An Introduction to Deep Learning

(part 3)

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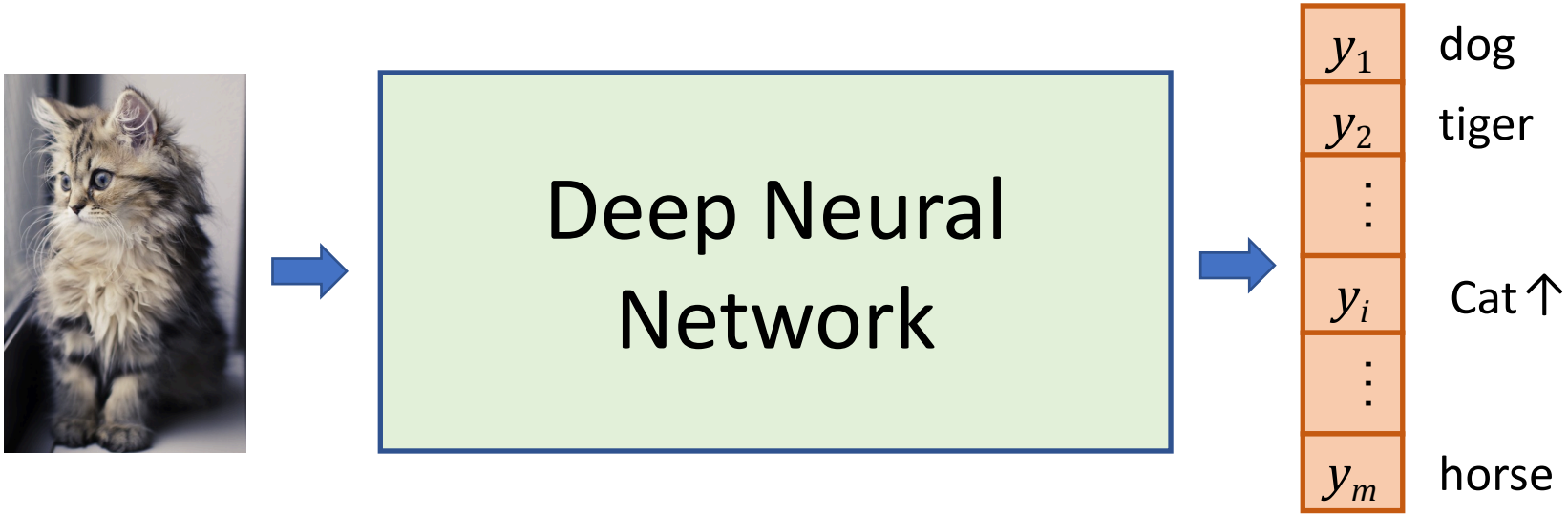
EMAT31530 - February 2021

Convolutional Neural Networks

So far, we have discussed

- Neural networks with Fully-Connected layers
- The optimization process / How the network is trained



Outline

- Convolutional Neural Networks
  - Different Layers
  - Popular Architectures
- Other Popular Neural Networks
  - Recurrent Neural Networks
  - Long Short-Term Memory Networks
  - Auto-Encoders
  - Generative Adversarial Networks

Convolutional Neural Networks

Convolutional Neural Networks

Image classification with **CNN**

- No need to pre-process images
- CNNs outperform traditional approaches

Convolutional Neural Network (CNN)

y_1 dog

y_2 tiger

$\vdots$

y_i Cat ↑

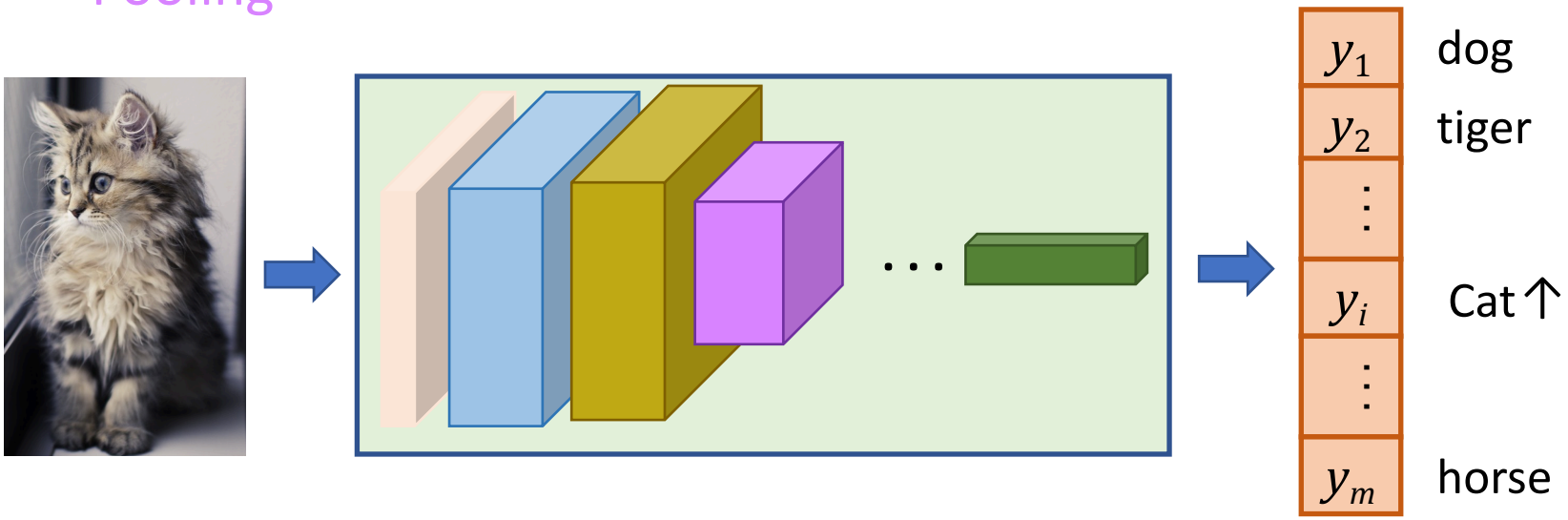
$\vdots$

y_m horse

Convolutional Neural Networks

Image classification with **CNN** - Layers in a CNN:

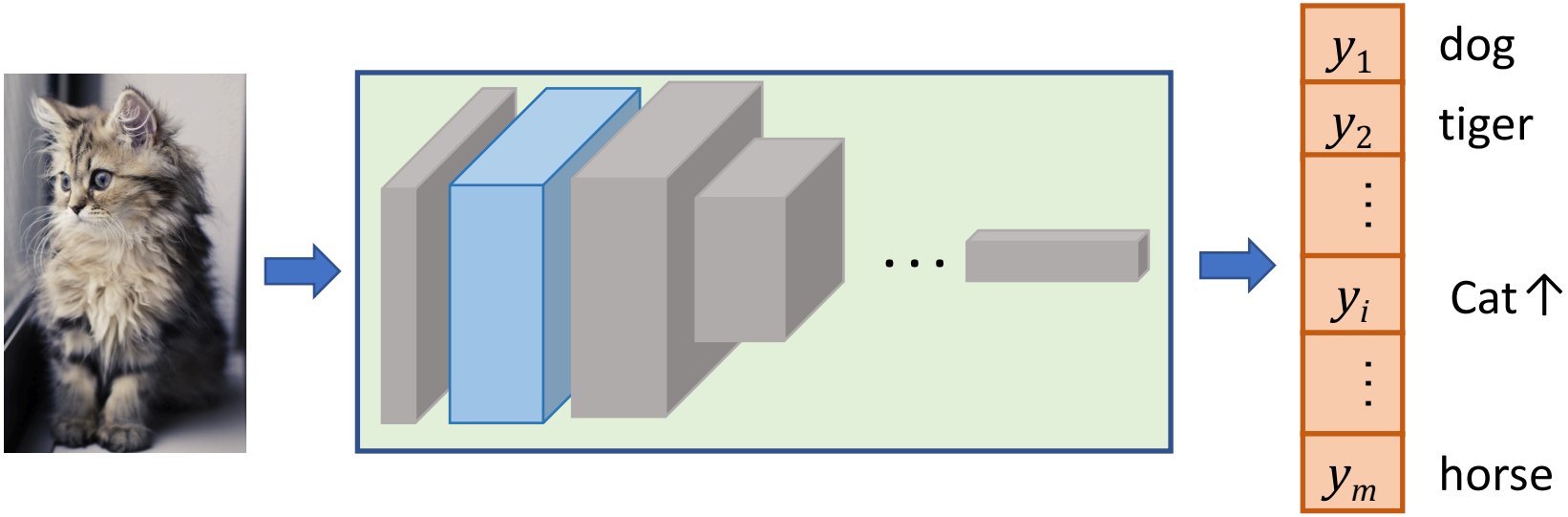
- Input
- Convolutional
- Activation (ReLU, …)
- Pooling
- Fully-Connected (FC)
- Drop-out
- Batch Normalisation (BN), ...



Convolutional Neural Networks

Convolutional layer

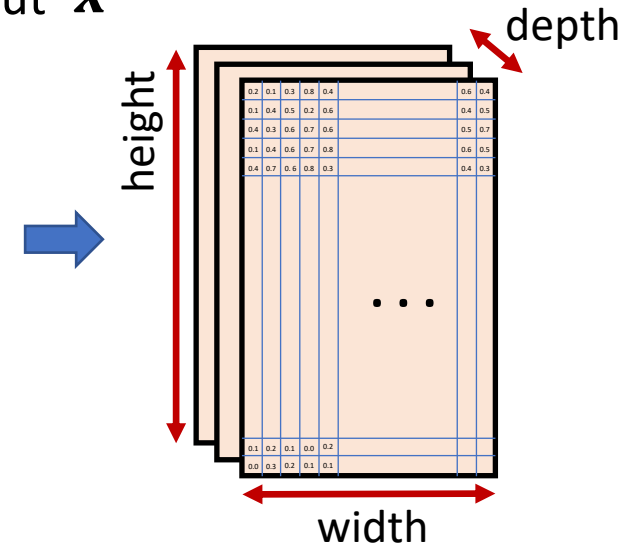
- It is the main building block of a CNN
- its neurons can have more than one dimension
- It captures the correlation among neighboring data points



