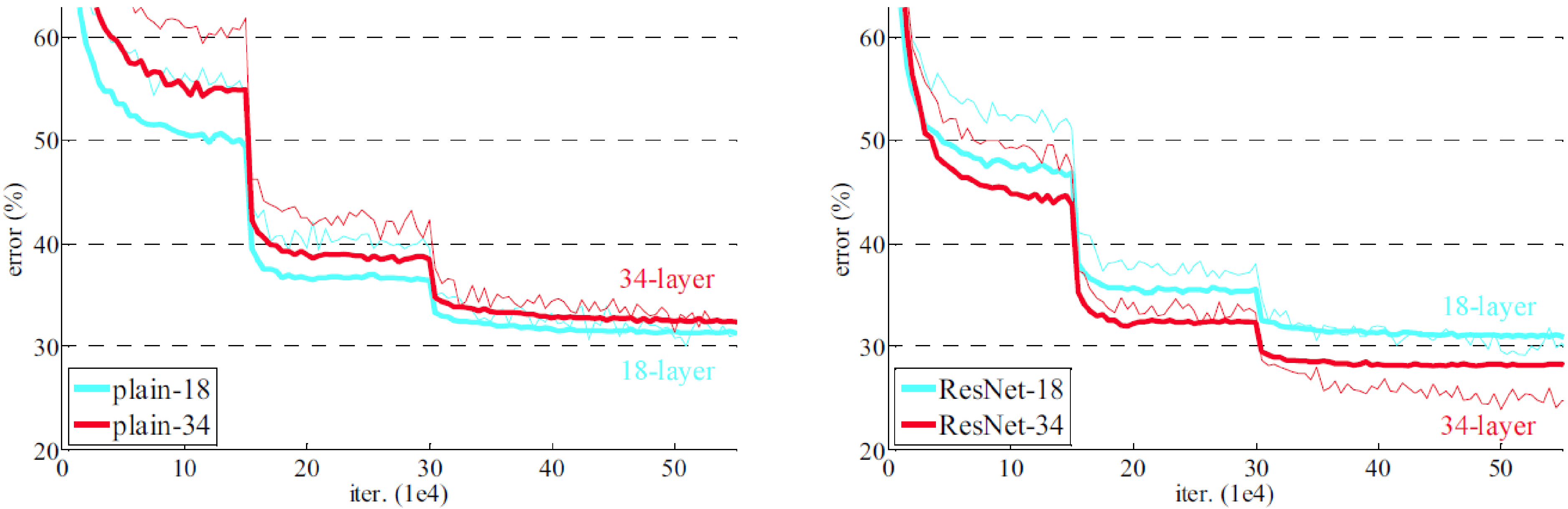
Issue of plain connection: gradients vanish as network becomes deeper





Deep Neural Network - ResNet

Effectiveness



Thin curves denote training error, and bold curves denote validation error.

Deep Neural Network - ResNet

Effectiveness

method	top-1 err.	top-5 err.
VGG [40] (ILSVRC'14)	-	8.43†
GoogLeNet [43] (ILSVRC'14)	-	7.89
VGG [40] (v5)	24.4	7.1
PReLU-net [12]	21.59	5.71
BN-inception [16]	21.99	5.81
ResNet-34 B	21.84	5.71
ResNet-34 C	21.53	5.60
ResNet-50	20.74	5.25
ResNet-101	19.87	4.60
ResNet-152	**19.38**	**4.49**

