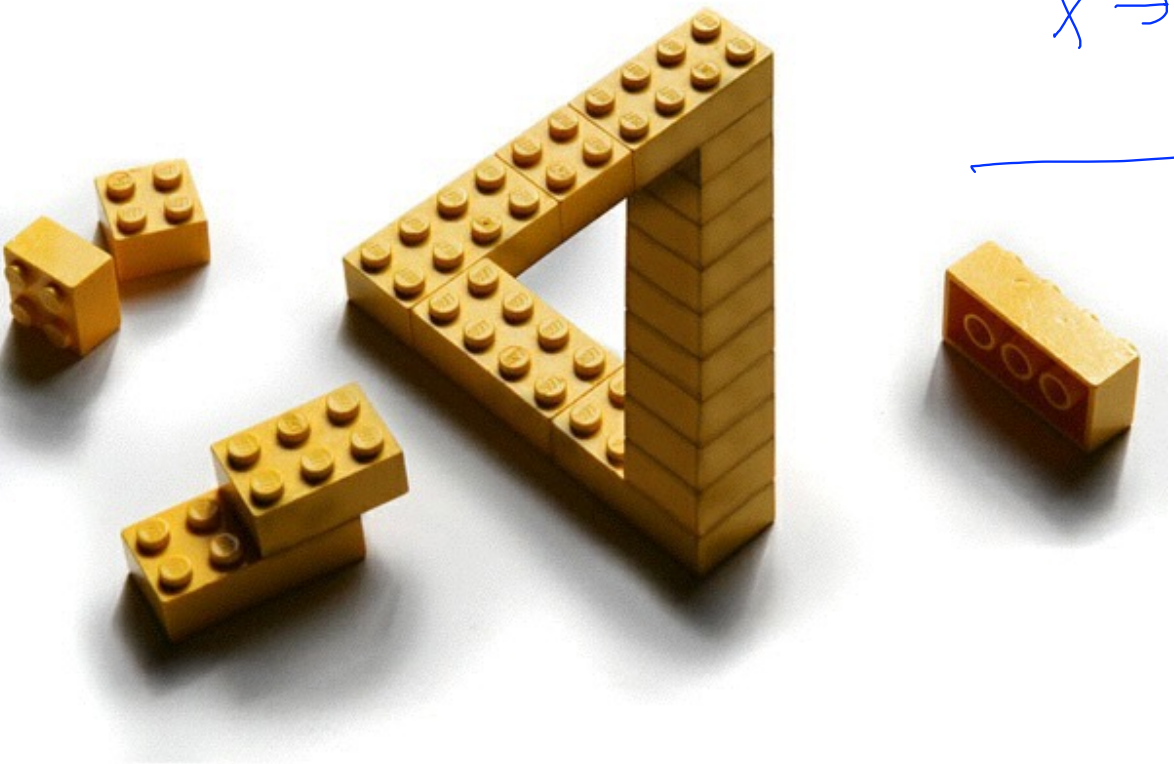
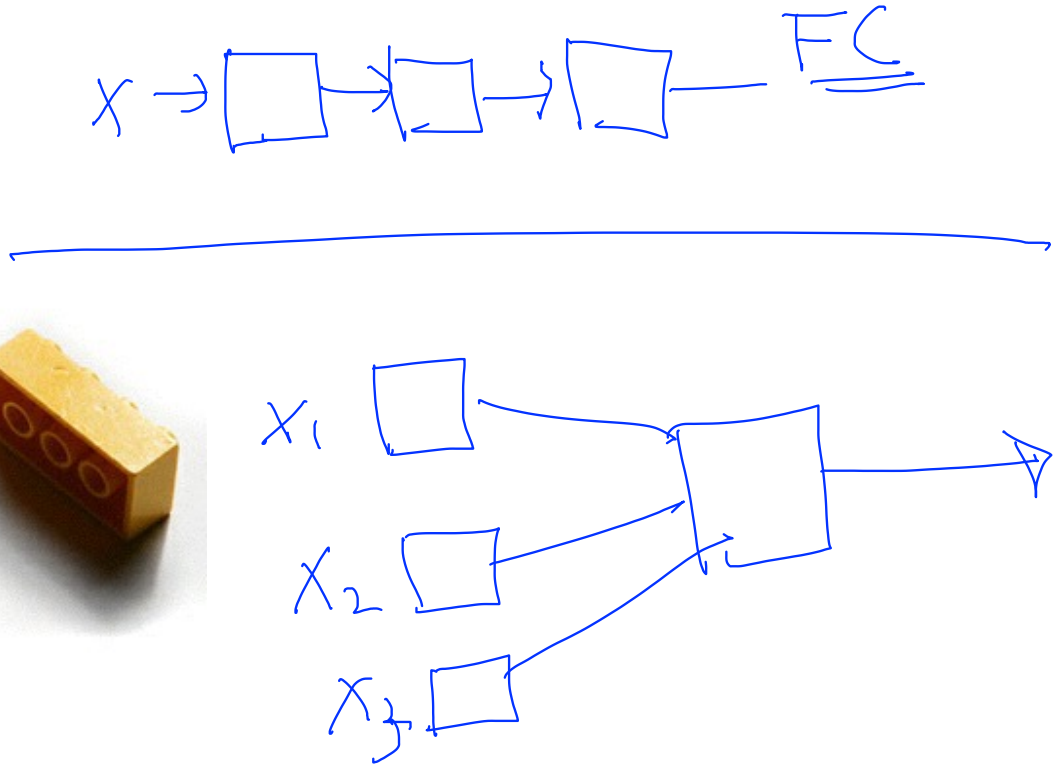
Lecture 11-1
CNN introduction

Sung Kim <hunkim+mr@gmail.com>

'The only limit is your imagination'





http://itchyi.squarespace.com/thelatest/2012/5/17/the-only-limit-is-your-imagination.html

Convolutional Neural Networks

http://cs231n.stanford.edu/

A bit of history:

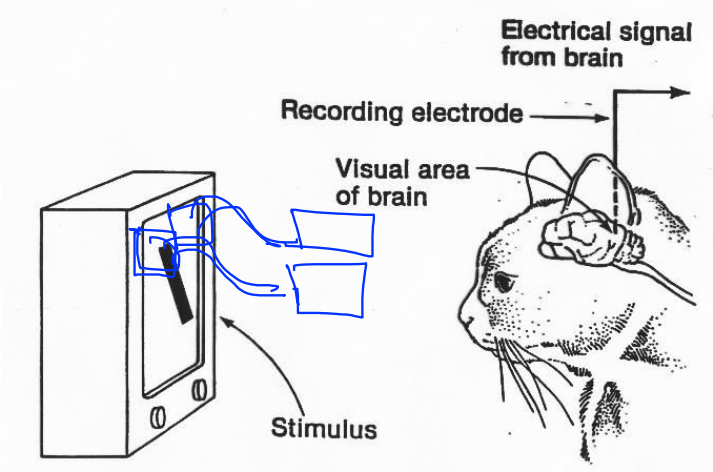
Hubel & Wiesel, 1959

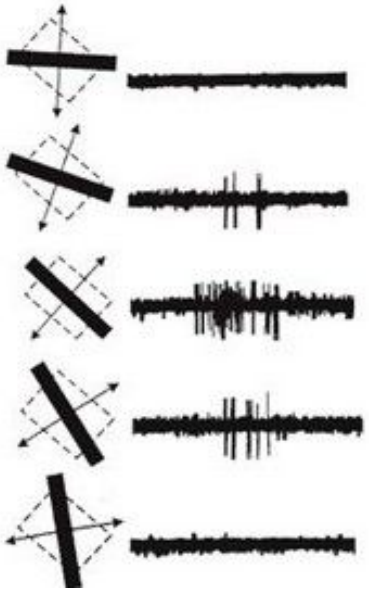
RECEPTIVE FIELDS OF SINGLE NEURONES IN
THE CAT'S STRIATE CORTEX

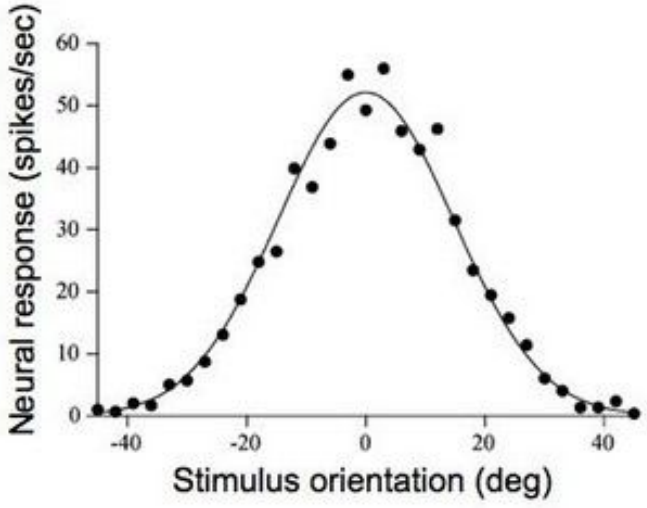
1962

RECEPTIVE FIELDS, BINOCULAR INTERACTION
AND FUNCTIONAL ARCHITECTURE IN
THE CAT'S VISUAL CORTEX

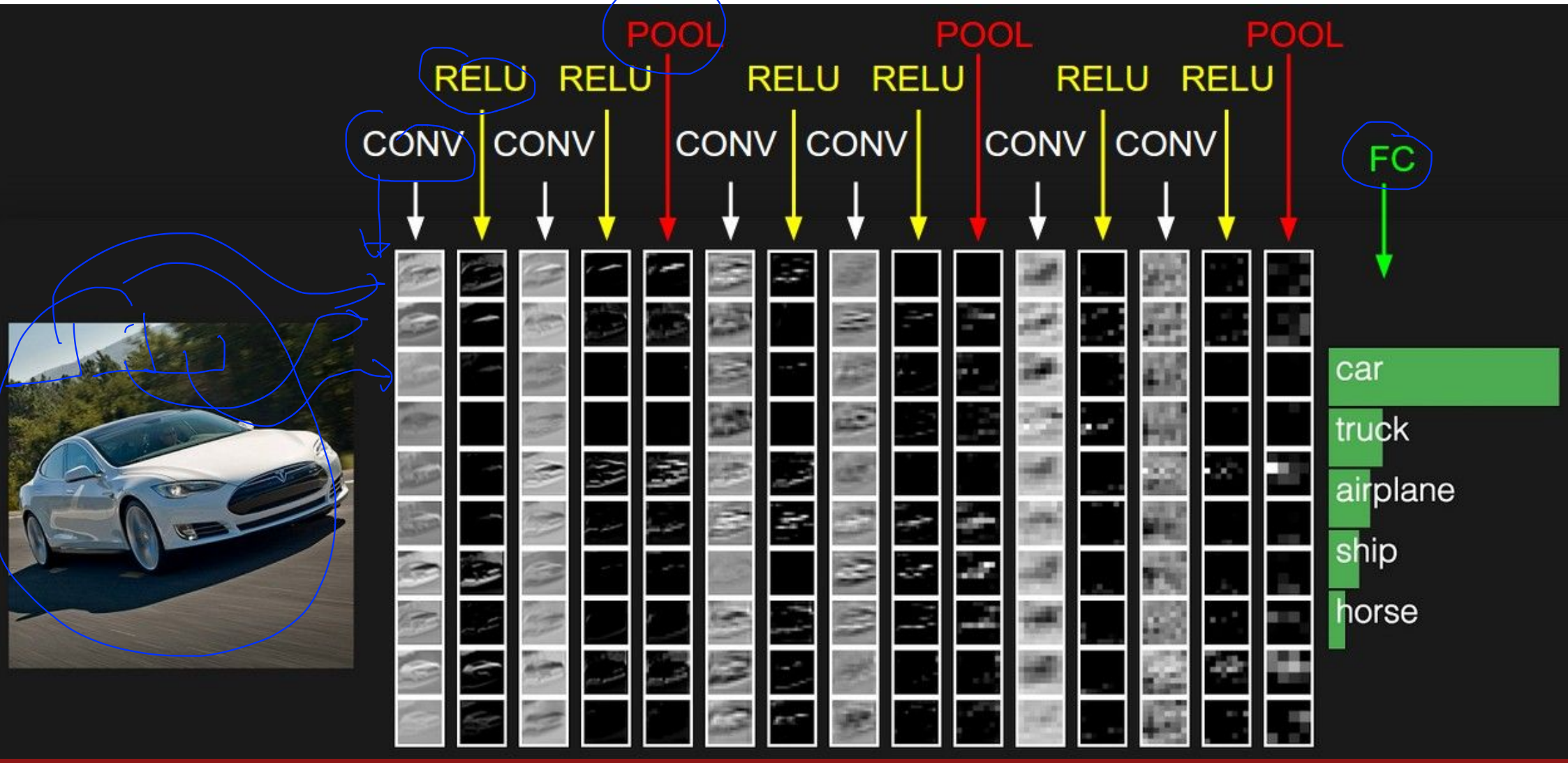
1968...