Convolutional Neural Networks

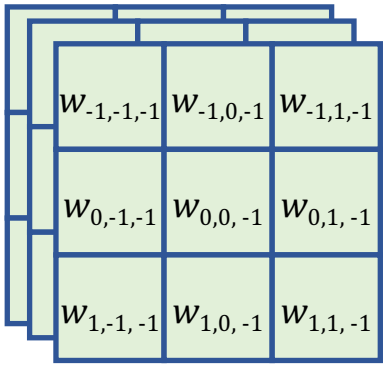
Convolutional layer

RGB image input $\boldsymbol{x}$



Convolution kernel

$\boldsymbol{w}$

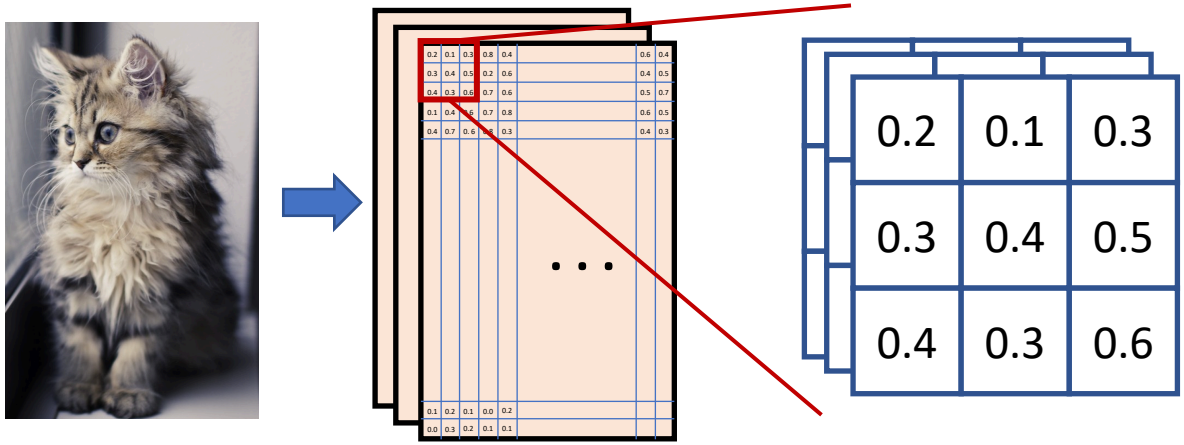


Kernel size: 3×3×3

Convolutional Neural Networks

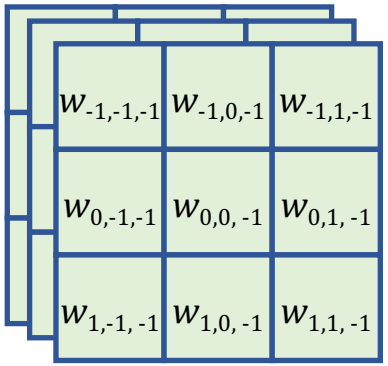
Convolutional layer

RGB image input $\boldsymbol{x}$



Convolution kernel

$\boldsymbol{w}$



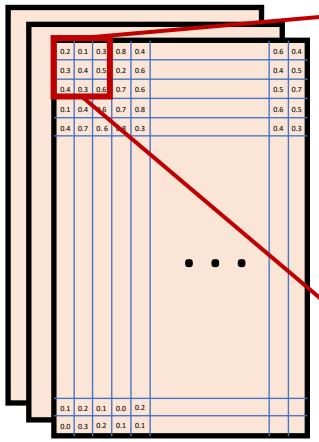
Kernel size: 3×3×3

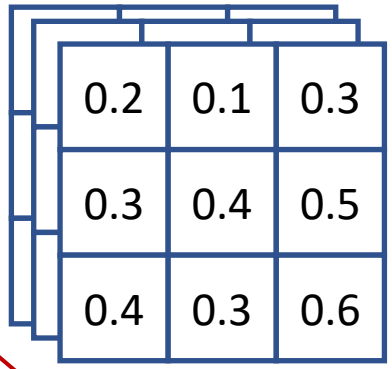
Convolutional Neural Networks

Convolutional layer

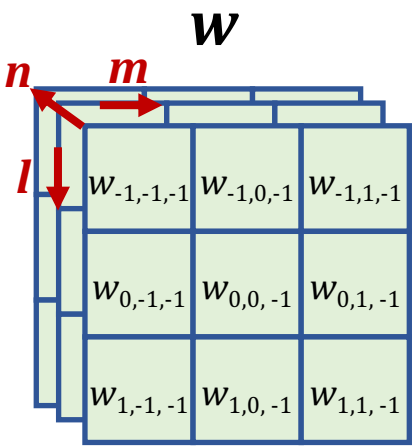
$$w_b + \sum_{l,m,n=-1}^{1} x_{i+l,j+m,k+n} w_{l,m,n}$$

RGB image input $\boldsymbol{x}$





$\boldsymbol{w}$

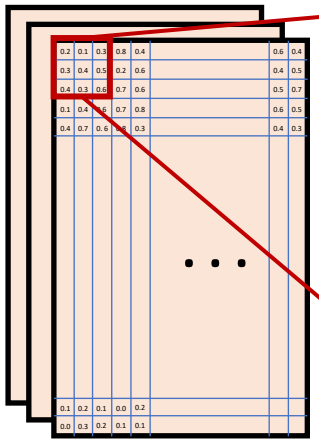


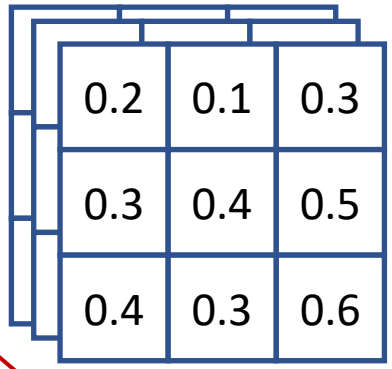
Convolutional Neural Networks

Convolutional layer

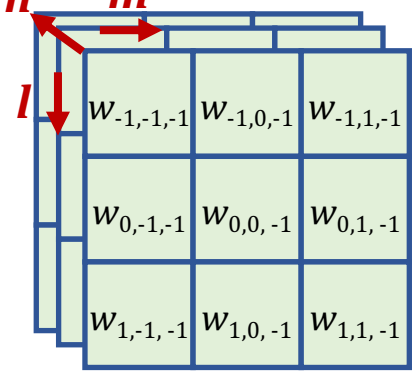
$$w_b + \sum_{l,m,n=-1}^{1} x_{i+l,j+m,k+n} w_{l,m,n}$$

RGB image input $\boldsymbol{x}$





$\boldsymbol{w}$

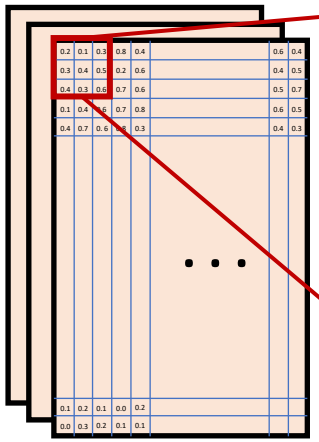


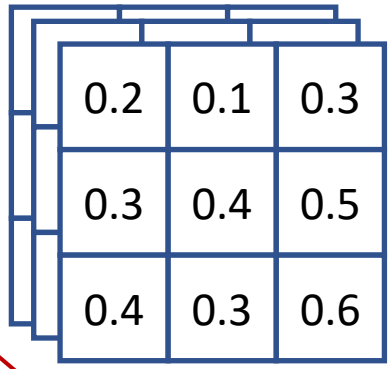
Convolutional Neural Networks

Convolutional layer

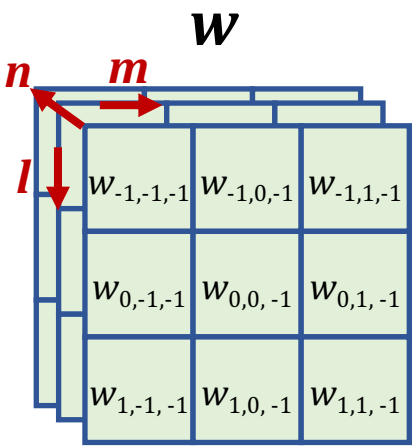
$$w_b + \sum_{l,m,n=-1}^{1} x_{i+l,j+m,k+n} w_{l,m,n}$$

RGB image input $\boldsymbol{x}$





$\boldsymbol{w}$

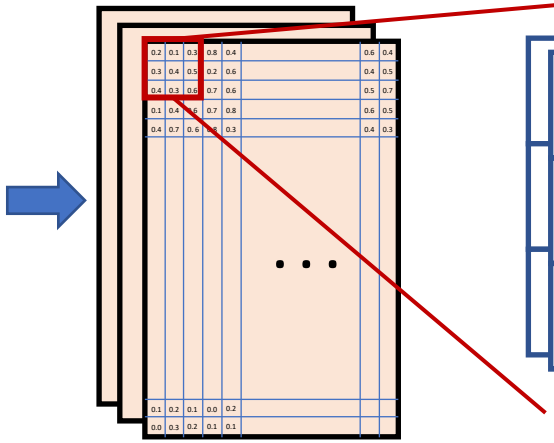


Convolutional Neural Networks

Convolutional layer

$$\text{bias } w_b + \sum_{l,m,n=-1}^{1} x_{i+l,j+m,k+n} w_{l,m,n}$$

RGB image input $\boldsymbol{x}$



0.2	0.1	0.3
0.3	0.4	0.5
0.4	0.3	0.6

$\boldsymbol{w}$

$\boldsymbol{n}$ $\boldsymbol{m}$ $\boldsymbol{l}$

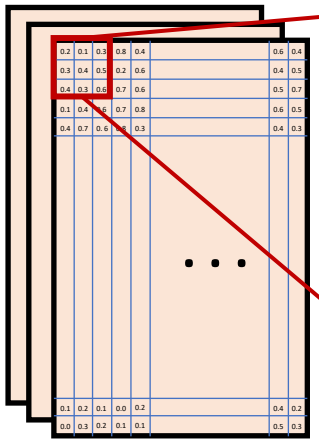
$w_{-1,-1,-1}$	$w_{-1,0,-1}$	$w_{-1,1,-1}$
$w_{0,-1,-1}$	$w_{0,0,-1}$	$w_{0,1,-1}$
$w_{1,-1,-1}$	$w_{1,0,-1}$	$w_{1,1,-1}$