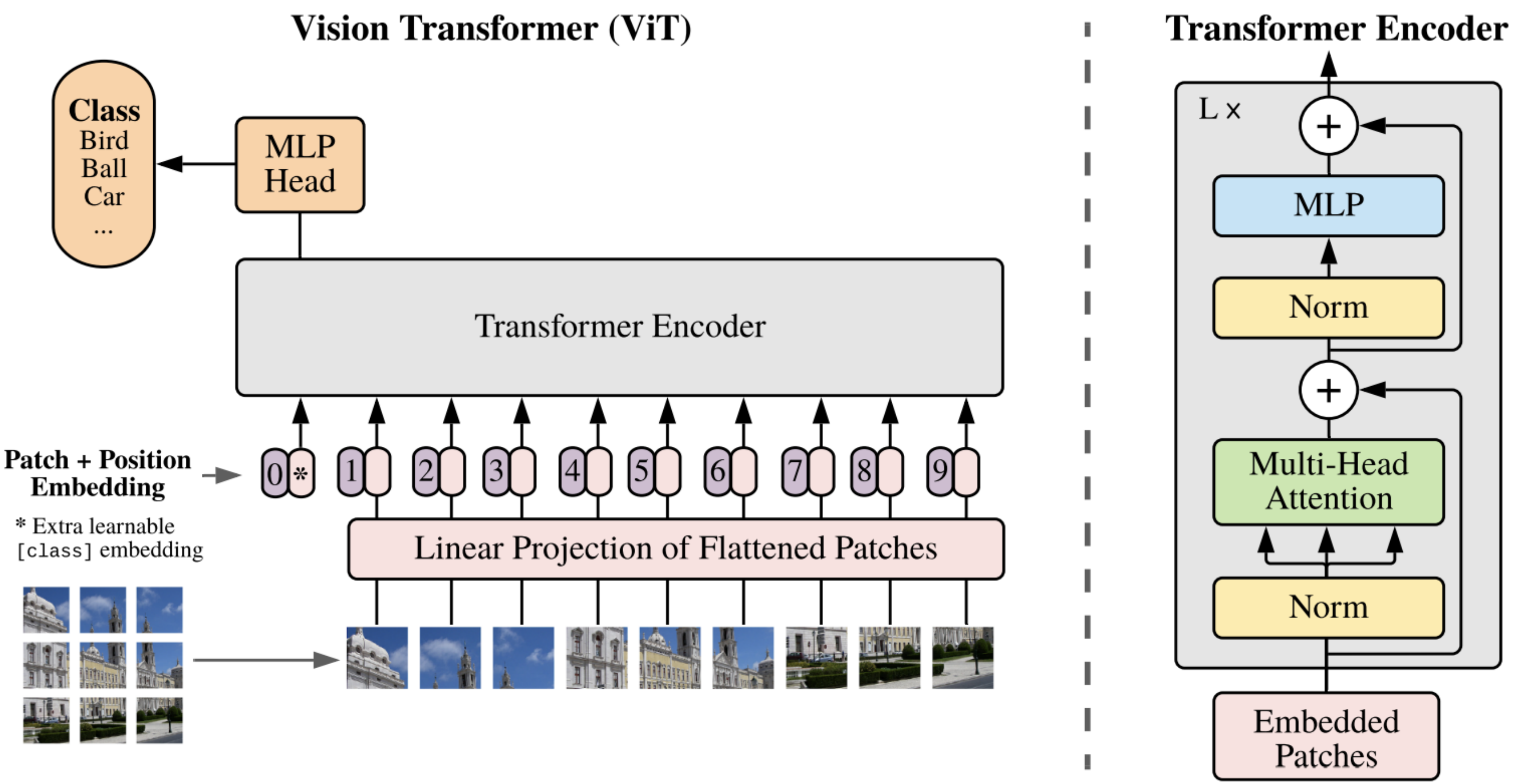
Single Model

method	top-5 err. (**test**)
VGG [40] (ILSVRC'14)	7.32
GoogLeNet [43] (ILSVRC'14)	6.66
VGG [40] (v5)	6.8
PReLU-net [12]	4.94
BN-inception [16]	4.82
ResNet (ILSVRC'15)	**3.57**

Ensemble

Vision Transformer (ViT)

Deep Neural Network - ViT



https://arxiv.org/pdf/2010.11929.pdf

Deep Neural Network - ViT

Performance

	Ours-JFT (ViT-H/14)	Ours-JFT (ViT-L/16)	Ours-I21k (ViT-L/16)	BiT-L (ResNet152x4)
ImageNet	**88.55** $\pm$ 0.04	87.76 $\pm$ 0.03	85.30 $\pm$ 0.02	87.54 $\pm$ 0.02
ImageNet ReaL	**90.72** $\pm$ 0.05	90.54 $\pm$ 0.03	88.62 $\pm$ 0.05	90.54
CIFAR-10	**99.50** $\pm$ 0.06	99.42 $\pm$ 0.03	99.15 $\pm$ 0.03	99.37 $\pm$ 0.06
CIFAR-100	**94.55** $\pm$ 0.04	93.90 $\pm$ 0.05	93.25 $\pm$ 0.05	93.51 $\pm$ 0.08
Oxford-IIIT Pets	**97.56** $\pm$ 0.03	97.32 $\pm$ 0.11	94.67 $\pm$ 0.15	96.62 $\pm$ 0.23
Oxford Flowers-102	99.68 $\pm$ 0.02	**99.74** $\pm$ 0.00	99.61 $\pm$ 0.02	99.63 $\pm$ 0.03
VTAB (19 tasks)	**77.63** $\pm$ 0.23	76.28 $\pm$ 0.46	72.72 $\pm$ 0.21	76.29 $\pm$ 1.70
TPUv3-core-days	2.5k	0.68k	0.23k	9.9k

https://arxiv.org/pdf/2010.11929.pdf

Deep Neural Network - ViT

Pros and Cons

Pros	Cons
Learn global features of images	Have a large number of parameters
Not as sensitive to data augmentation as CNNs	Not as efficient as CNNs at processing images
Can be used for a variety of image classification tasks	Not as interpretable as CNNs

https://arxiv.org/pdf/2010.11929.pdf