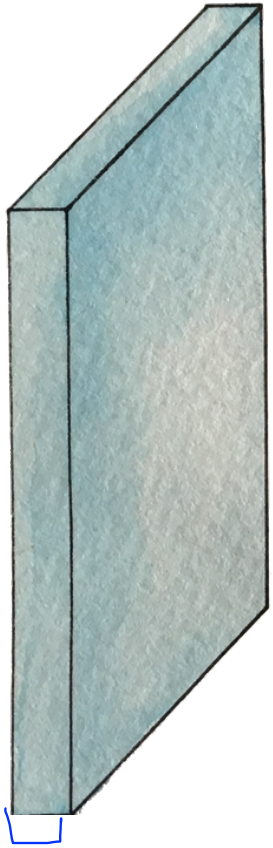




preview:

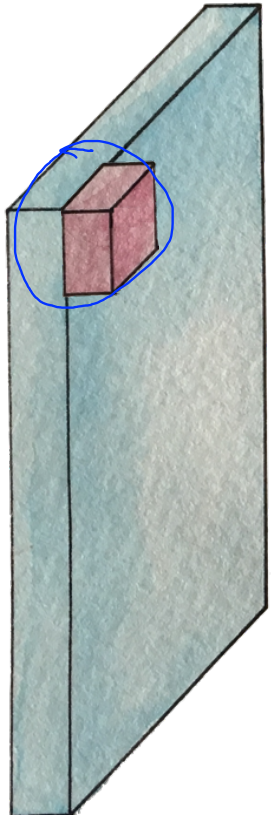

POOL
POOL
POOL
RELU
RELU
RELU
RELU
RELU
RELU
CONV
CONV
CONV
CONV
CONV
CONV
FC
car
truck
airplane
ship
horse

Start with an image (width x hight x depth)



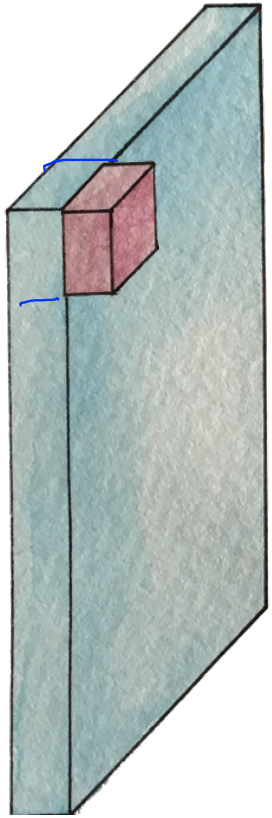
32x32x3 image

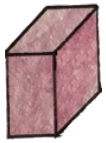
Let's focus on a small area only



32x32x3 image

Let's focus on a small area only (5x5x3)

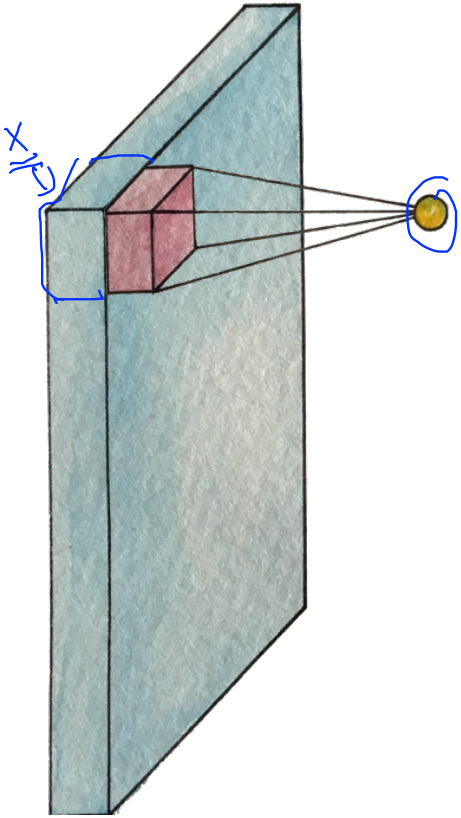




32x32x3 image

5x5x3 filter

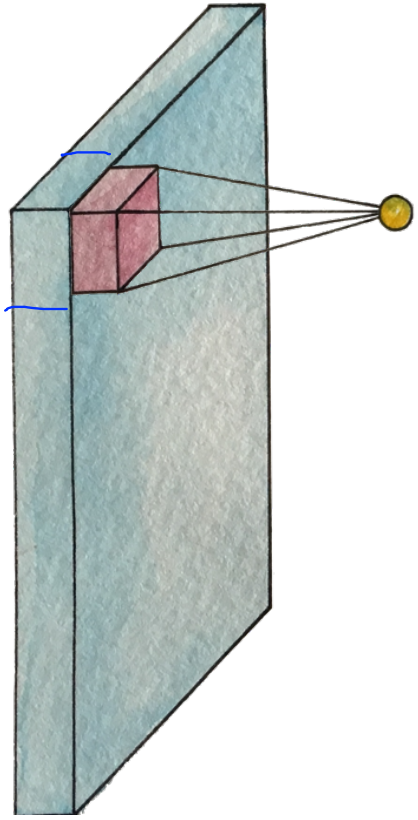
Get one number using the filter



one number!

32x32x3 image

Get one number using the filter

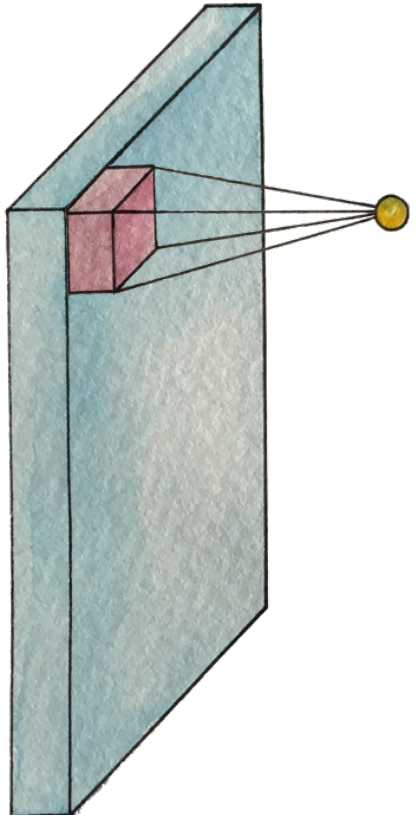


one number! =Wx+b =ReLU(Wx+b)

5x5x3 filter

32x32x3 image

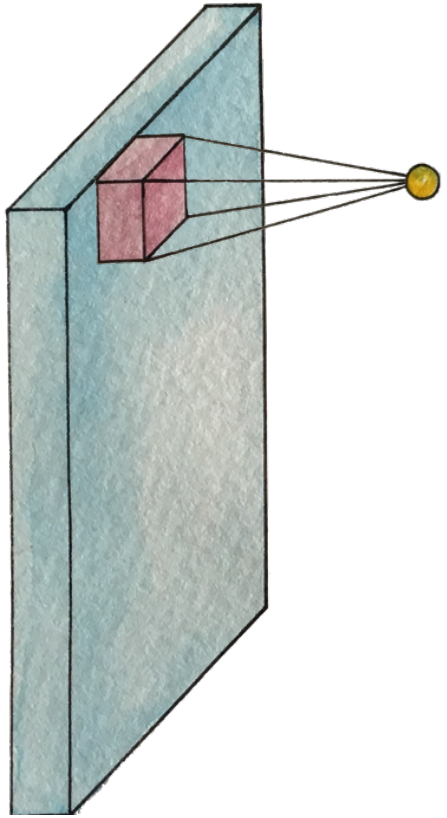
Let's look at other areas with the same filter (w)



one number!

32x32x3 image

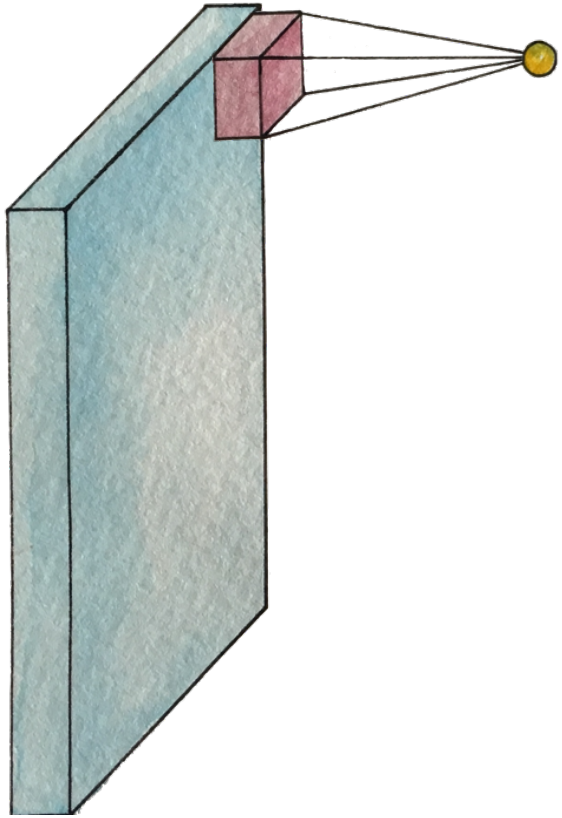
Let's look at other areas with the same filter (w)



one number!

32x32x3 image

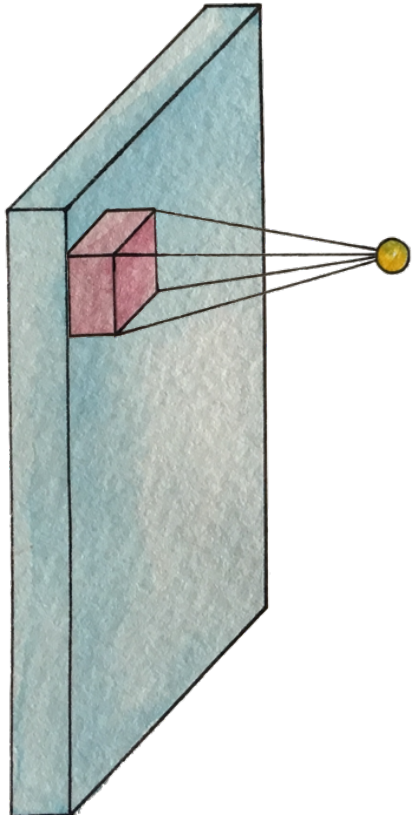
Let's look at other areas with the same filter (w)



one number!

32x32x3 image

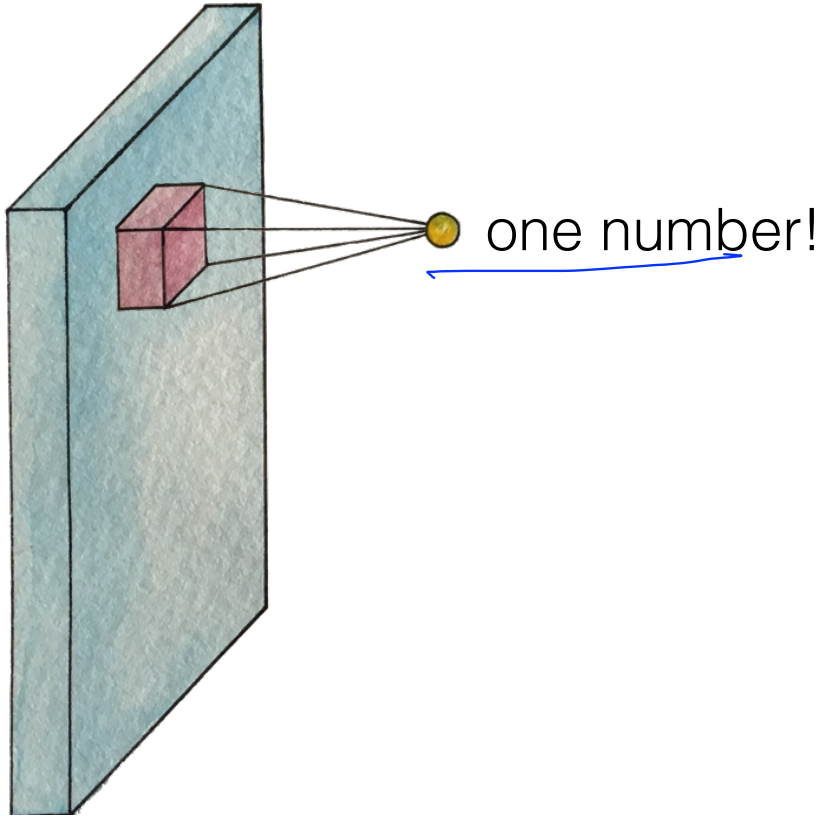
Let's look at other areas with the same filter (w)



one number!