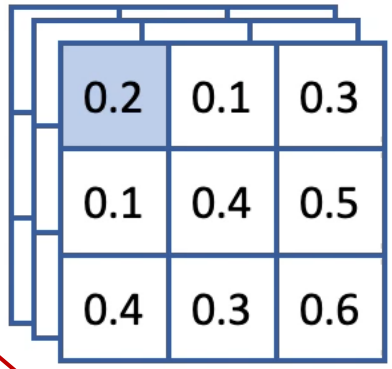
Convolutional Neural Networks

Convolutional layer

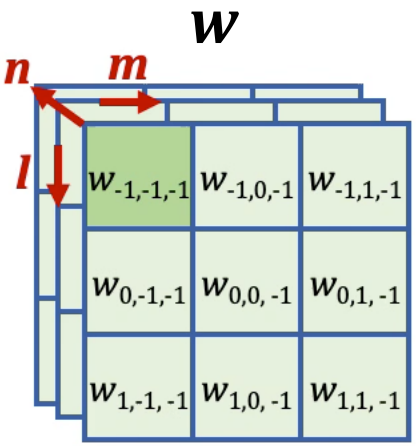
$$w_b + \sum_{l,m,n=-1}^{1} x_{i+l,j+m,k+n} w_{l,m,n}$$

RGB image input $\boldsymbol{x}$





$\boldsymbol{w}$



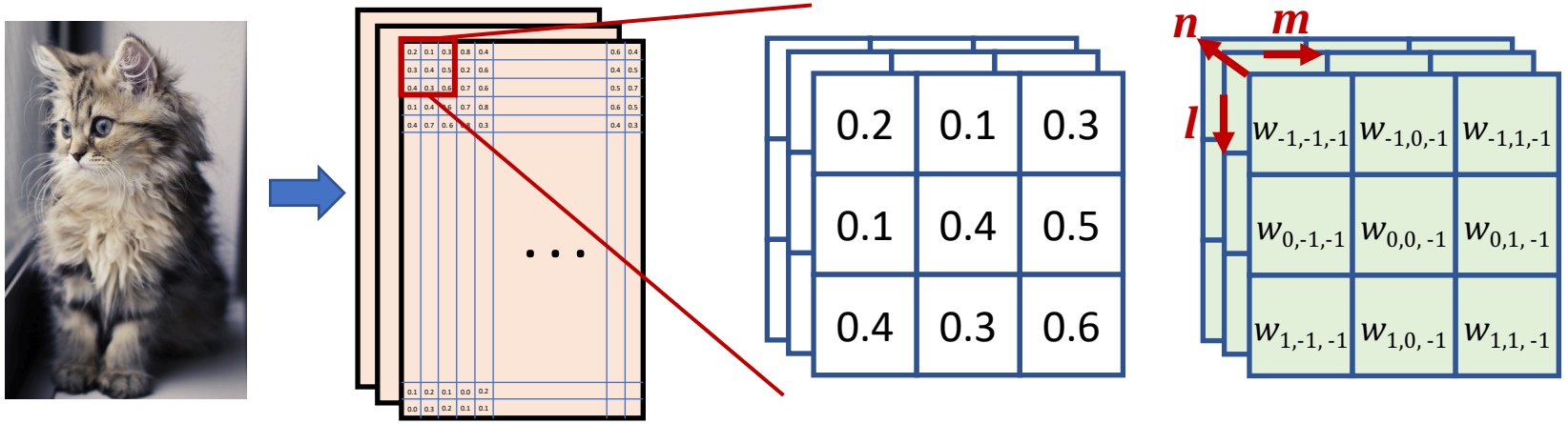
$w_b + 0.2 \times w_{-1,-1,-1}$

Convolutional Neural Networks

Convolutional layer

$$w_b + \sum_{l,m,n=-1}^{1} x_{i+l,j+m,k+n} w_{l,m,n}$$

RGB image input $\boldsymbol{x}$



This is repeated for every pixel of the image (if *stride*=1)

Image is padded for the bordering pixels

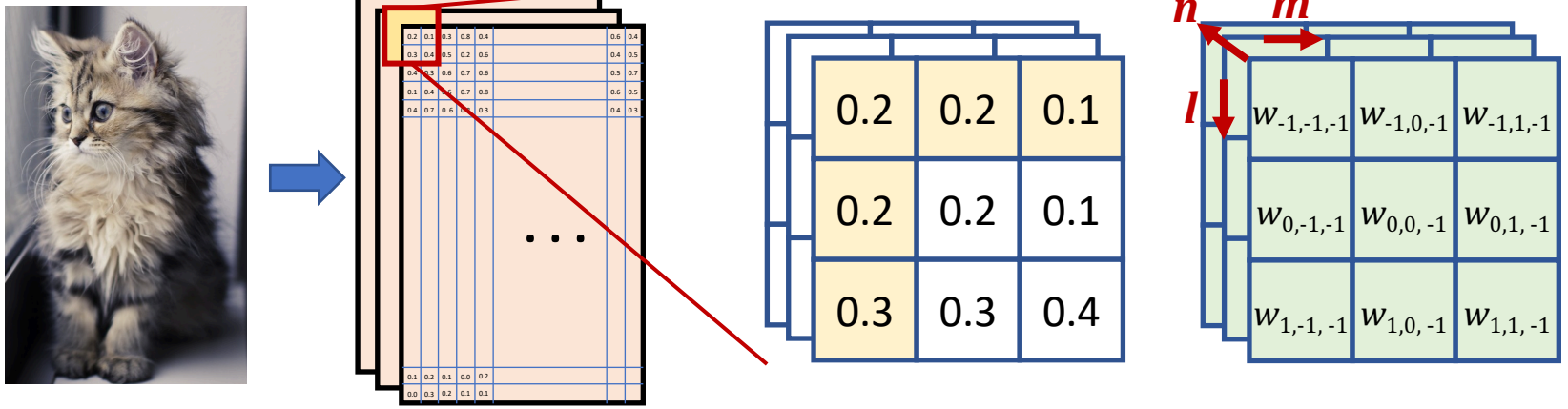
So that the output is the same size as its input

Convolutional Neural Networks

Convolutional layer

$$w_b + \sum_{l,m,n=-1}^{1} x_{i+l,j+m,k+n} w_{l,m,n}$$

RGB image input $\boldsymbol{x}$



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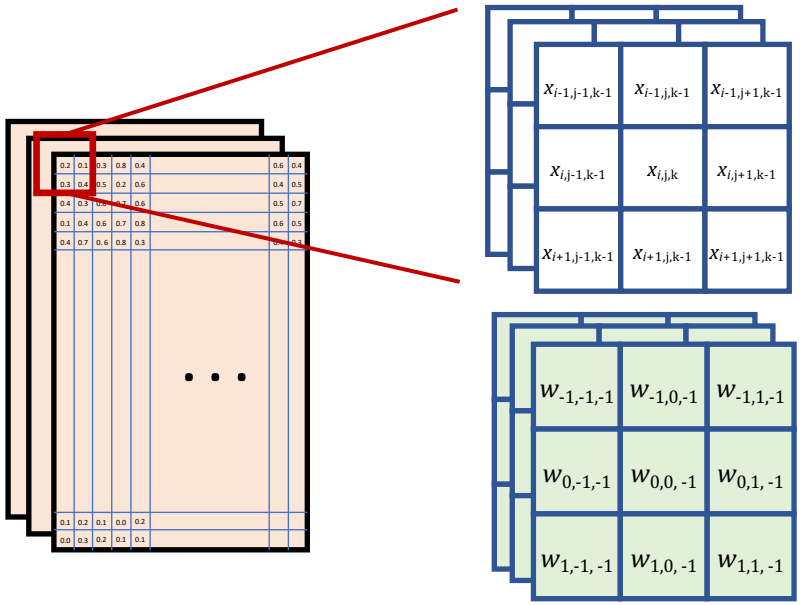
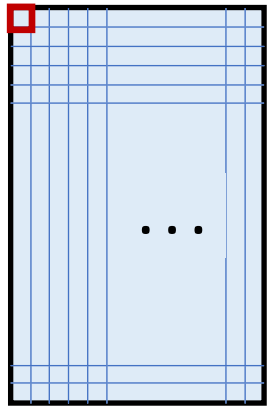
Convolutional Neural Networks

Convolutional layer

RGB image input



Conv layer output



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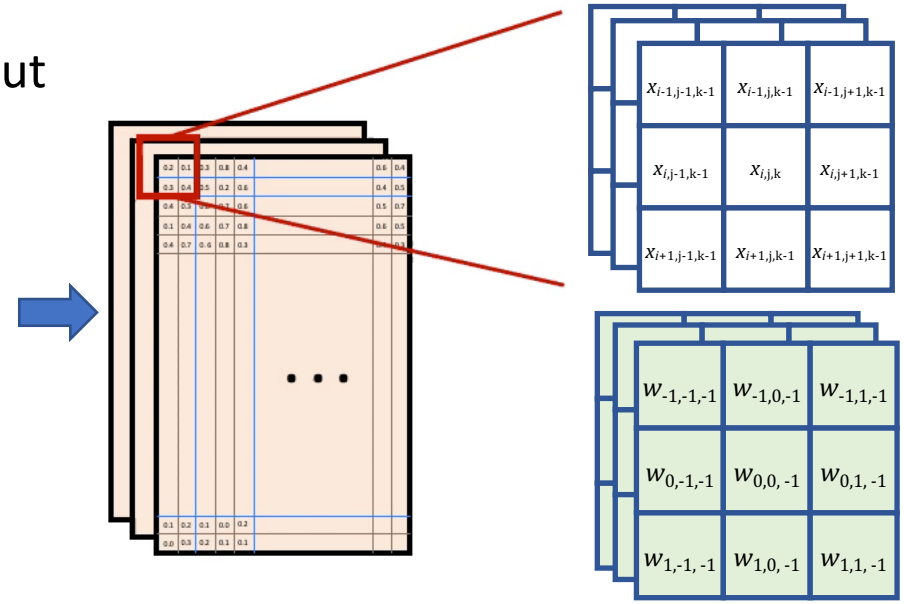
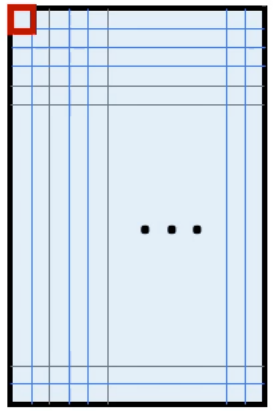
Convolutional Neural Networks

Convolutional layer

RGB image input



Conv layer output



This is repeated for every pixel of the image (if *stride*=1)

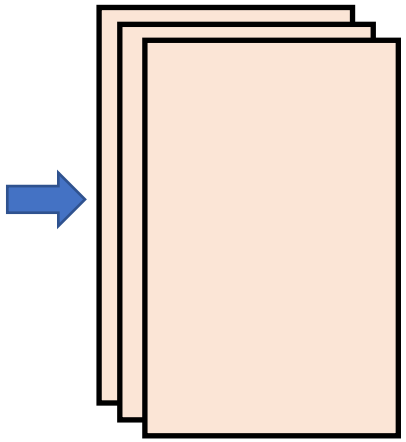
Image is padded for the bordering pixels