32x32x3 image

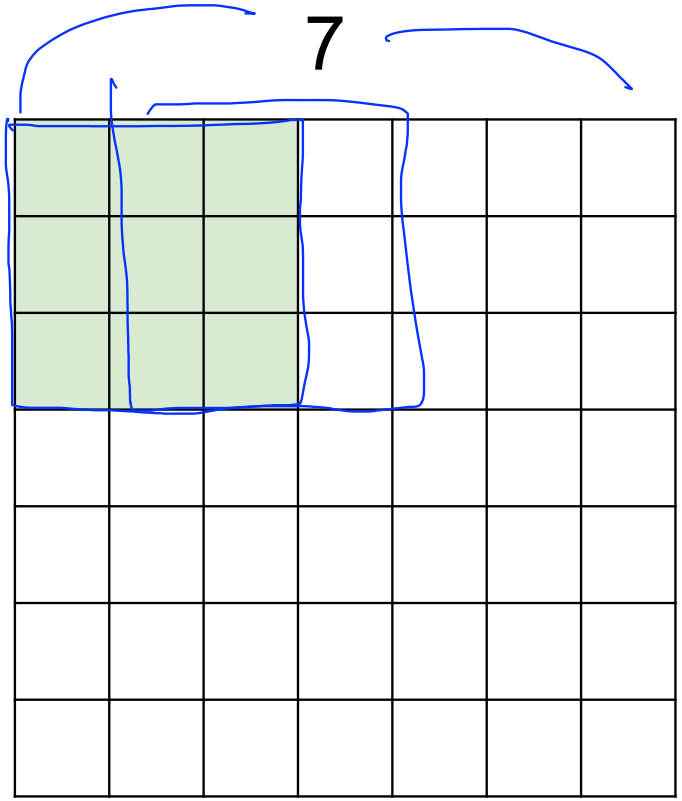
Let's look at other areas with the same filter (w)



32x32x3 image

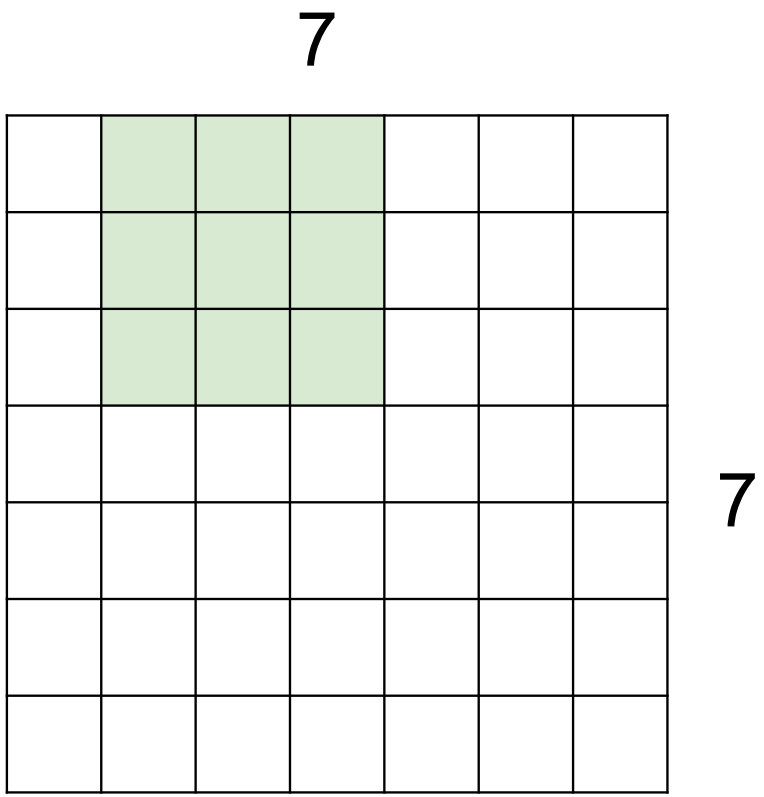
How many numbers can we get?

A closer look at spatial dimensions:



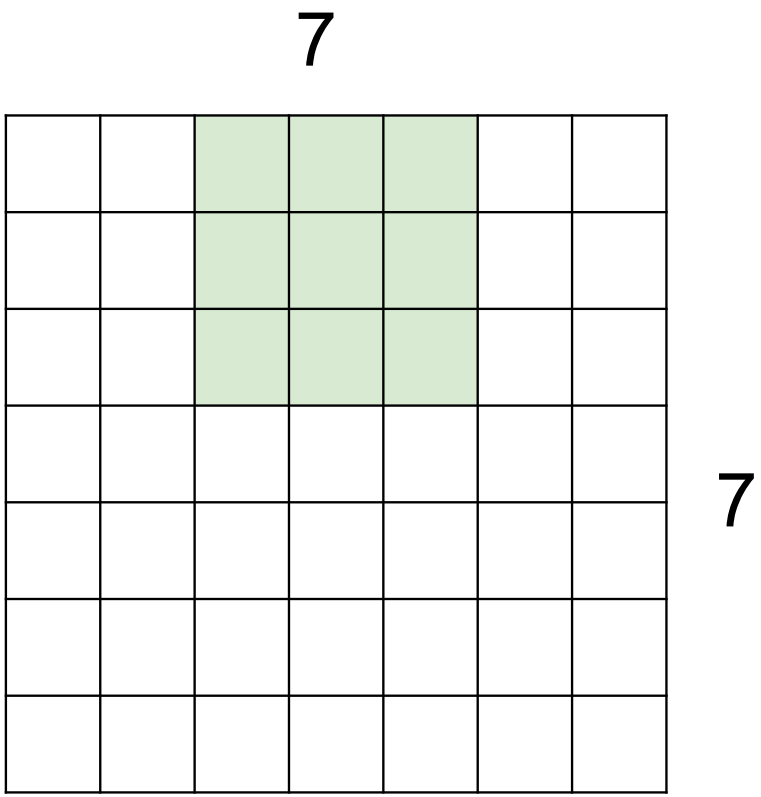
7x7 input (spatially)
assume 3x3 filter

A closer look at spatial dimensions:



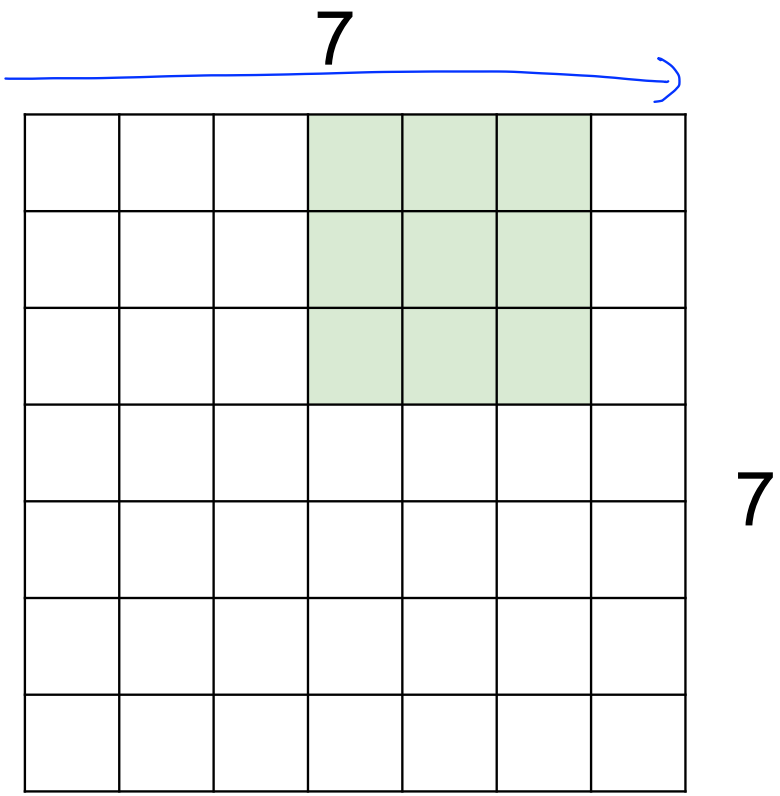
7x7 input (spatially)
assume 3x3 filter

A closer look at spatial dimensions:



7x7 input (spatially)
assume 3x3 filter

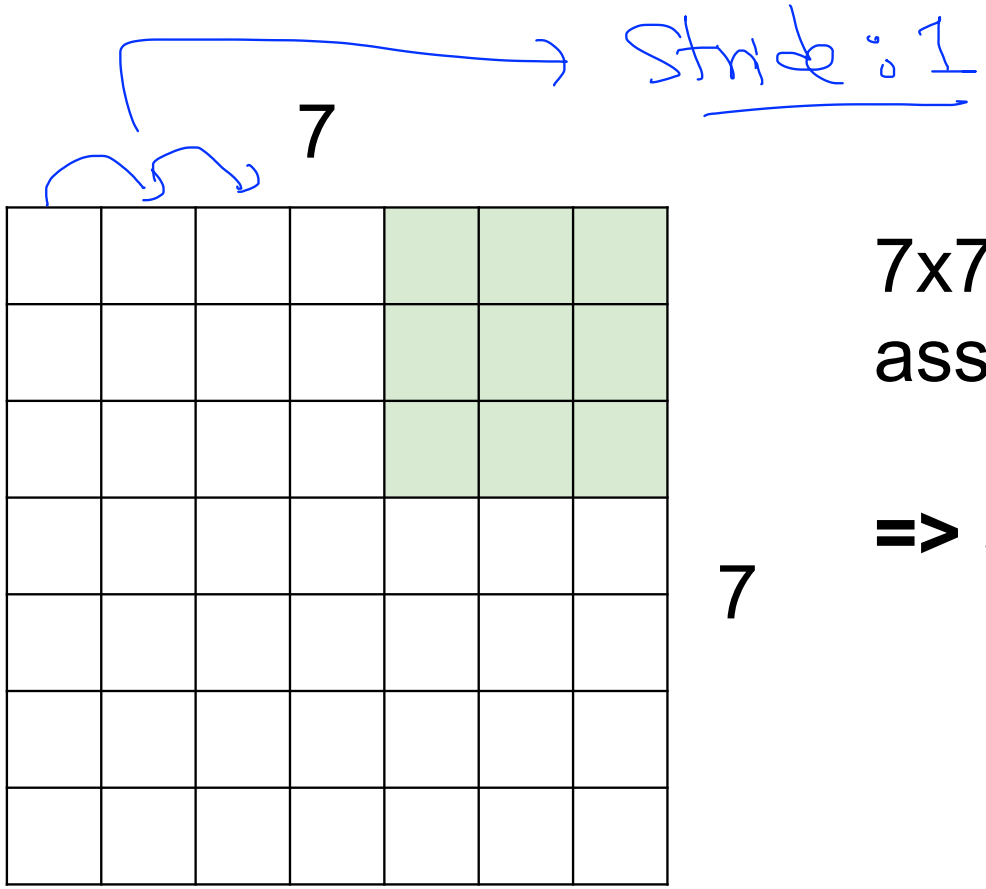
A closer look at spatial dimensions:



7x7 input (spatially)
assume 3x3 filter

5x5

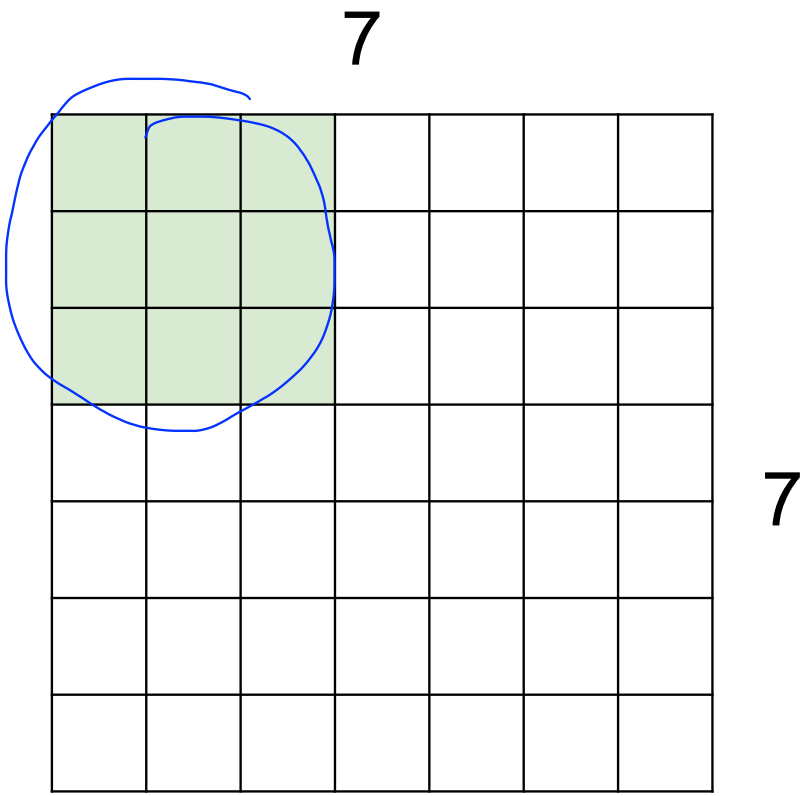
A closer look at spatial dimensions:



7x7 input (spatially)
assume 3x3 filter

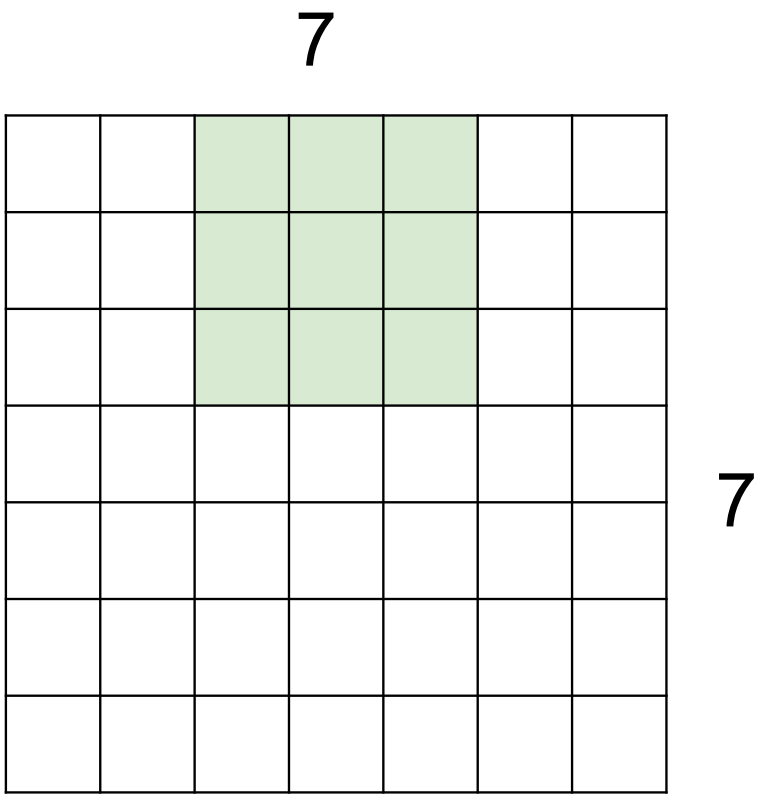
=> 5x5 output

A closer look at spatial dimensions:



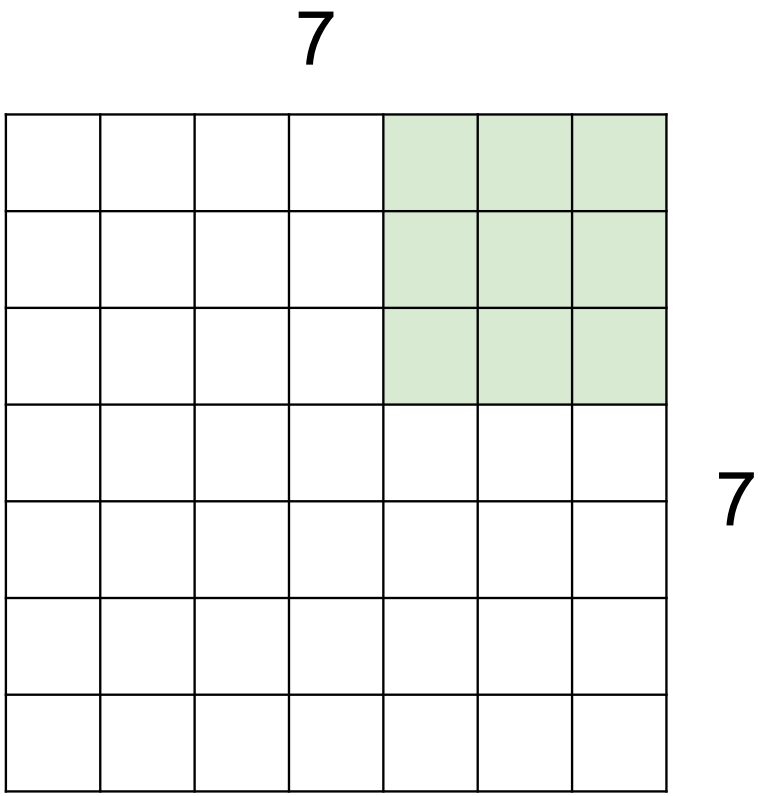
7x7 input (spatially)
assume 3x3 filter
applied **with stride 2**

A closer look at spatial dimensions:

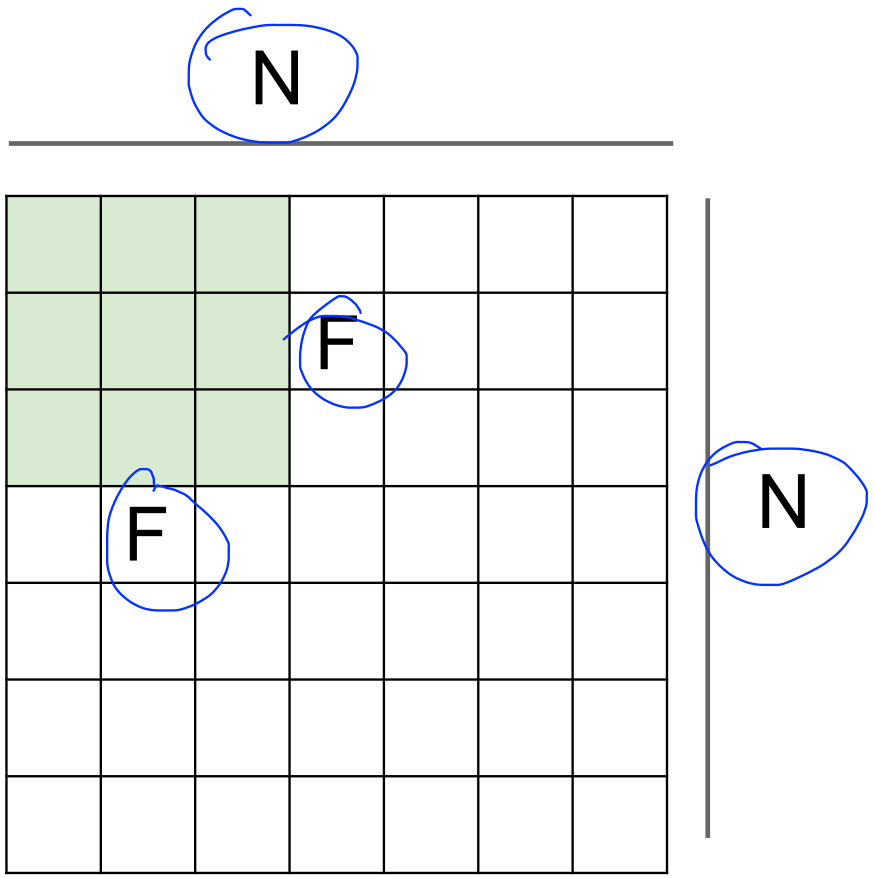


7x7 input (spatially)
assume 3x3 filter
applied **with stride 2**

A closer look at spatial dimensions:



7x7 input (spatially)
assume 3x3 filter
applied **with stride 2**
=> 3x3 output!



Output size:

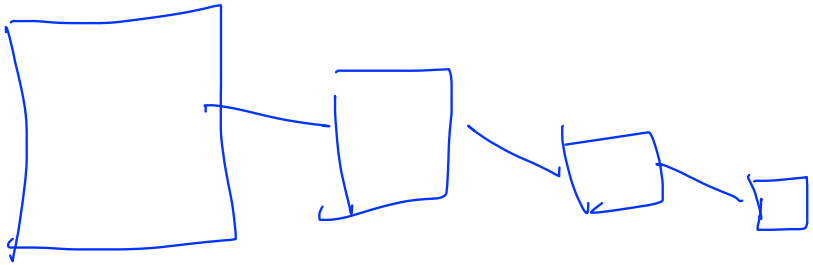
(N - F) / stride + 1

e.g. N = 7, F = 3:

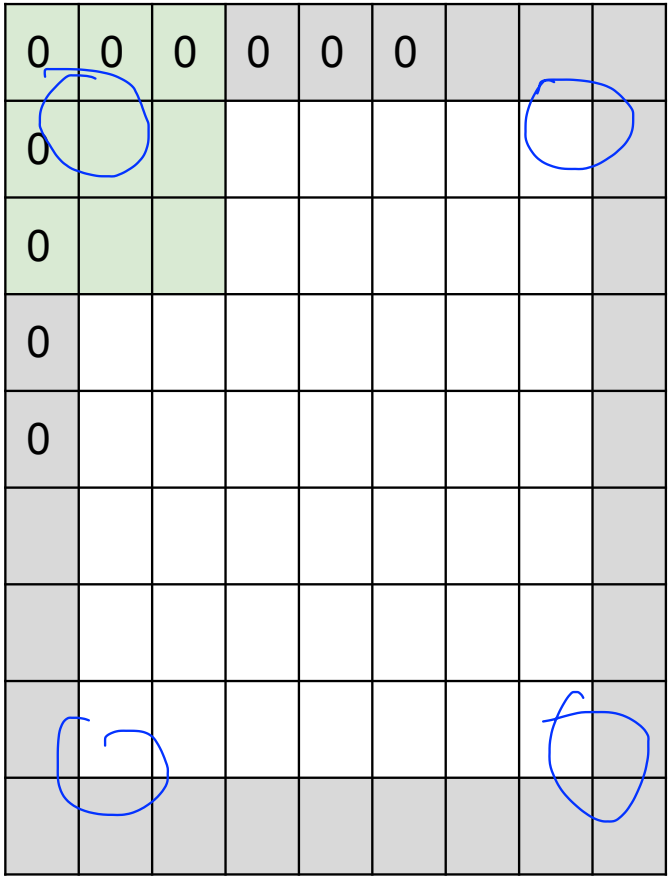
stride 1 => (7 - 3)/1 + 1 = 5

stride 2 => (7 - 3)/2 + 1 = 3

~~stride 3 => (7 - 3)/3 + 1 = 2.33 :\~~



In practice: Common to zero pad the border



e.g. input 7x7
3x3 filter, applied with **stride 1**
pad with 1 pixel border => what is the output?

7x7 → 9x9
pad

(recall:)
(N - F) / stride + 1

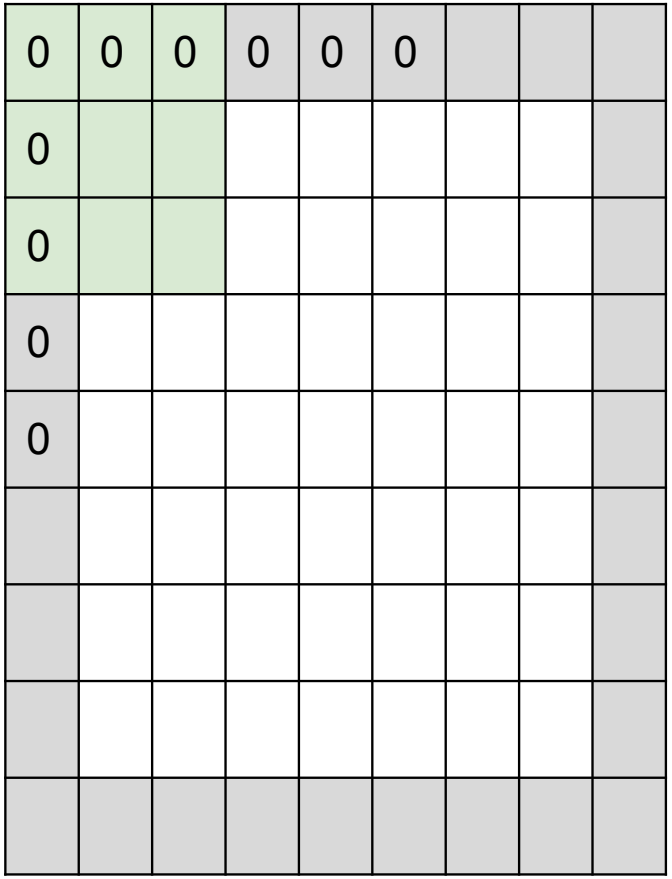
In practice: Common to zero pad the border

0	0	0	0	0	0			
0								
0								
0								
0								

e.g. input 7x7
3x3 filter, applied with **stride 1**
pad with 1 pixel border => what is the output?

7x7 output!

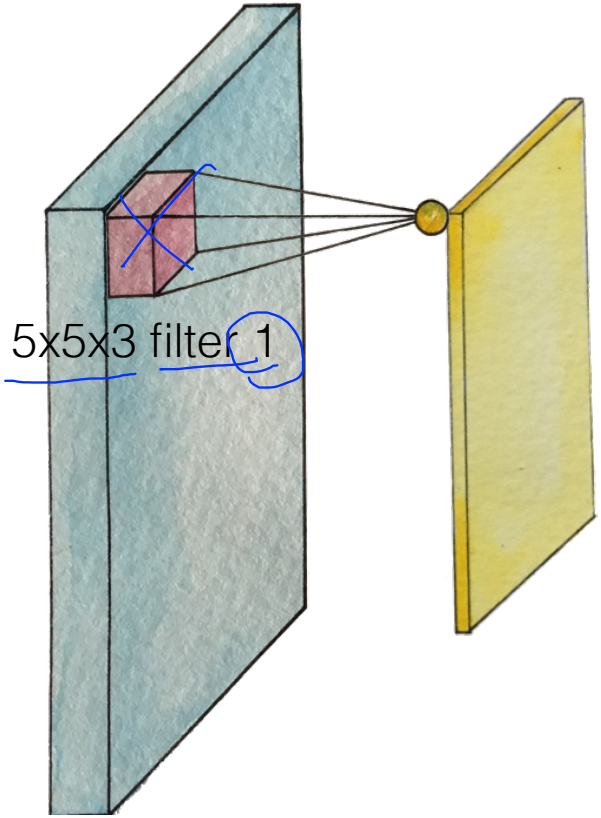
In practice: Common to zero pad the border



e.g. input 7x7
3x3 filter, applied with **stride 1**
pad with 1 pixel border => what is the output?

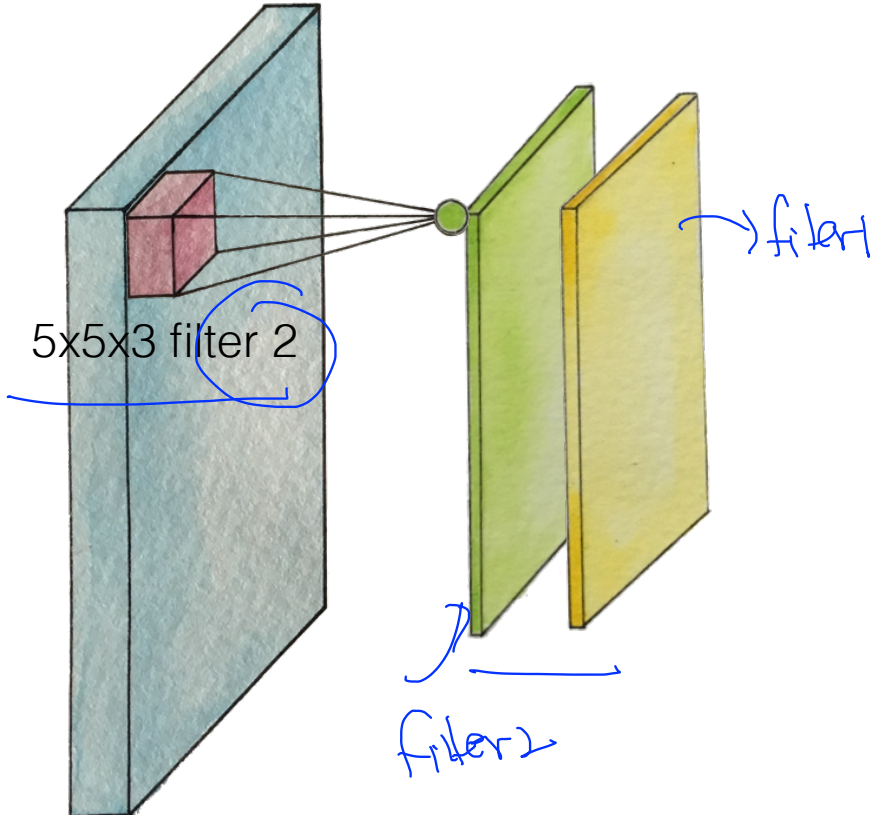
7x7 output!
in general, common to see CONV layers with stride 1, filters of size FxF, and zero-padding with (F-1)/2. (will preserve size spatially)
e.g. F = 3 => zero pad with 1
F = 5 => zero pad with 2
F = 7 => zero pad with 3