So that the output is the same size as its input

Convolutional Neural Networks

Convolutional layer

RGB image input x



$w^{(1)}$

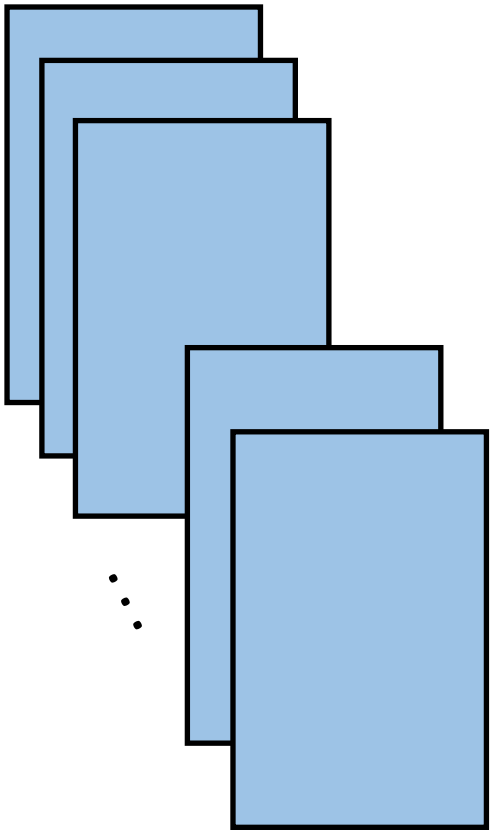
$w^{(2)}$

$w^{(3)}$

$w^{(c-1)}$

$w^{(c)}$

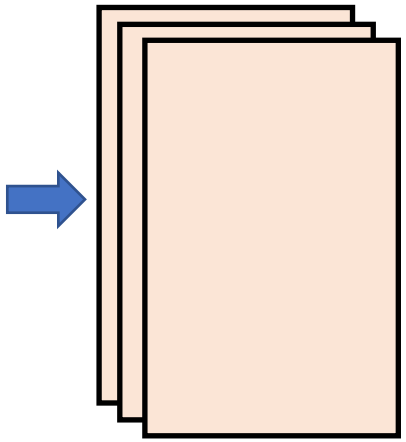
Conv layer output

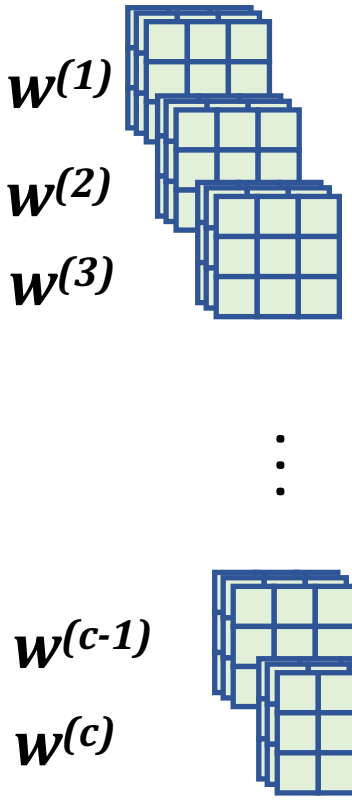


Convolutional Neural Networks

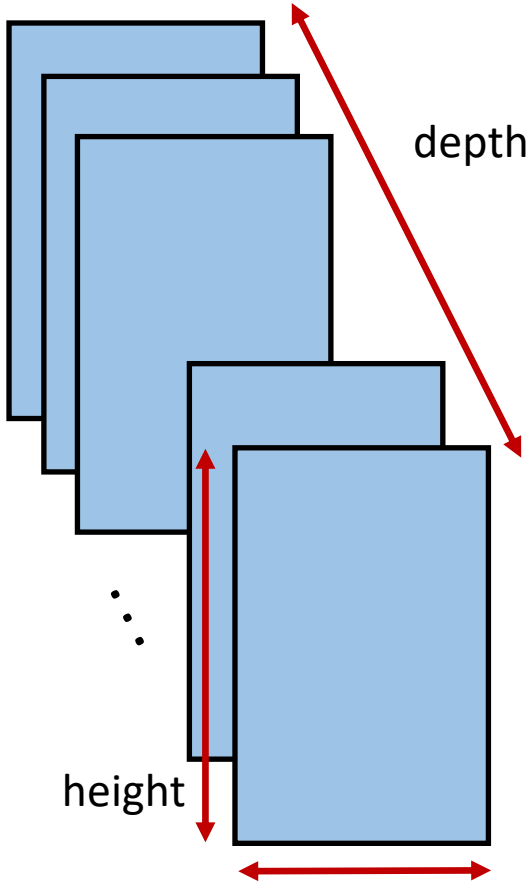
Convolutional layer

RGB image input x





Conv layer output

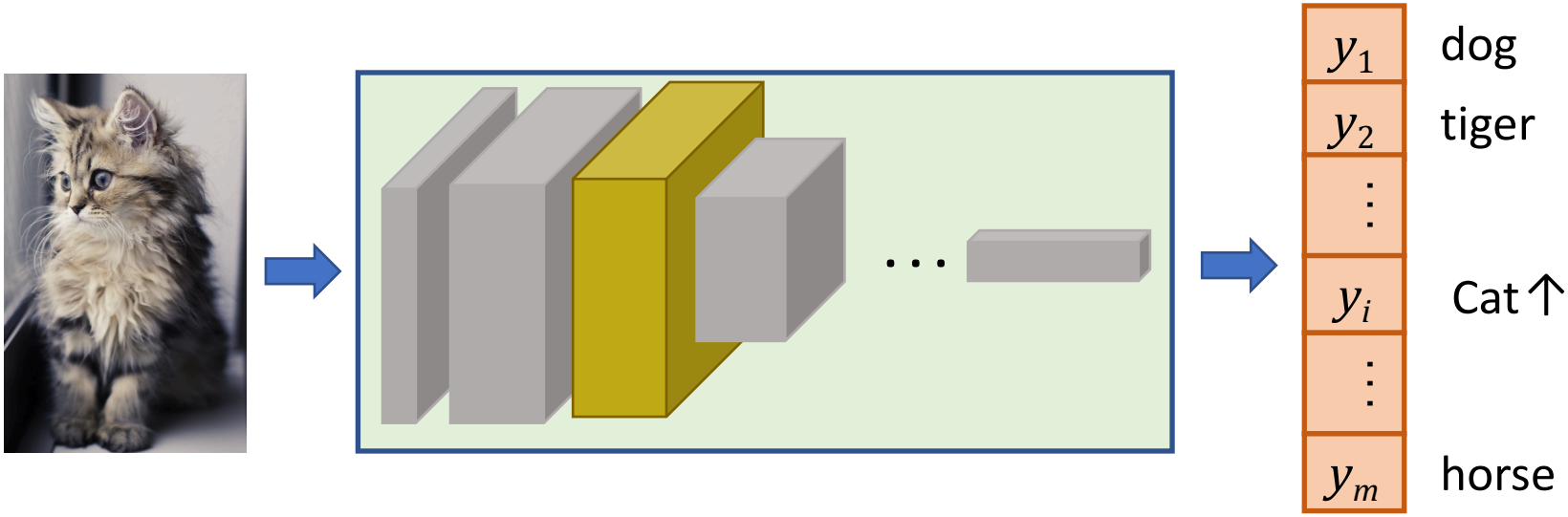


This can be used as the input to another layer

Convolutional Neural Networks

Activation layer

- It introduces non-linearity to the network
- Non-linearity helps the network learn complex patterns
- The most common activations are Sigmoid, ReLU and Tanh

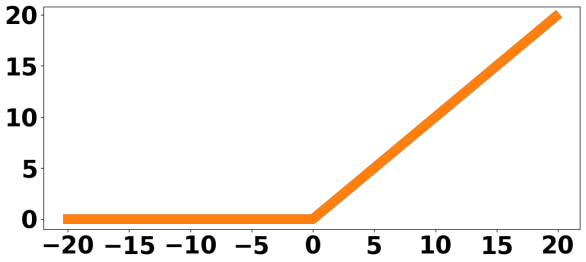


Convolutional Neural Networks

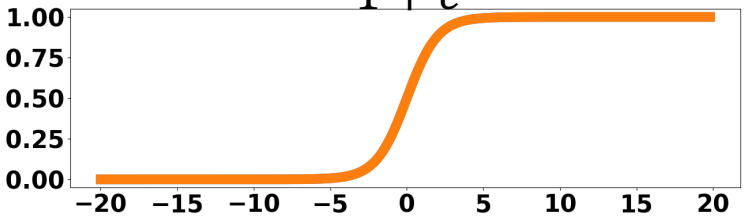
Activation layer

$$ReLU(x) = \max(0, x)$$

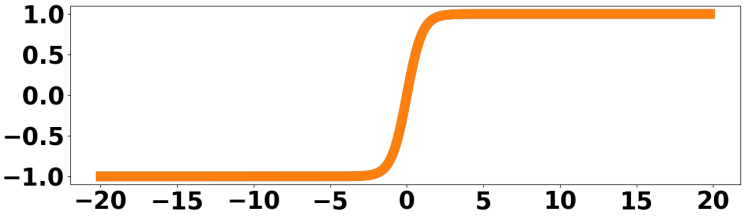
(*Rectified Linear Unit*)