Swiping the entire image



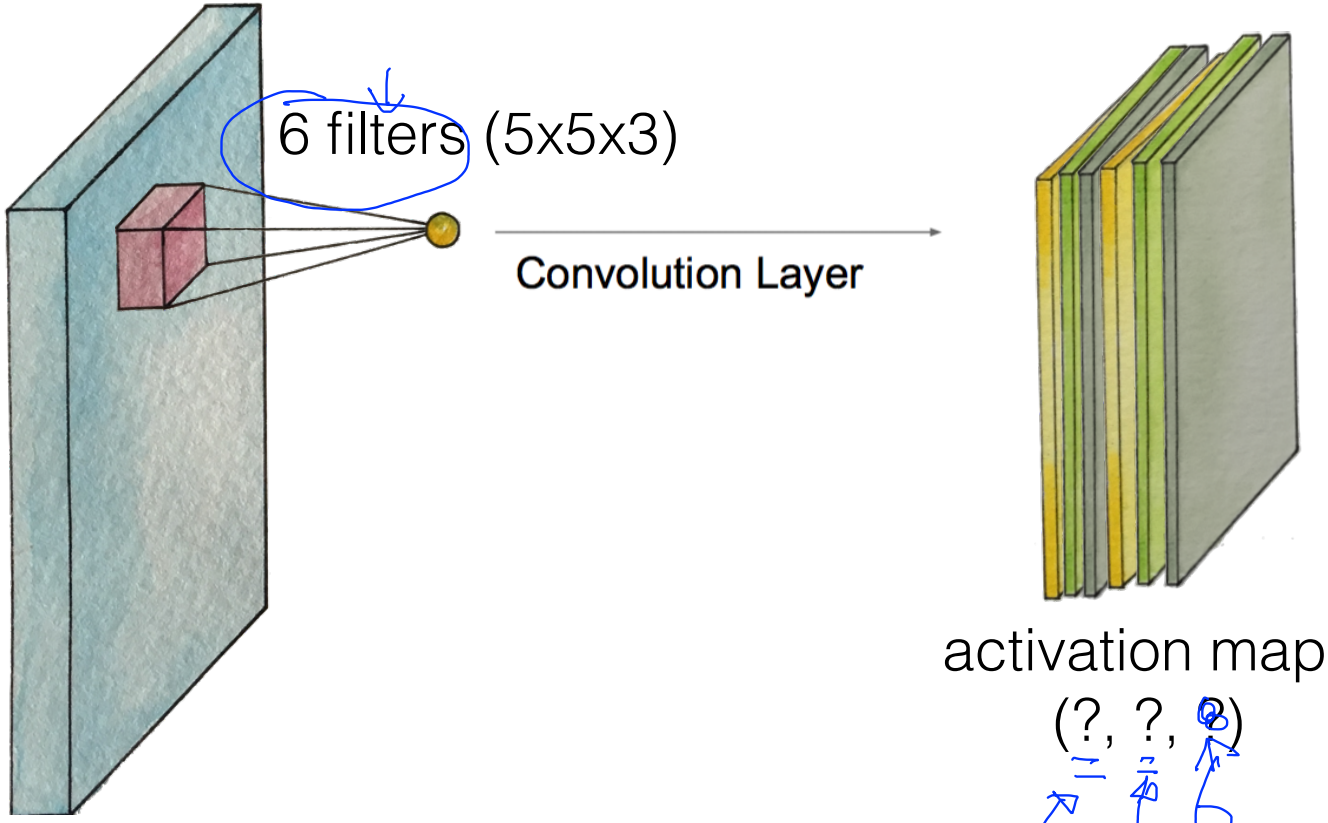
32x32x3 image

Swiping the entire image



32x32x3 image

Swiping the entire image

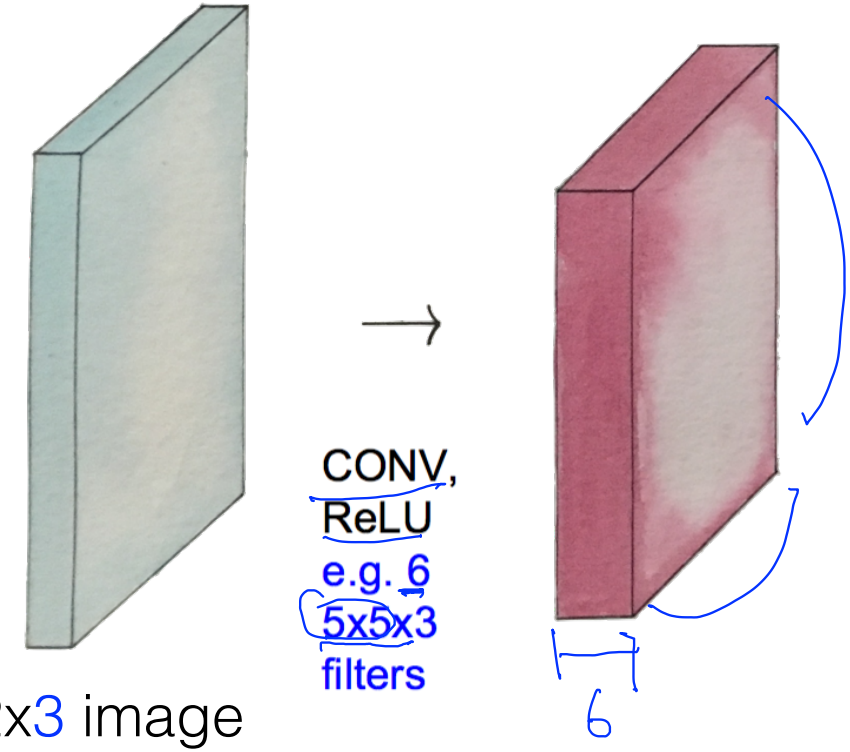


32x32x3 image

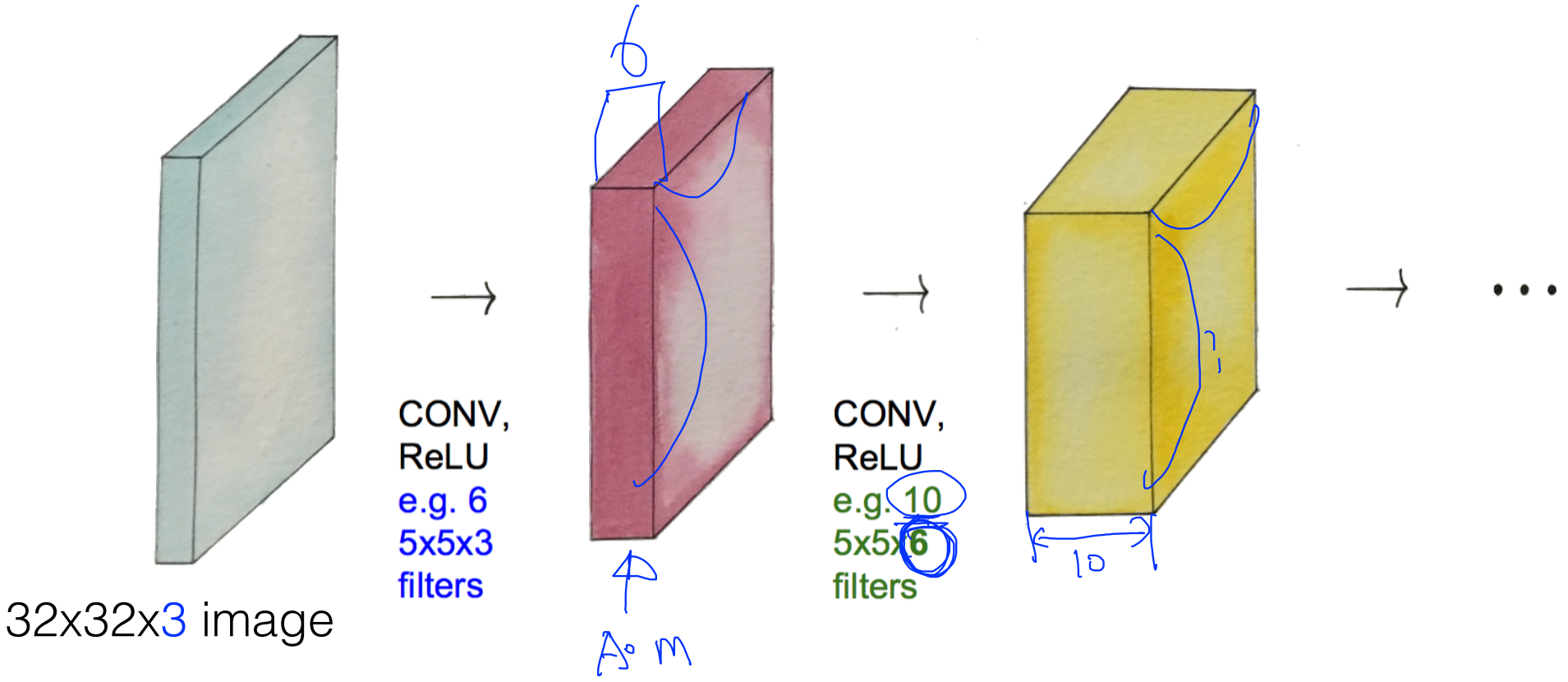
activation maps

(?, ?, 6)