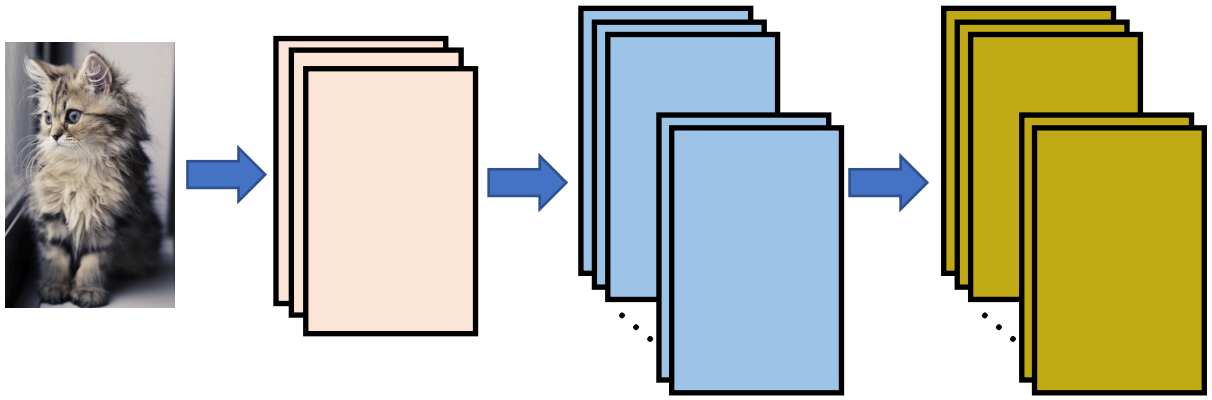


$$\sigma(x) = \frac{1}{1 + e^{-x}}$$



$$tanh(x)$$

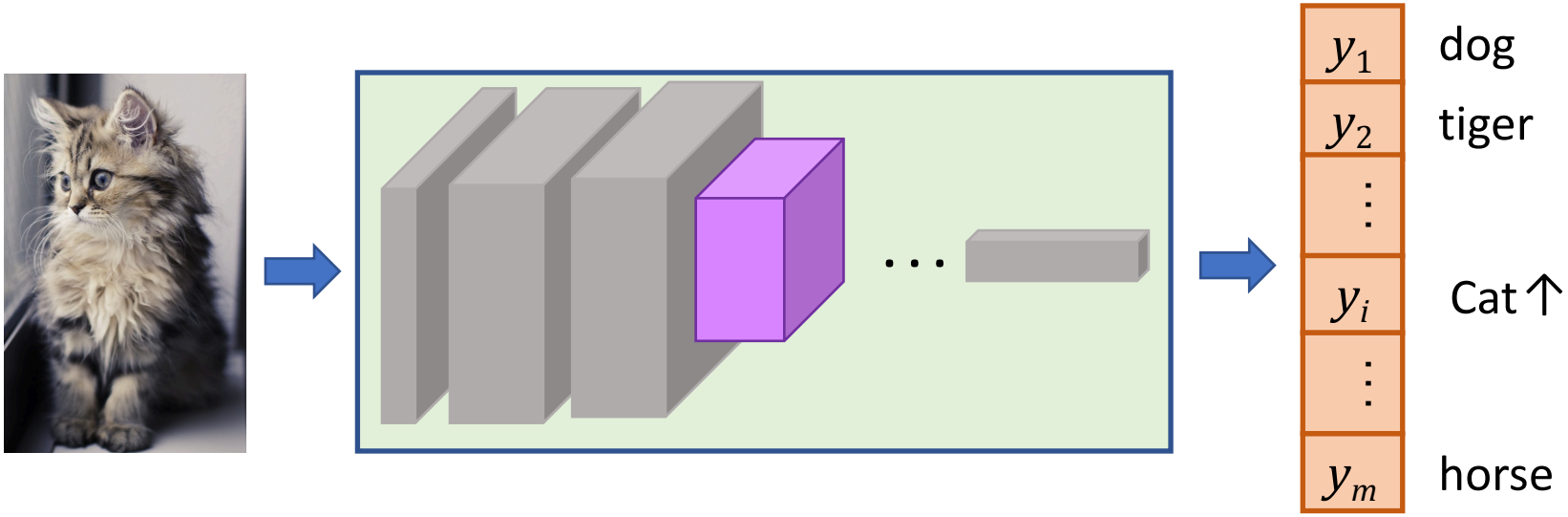




Convolutional Neural Networks

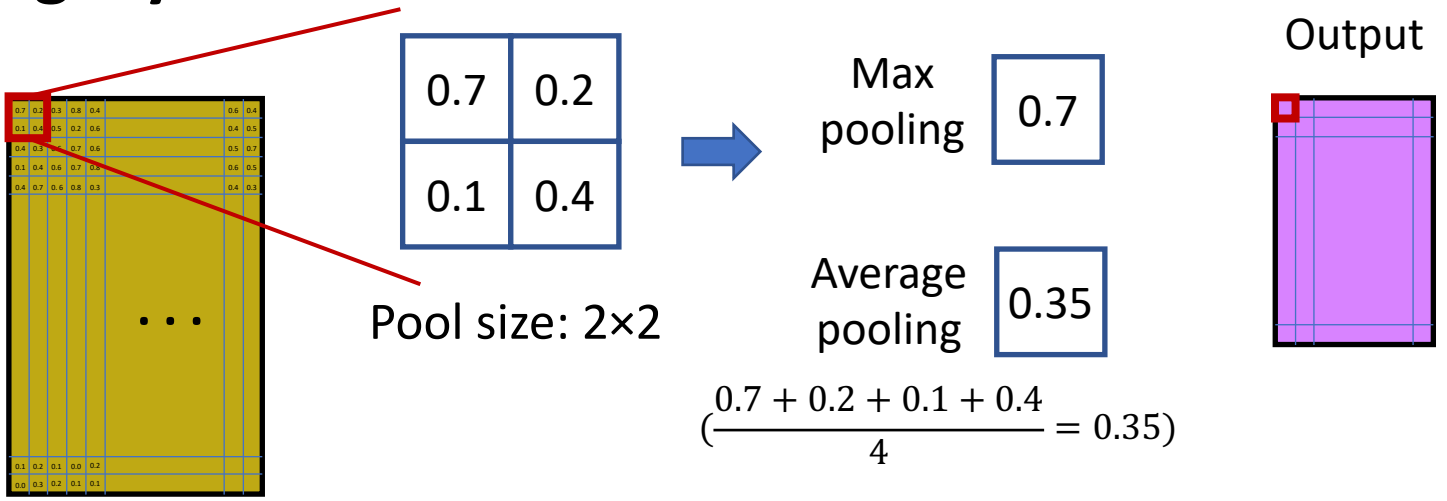
Pooling layer

- It down-samples its input
- It reduces the network sensitivity to the features' location
- Two common pooling layers are average and max pooling



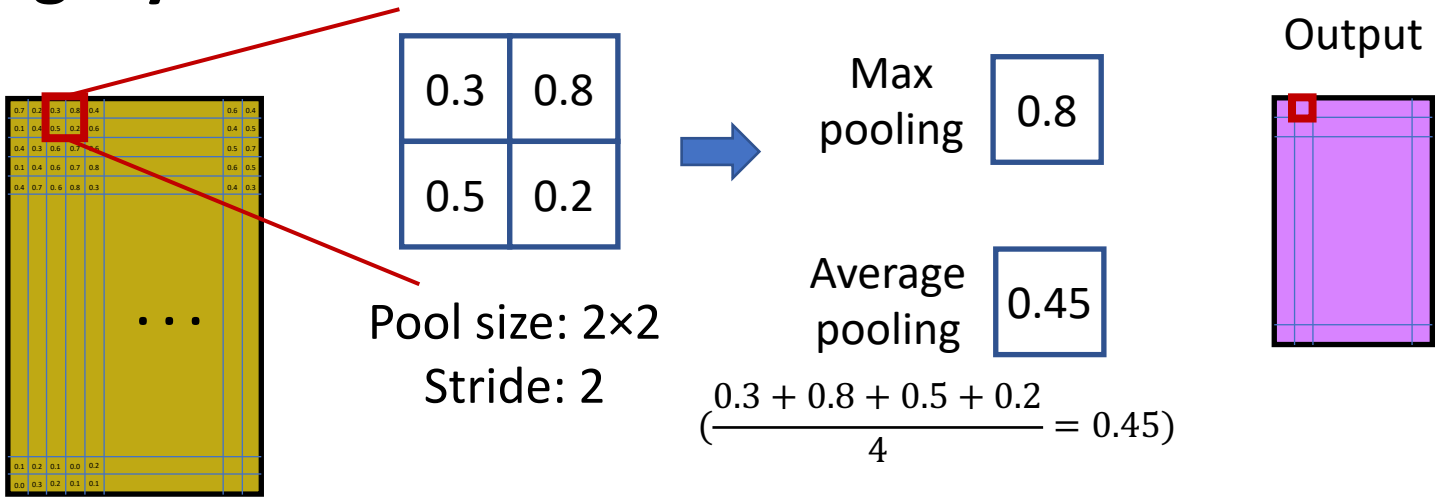
Convolutional Neural Networks

Pooling layer



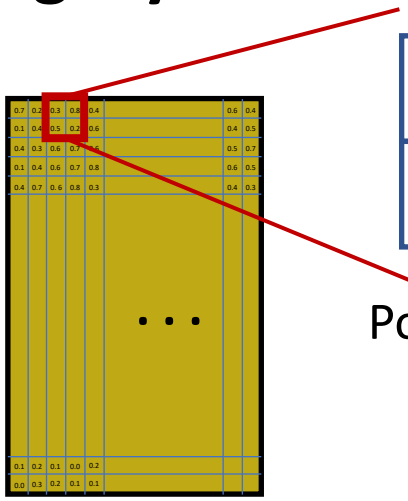
Convolutional Neural Networks

Pooling layer



Convolutional Neural Networks

Pooling layer



0.3	0.8
0.5	0.2

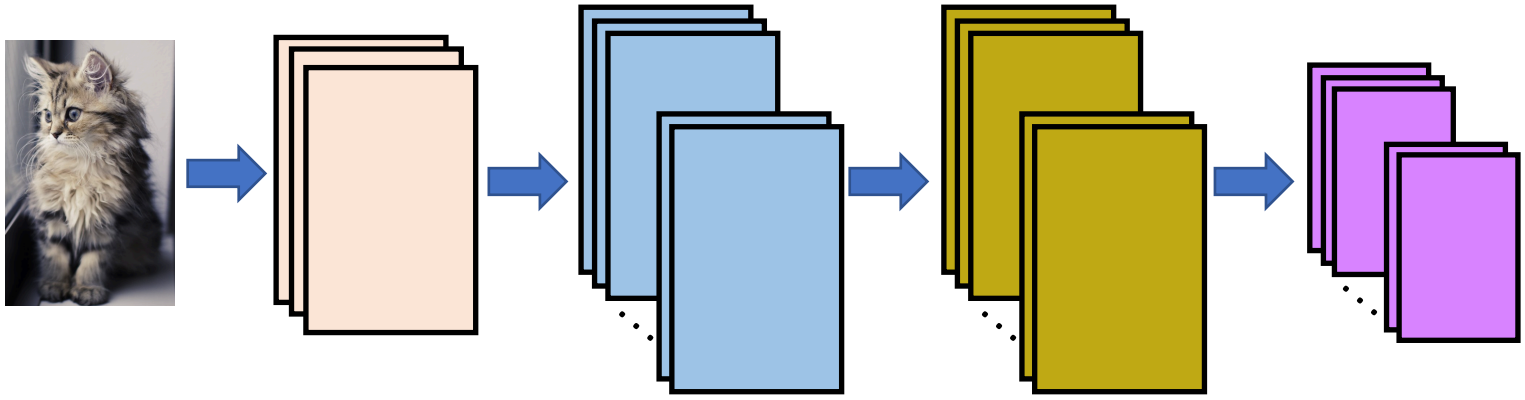
Pool size: 2×2
Stride: 2

Max pooling → 0.8

Average pooling → 0.45

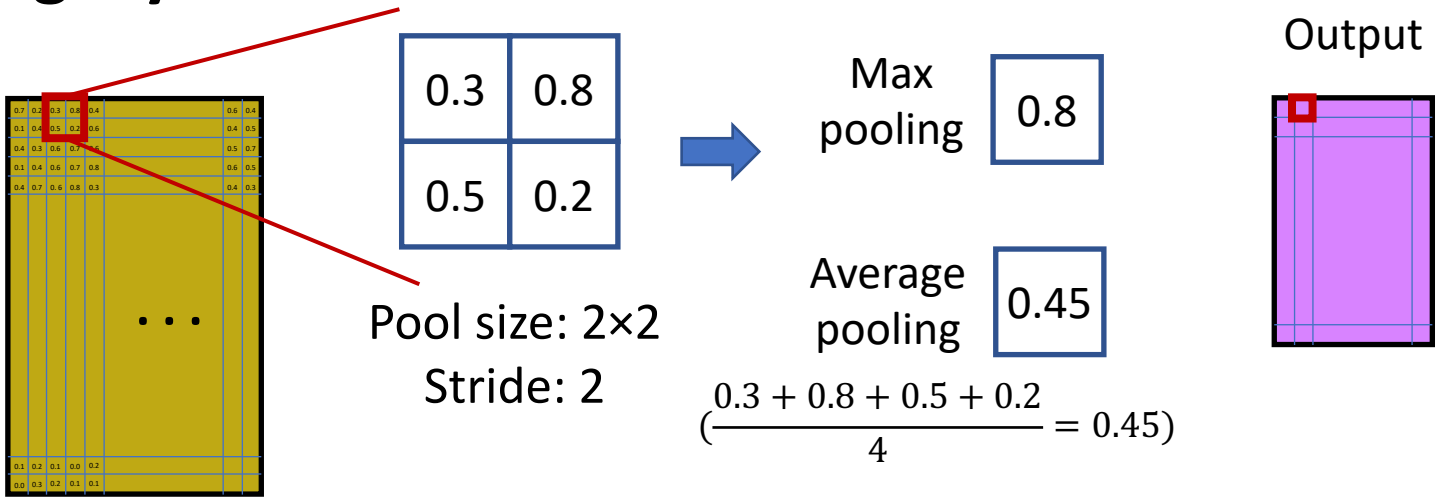
$$\left(\frac{0.3 + 0.8 + 0.5 + 0.2}{4} = 0.45\right)$$

Output



Convolutional Neural Networks

Pooling layer

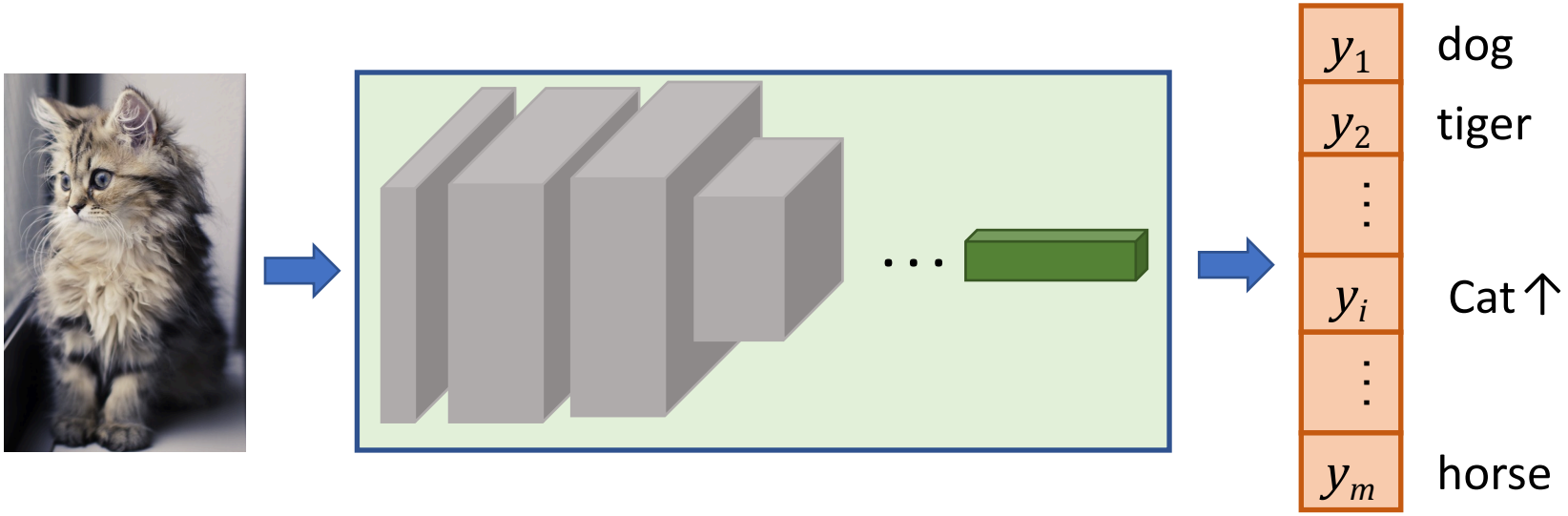


Pooling layer is not learnable

Convolutional Neural Networks

Fully-Connected layer

- It connects all its inputs to all the outputs
- It is usually used as the last layers of a network (before classification)



Convolutional Neural Networks

Fully-Connected layer

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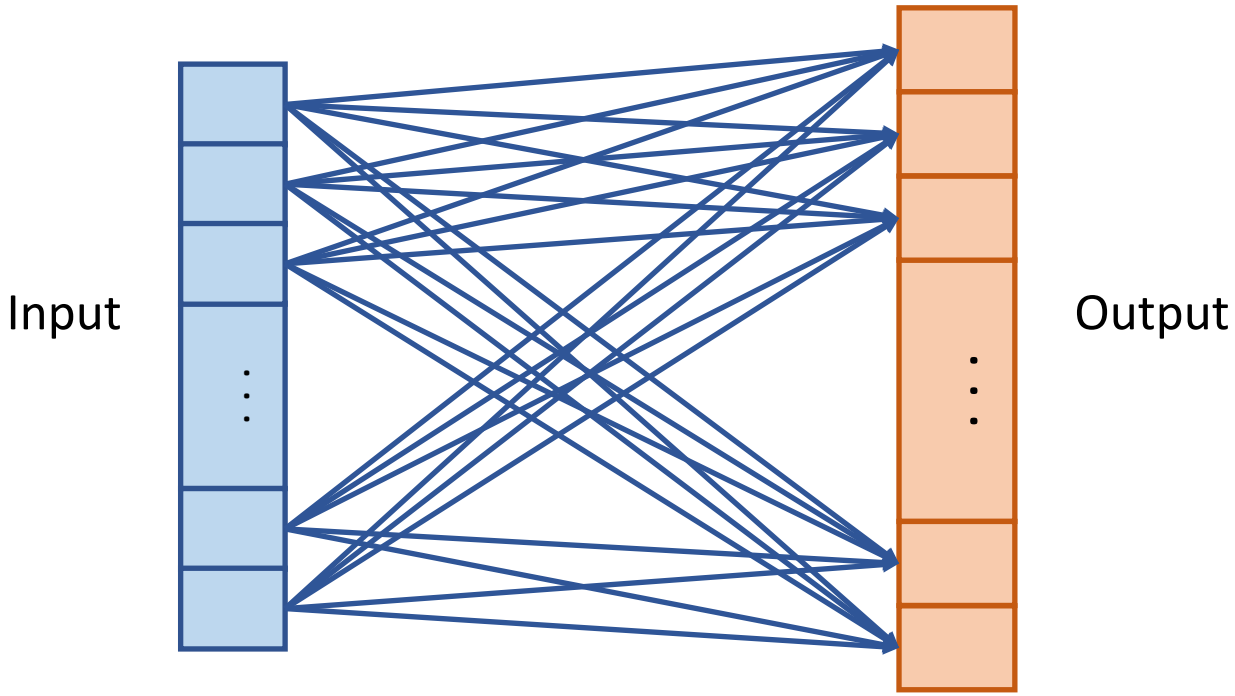
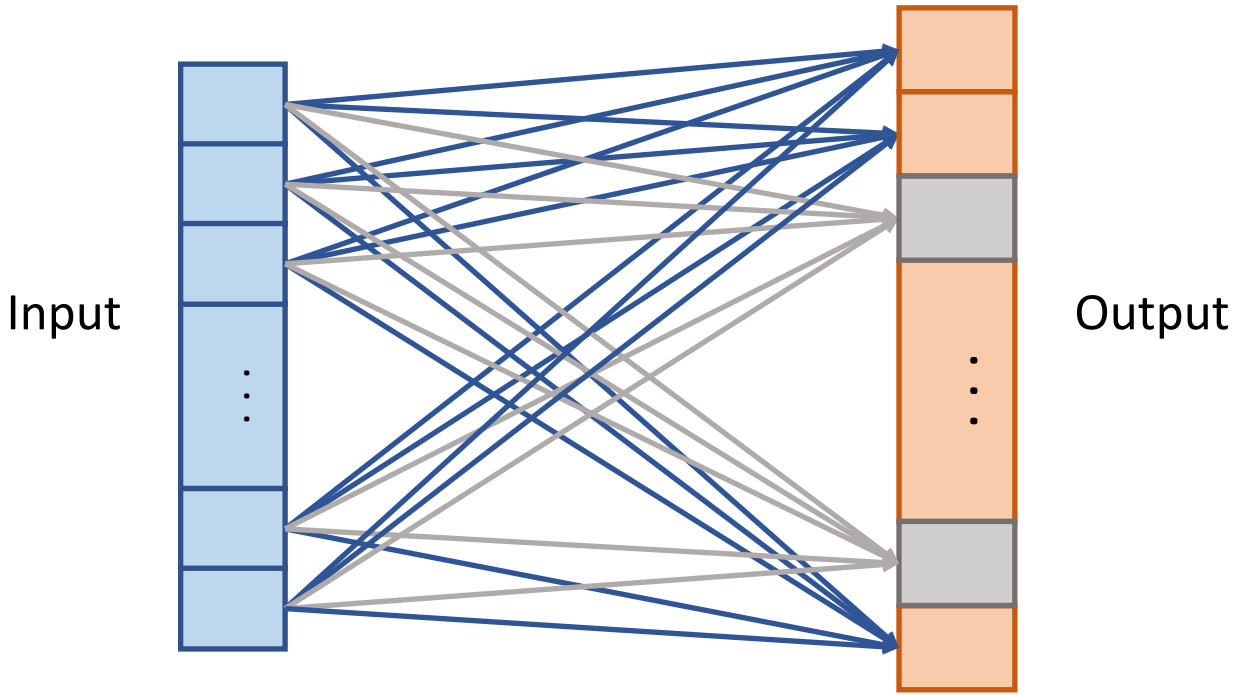