Convolution layers

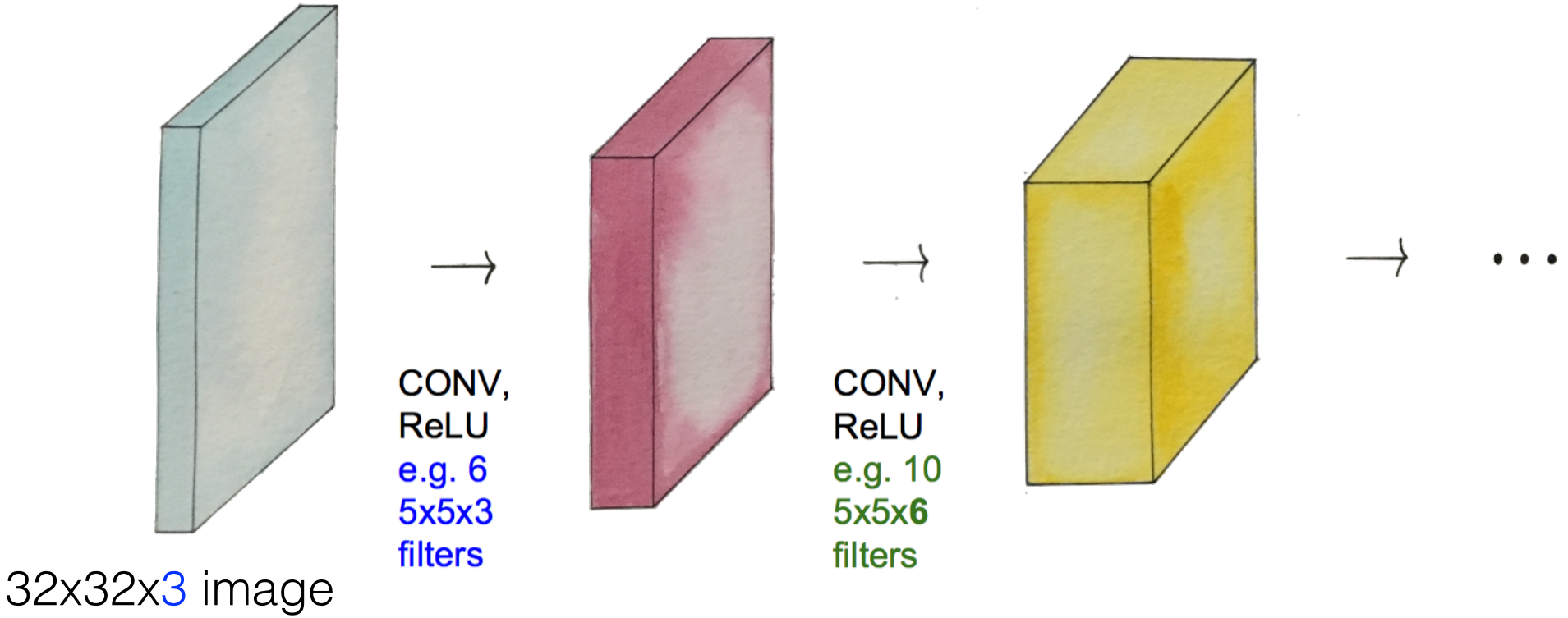


Convolution layers



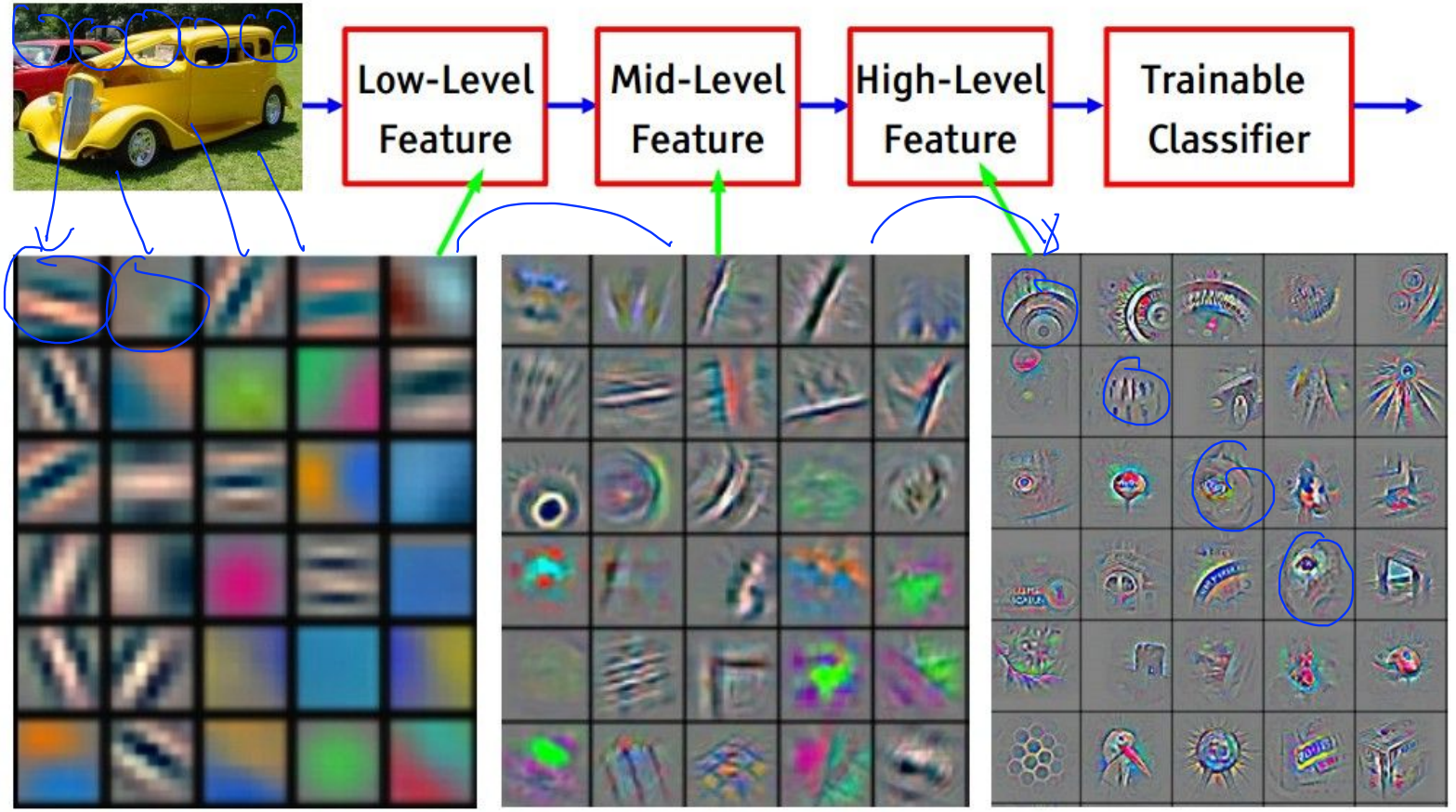
Convolution layers

How many weight variables? How to set them?



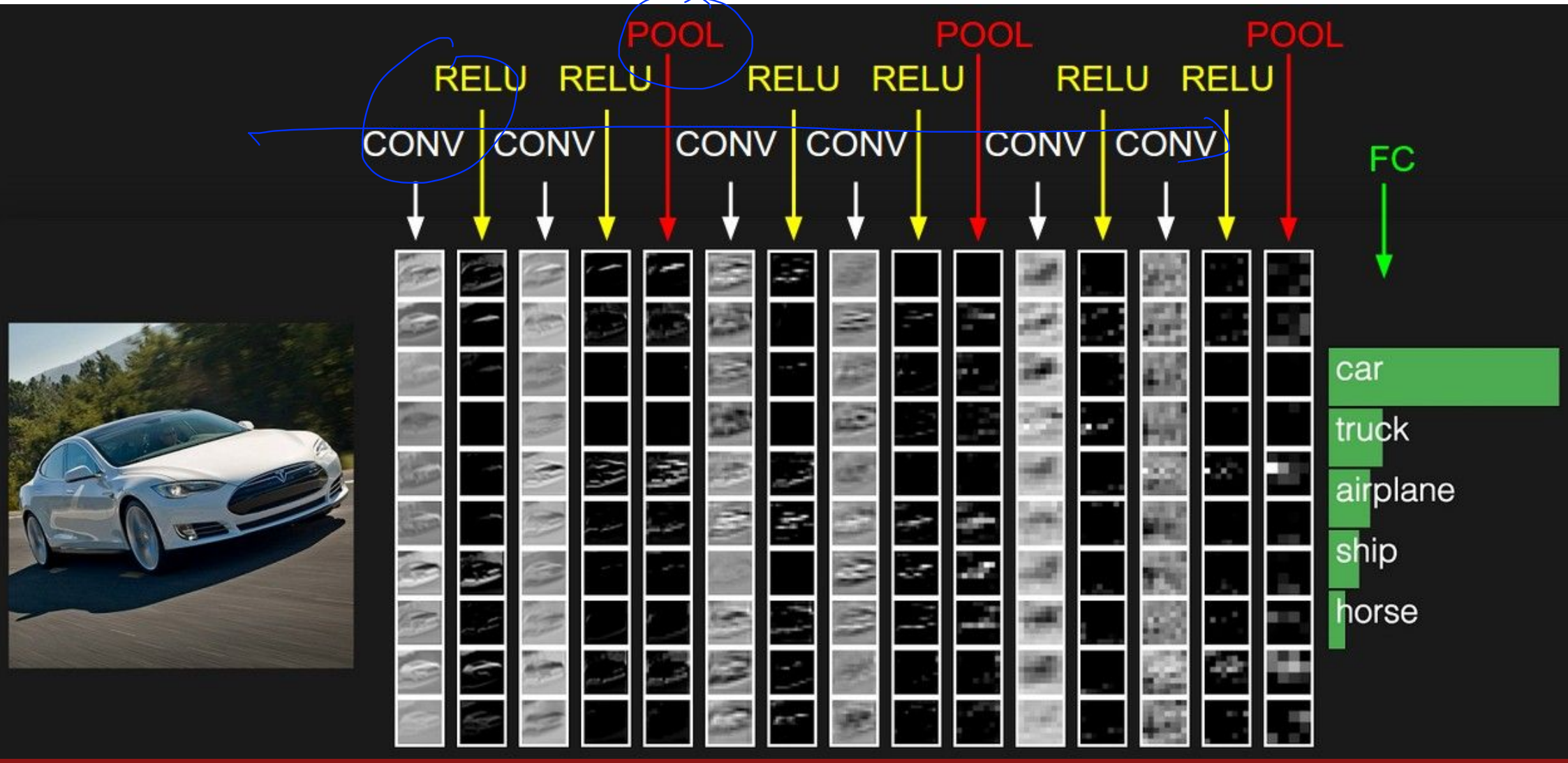
Preview

[From recent Yann LeCun slides]



Feature visualization of convolutional net trained on ImageNet from [Zeiler & Fergus 2013]

preview:


POOL
POOL
POOL
RELU
RELU
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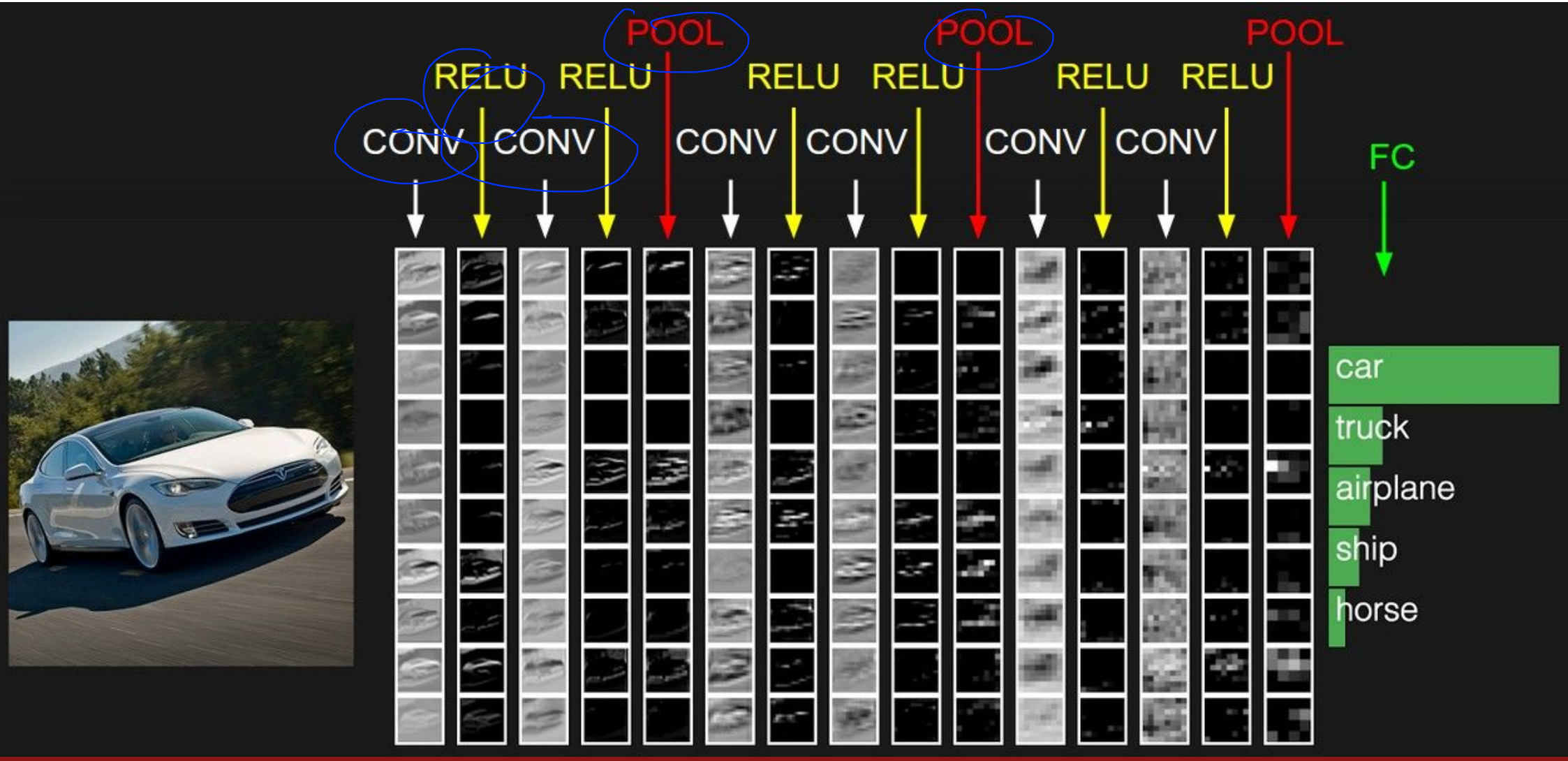
RELU
RELU
RELU
CONV
CONV
CONV
CONV
CONV
CONV
FC
car
truck
airplane
ship
horse

Lecture 11-2

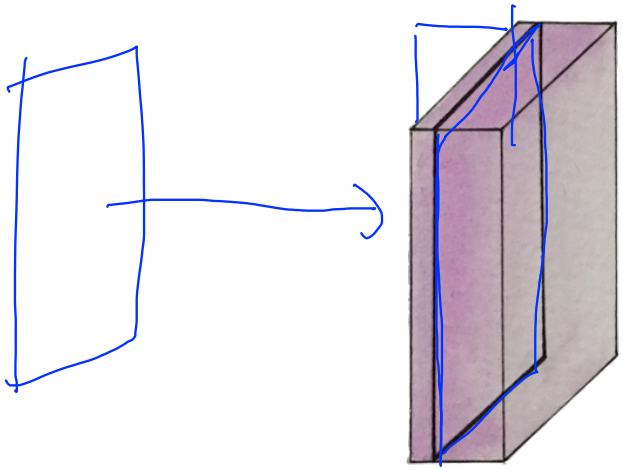
CNN introduction: Max pooling and others

Sung Kim <hunkim+mr@gmail.com>

preview:

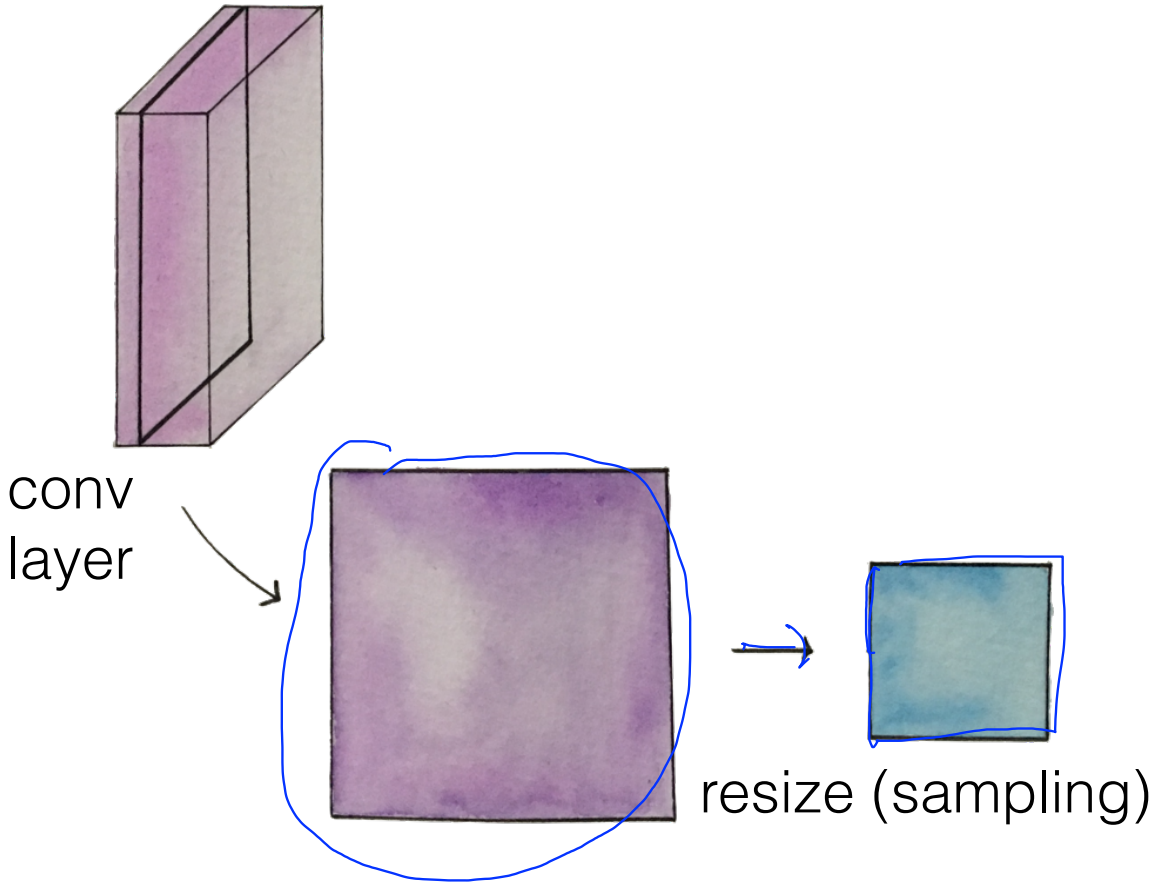

POOL
POOL
POOL
RELU
RELU
RELU
RELU
RELU
RELU
CONV
CONV
CONV
CONV
CONV
CONV
FC
car
truck
airplane
ship
horse

Pooling layer (sampling)

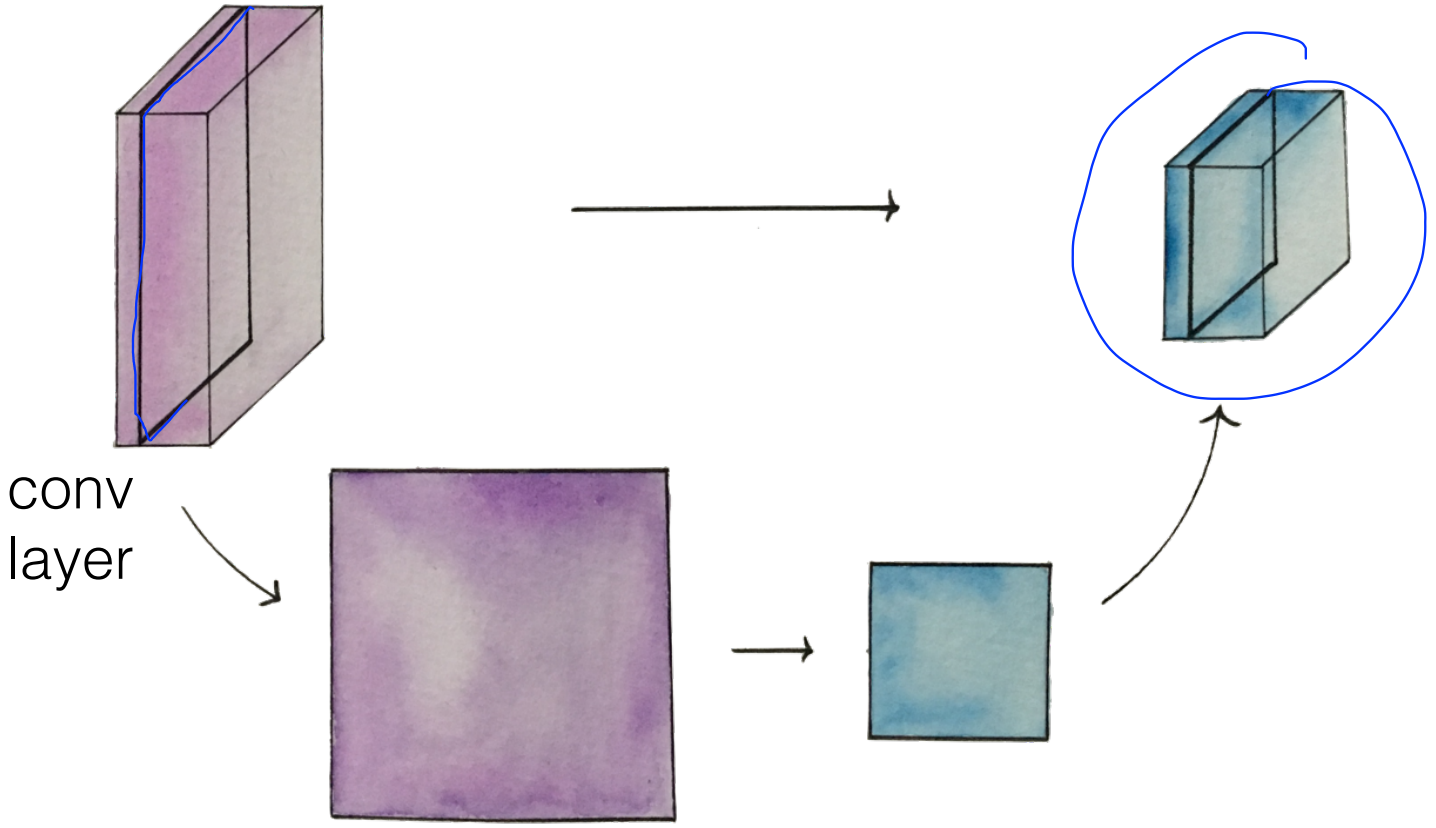


conv
layer

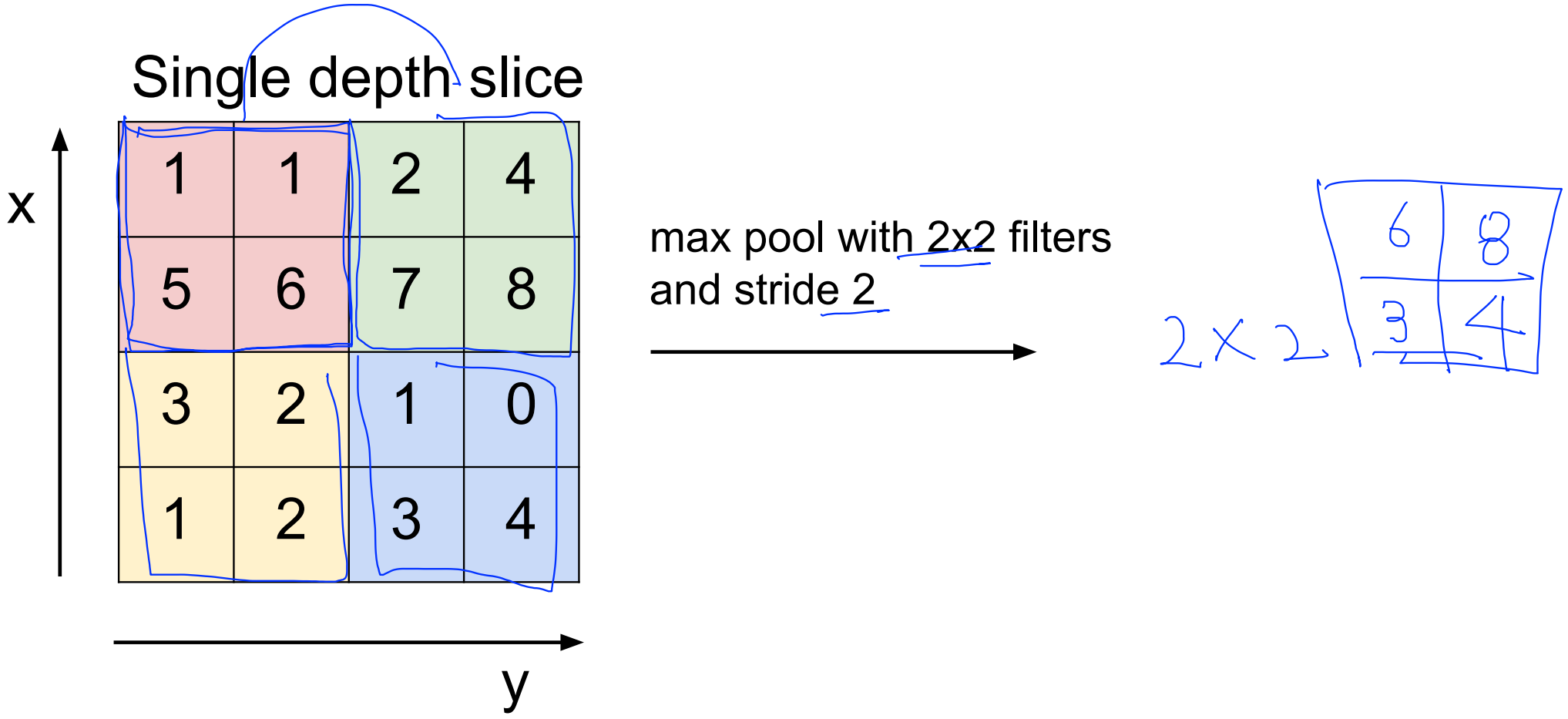
Pooling layer (sampling)



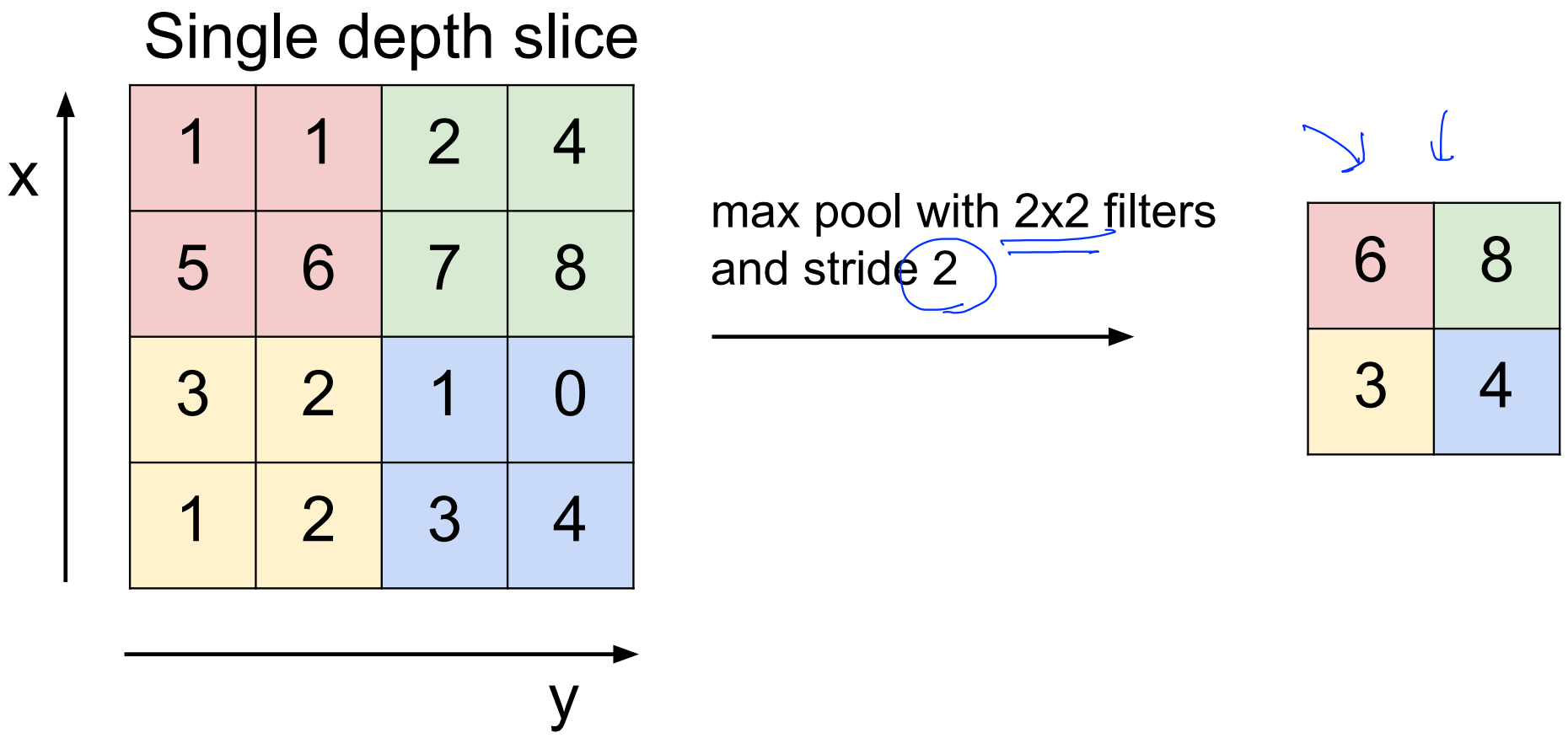
Pooling layer (sampling)