Convolutional Neural Networks

Drop-out layer

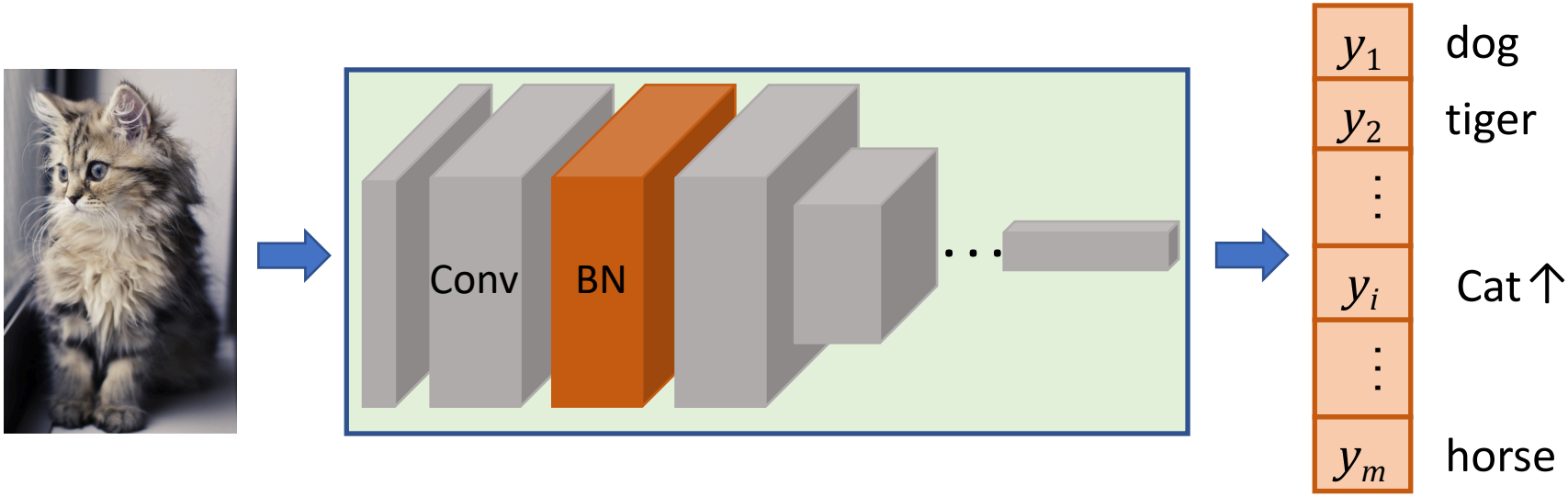
- It randomly drops out (sets to 0) neurons during training
- This prevents over-fitting (regularisation)



Convolutional Neural Networks

Batch-Normalisation layer

- It normalises its input across mini-batches
- It stabilises the network against the changes in the distribution of its input
- It helps the network generalise better to test data (regularisation)



Convolutional Neural Networks

Batch-Normalisation layer

It subtracts the mini-batch mean from its input
and divides it by the mini-batch standard deviation

$$\hat{x} = \frac{\boldsymbol{x} - m}{s}$$

This is then shifted and scaled by two learnable parameters

$$x^{BN} = \hat{x}.\gamma + \beta$$

The BN output has a distribution with
mean β and standard deviation γ

Popular
CNN Architectures

Popular CNN Architectures

CNN – VGG16

- It has 138 million parameters
- Its output layer has 1000 neurons

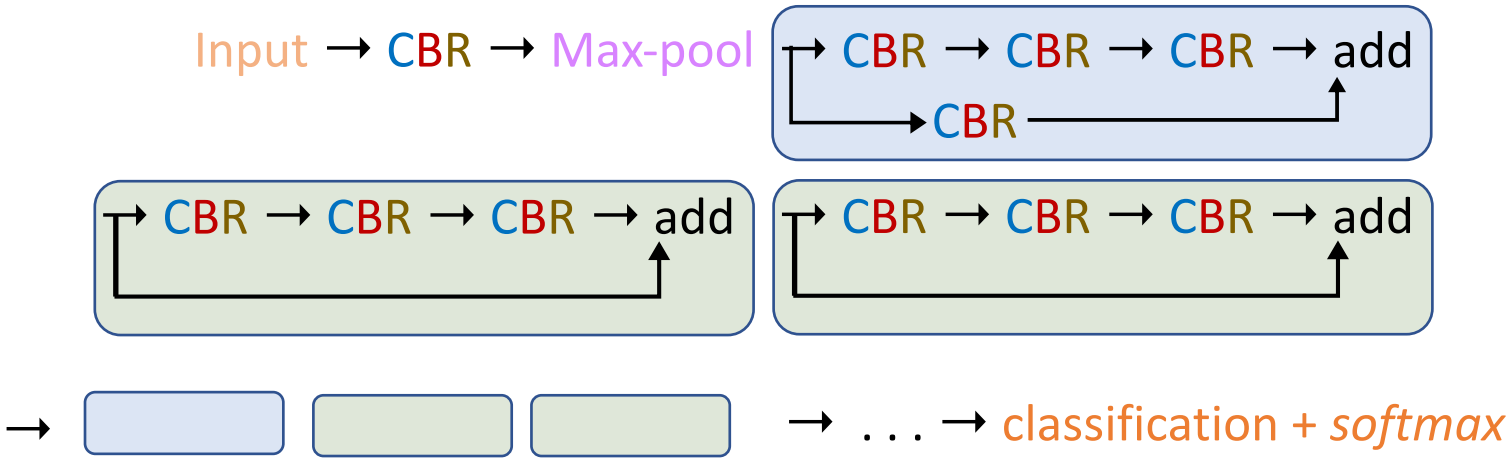
Input → Conv → ReLU → Conv → ReLU → Max-pool
→ Conv → ReLU → Conv → ReLU → Max-pool
→ Conv → ReLU → Conv → ReLU → Conv → ReLU → Max-pool
→ Conv → ReLU → Conv → ReLU → Conv → ReLU → Max-pool
→ Conv → ReLU → Conv → ReLU → Conv → ReLU → Max-pool
→ FC → ReLU → FC → ReLU → classification + *softmax*

Simonyan and Zisserman, Very Deep Convolutional Networks for Large Scale Image Recognition, 2014

Popular CNN Architectures

CNN – ResNet

- It uses residual (shortcut) connections
- It has increased the number of layers (152)
- It has 26 million parameters (CBR: Conv → BN → ReLU)



He et al, Deep Residual Learning for Image Recognition, 2016

Popular CNN Architectures

CNN for image classification

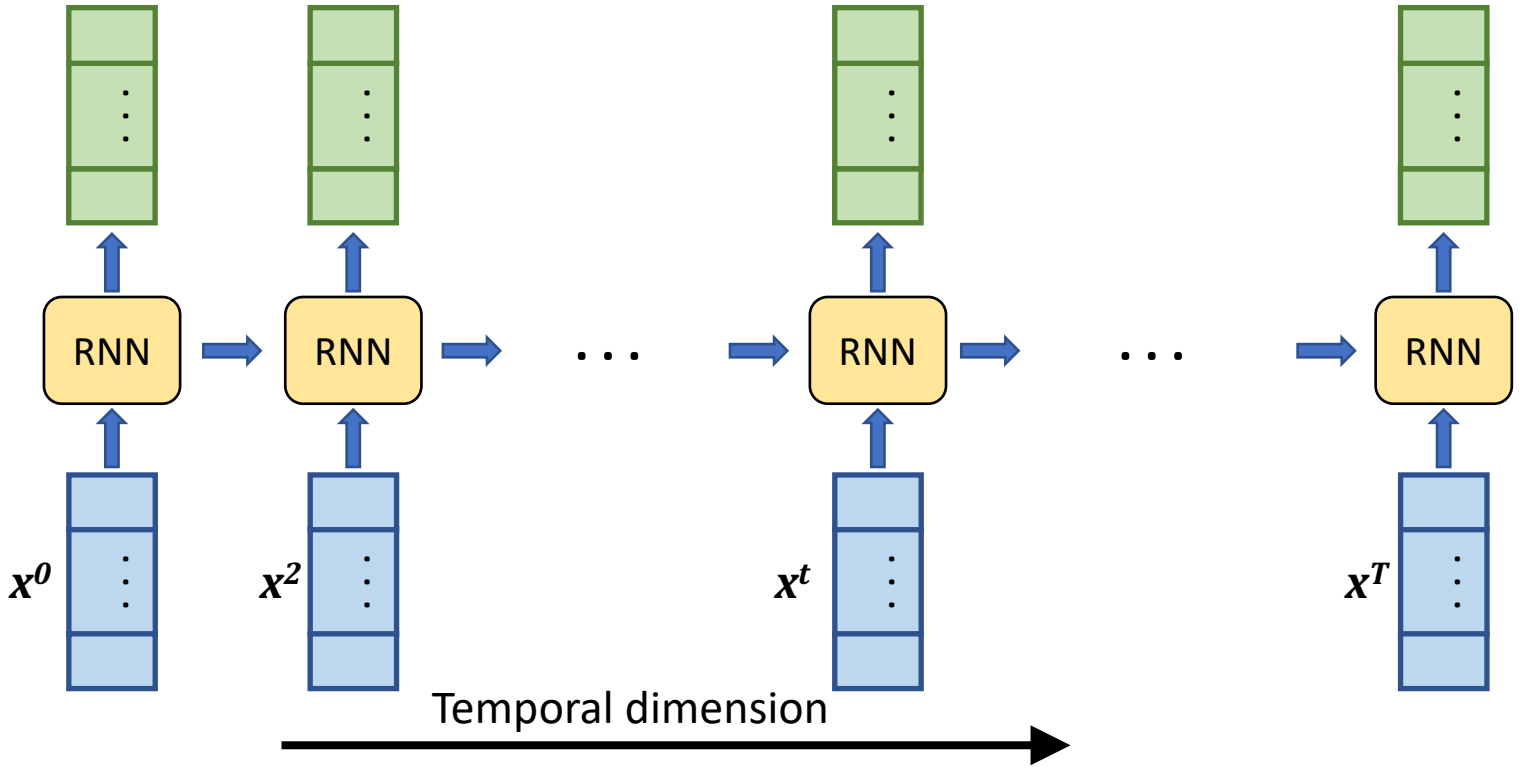
- AlexNet
- Inception-v1/ v2/ v4
- Inception-ResNets
- Xception
- DenseNet
- ResNeXt

Other Popular Neural Networks

Other Popular Neural Networks

Recurrent Neural Networks (RNN)

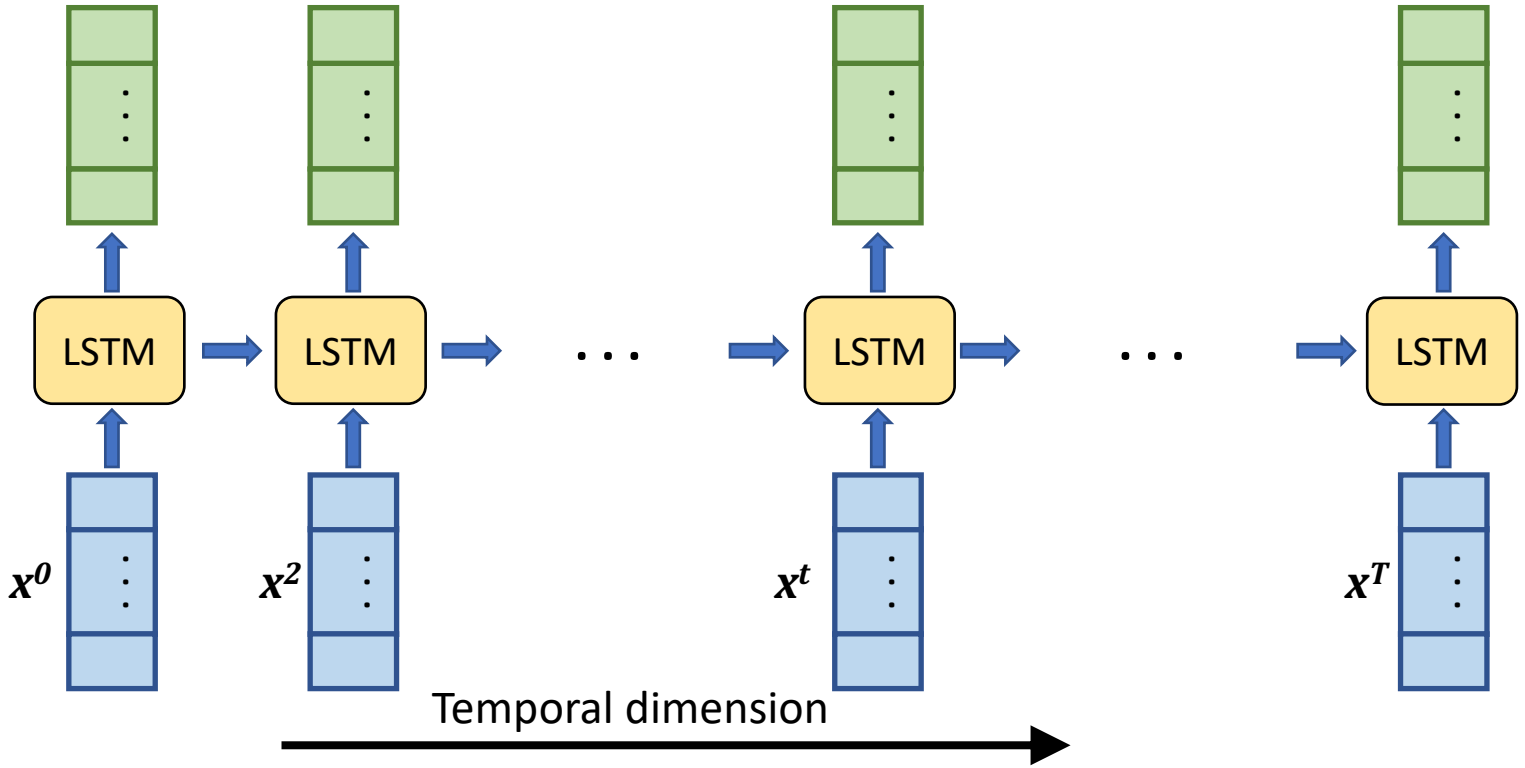
- They process sequences of data
- They back-propagate loss through time



Other Popular Neural Networks

Long Short-Term Memory Networks (LSTM)

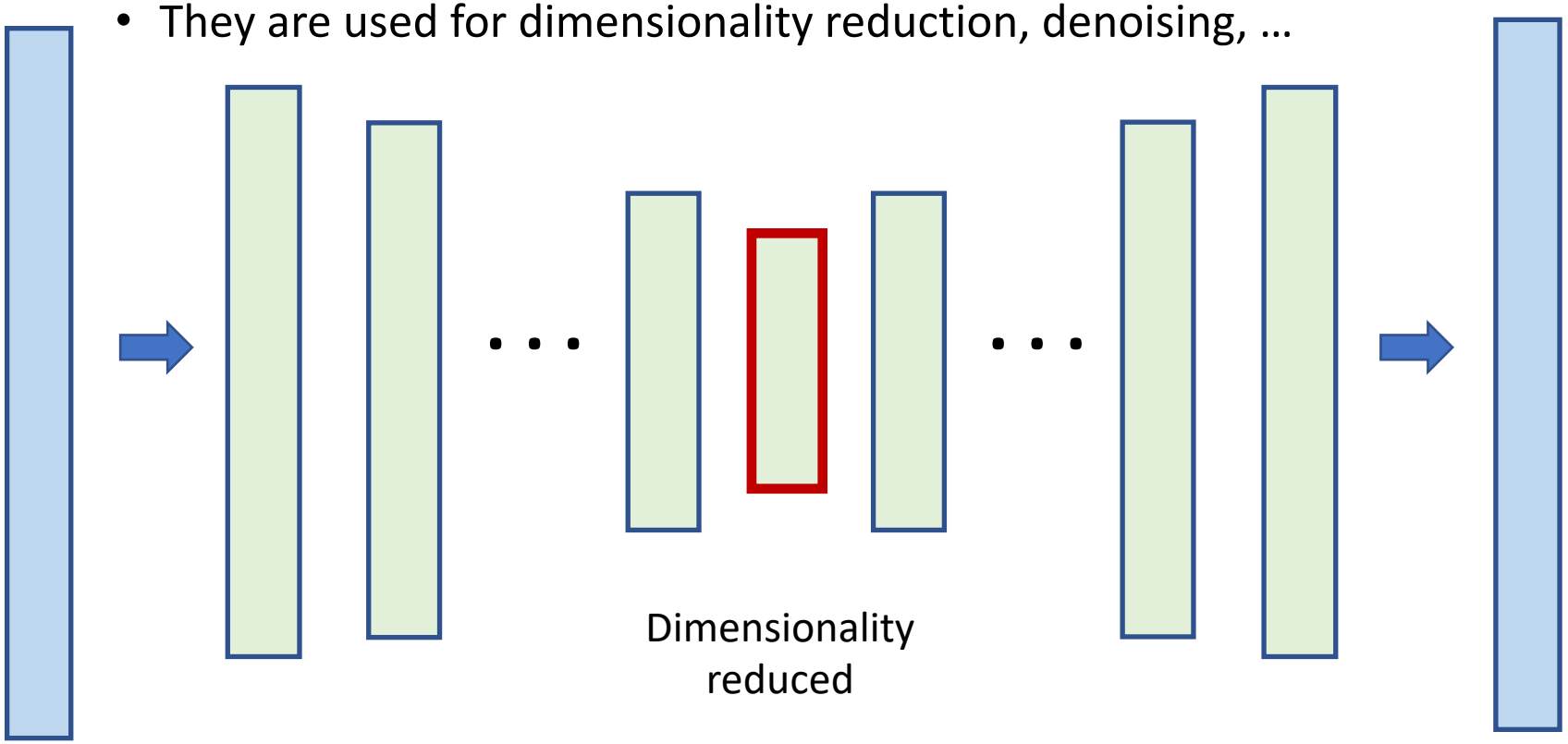
- They are a special type of Recurrent Networks
- They can store information in their memory for long durations



Other Popular Neural Networks

Auto-Encoders

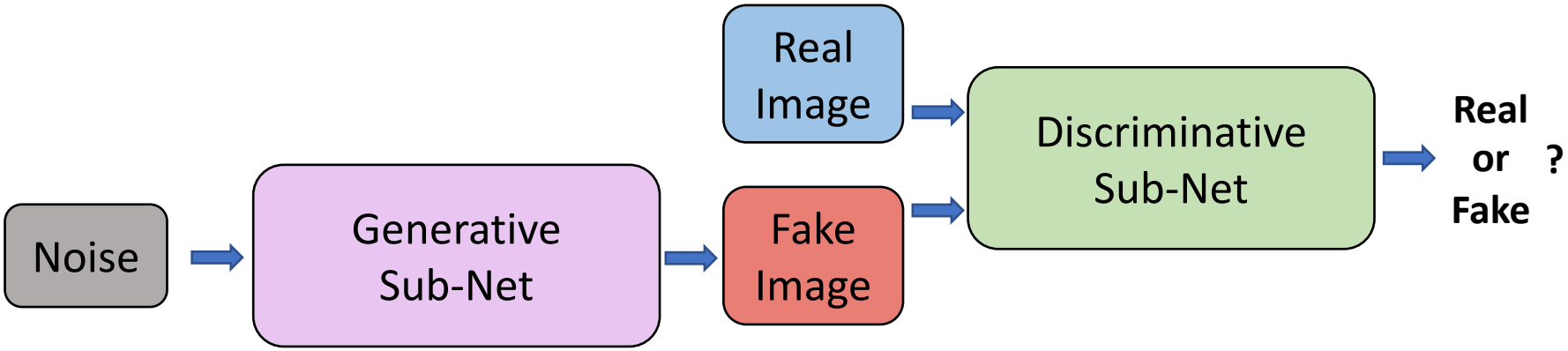
- They reconstruct their input
- They are used for dimensionality reduction, denoising, …



Other Popular Neural Networks

Generative Adversarial Networks (GAN)

- They are generative models – e.g. when trained they can generate fake images out of noise
- They have two sub-network (discriminative and generative)
- The two sub-networks compete against each other (adversarial)



Summary and Conclusion

- We saw different types of layers in a CNN

  Convolutional, Activation, Pooling

  Fully-Connected, Drop-out, Batch Normalisation, ...

- We saw some popular neural networks
  - CNN (VGG and ResNet)
  - RNN and LSTM
  - Auto-Encoder
  - GAN

Thanks for your attention