MAX POOLING

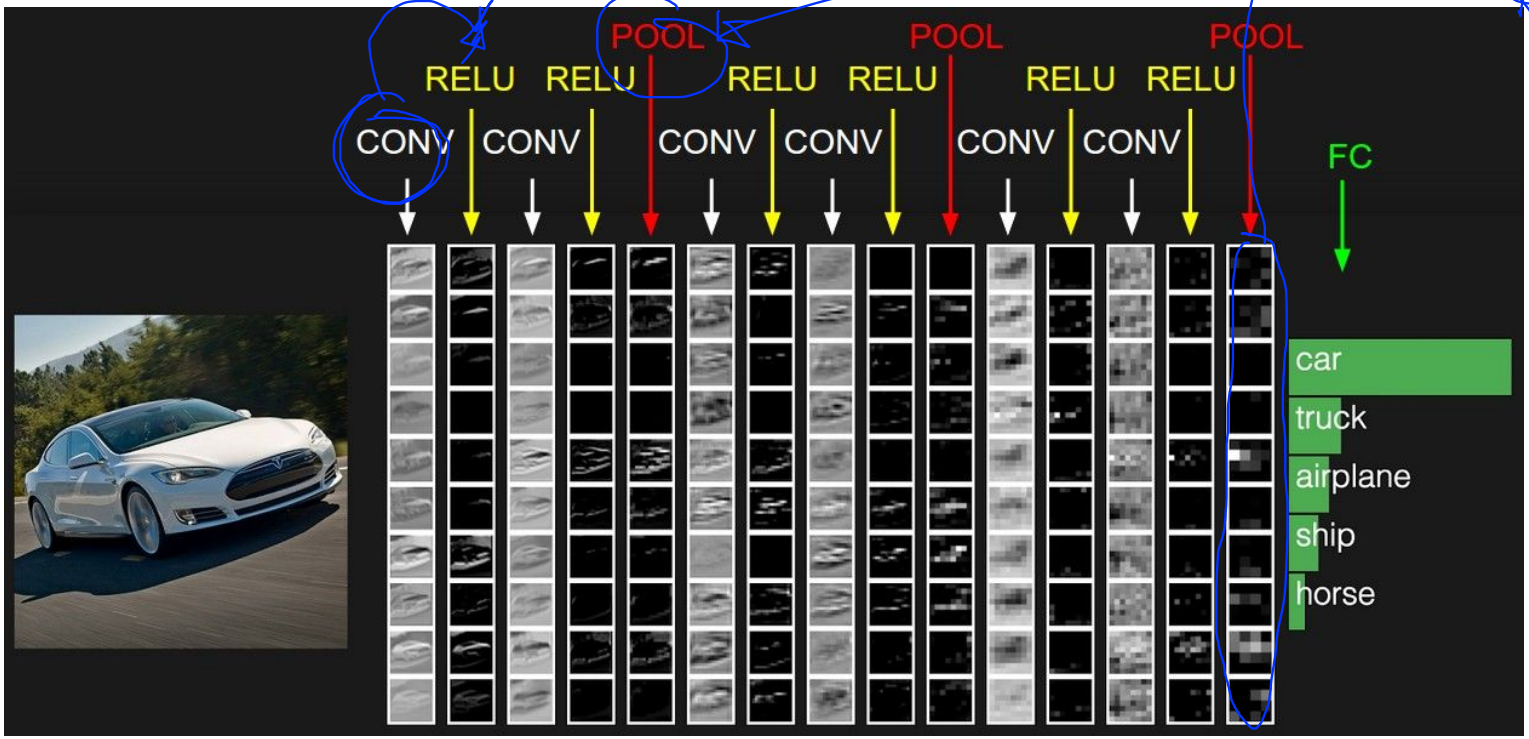

Single depth slice
x
y
1 1 2 4
5 6 7 8
3 2 1 0
1 2 3 4
max pool with 2x2 filters
and stride 2
6 8
3 4

MAX POOLING


Single depth slice
x
y
1 1 2 4
5 6 7 8
3 2 1 0
1 2 3 4
max pool with 2x2 filters
and stride 2
6 8
3 4

Fully Connected Layer (FC layer)

- Contains neurons that connect to the entire input volume, as in ordinary Neural Networks



[ConvNetJS demo: training on CIFAR-10]

http://cs.stanford.edu/people/karpathy/convnetjs/demo/cifar10.html

Lecture 11-3

CNN case study

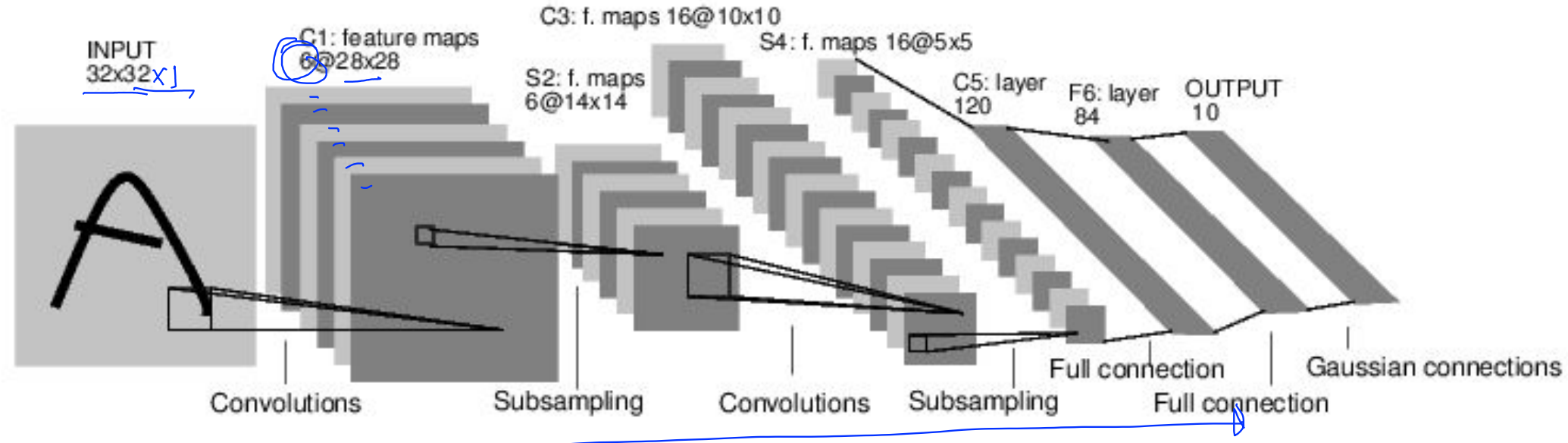
Sung Kim <hunkim+mr@gmail.com>
http://hunkim.github.io/ml/

Convolutional Neural Networks

http://cs231n.stanford.edu/

Case Study: LeNet-5

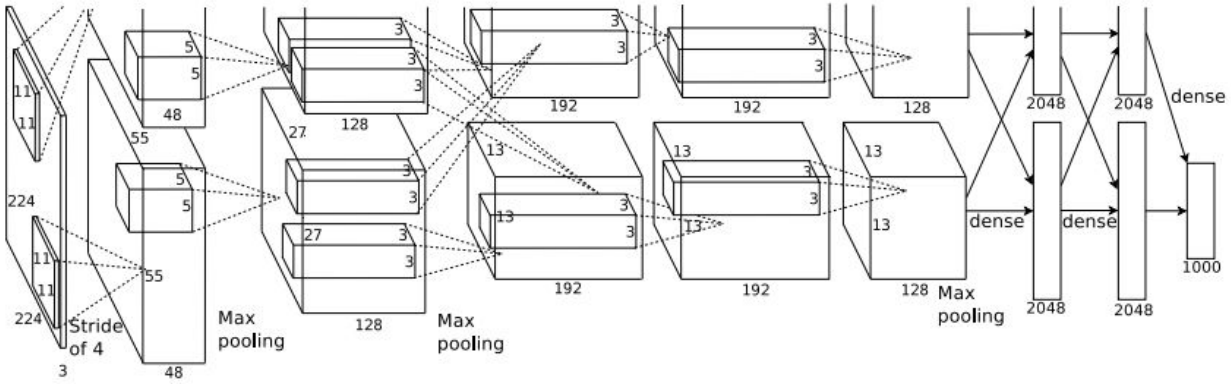
[LeCun et al., 1998]



Conv filters were 5x5, applied at stride 1
Subsampling (Pooling) layers were 2x2 applied at stride 2
i.e. architecture is [CONV-POOL-CONV-POOL-CONV-FC]

Case Study: AlexNet

[Krizhevsky et al. 2012]



Input: 227x227x3 images

First layer (CONV1): 96 11x11 filters applied at stride 4

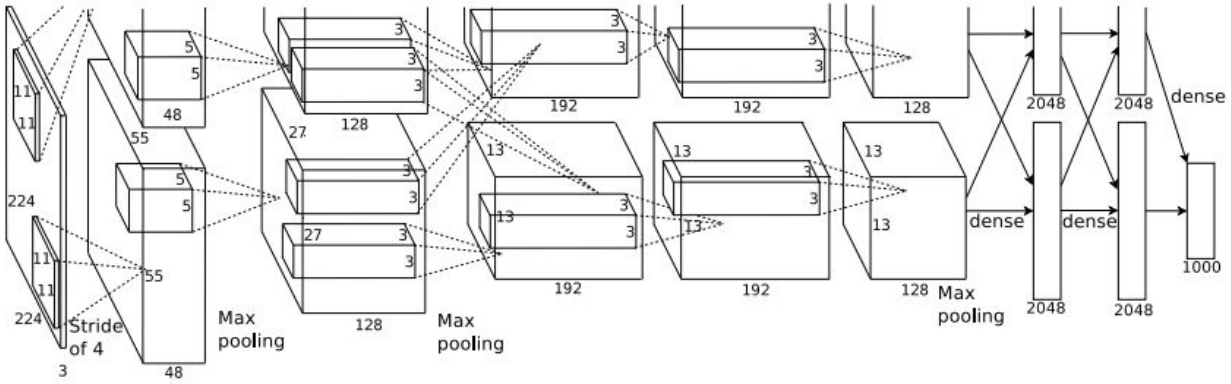
=>

Output volume **[55x55x96]**

Parameters: (11*11*3)*96 = **35K**

Case Study: AlexNet

[Krizhevsky et al. 2012]

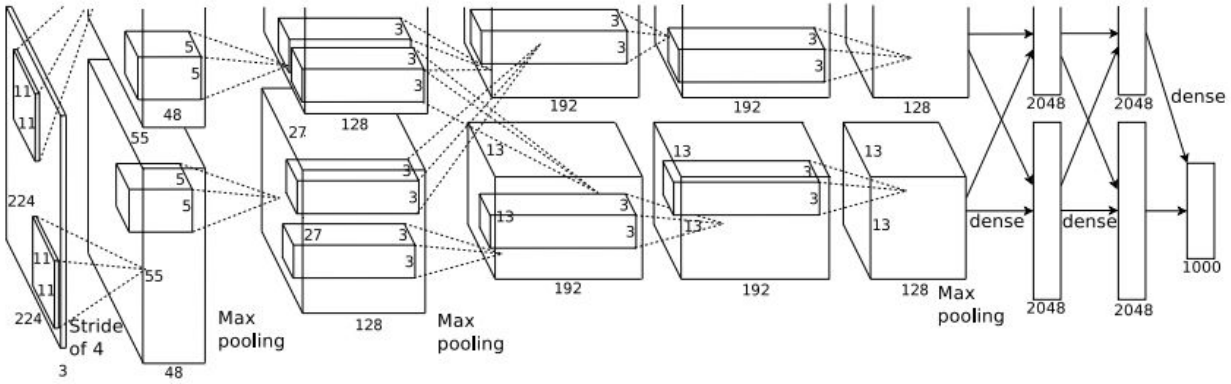


Input: 227x227x3 images
After CONV1: 55x55x96

Second layer (POOL1): 3x3 filters applied at stride 2
Output volume: 27x27x96
Parameters: 0!

Case Study: AlexNet

[Krizhevsky et al. 2012]



Input: 227x227x3 images
After CONV1: 55x55x96
After POOL1: 27x27x96
...

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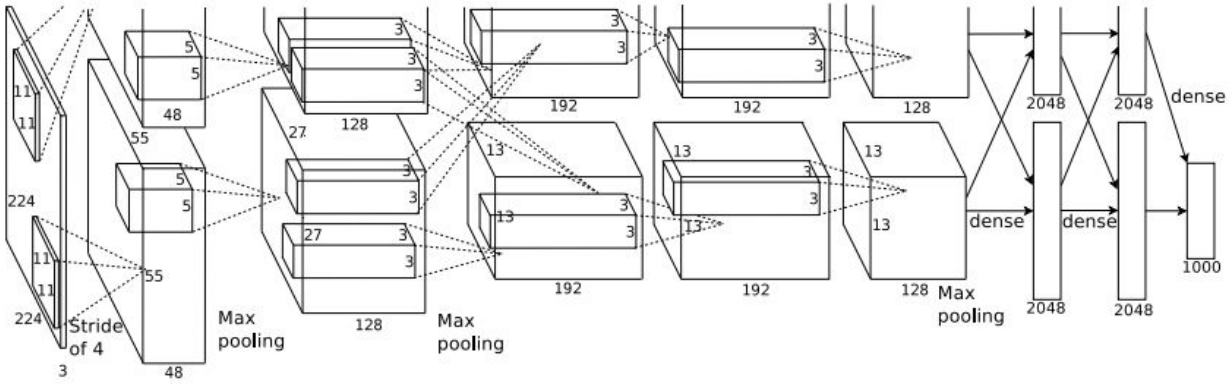
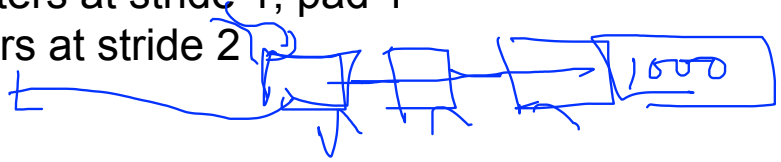


Full (simplified) AlexNet architecture:
[227x227x3] INPUT
[55x55x96] CONV1: 96 11x11 filters at stride 4, pad 0
[27x27x96] MAX POOL1: 3x3 filters at stride 2
[27x27x96] NORM1: Normalization layer
[27x27x256] CONV2: 256 5x5 filters at stride 1, pad 2
[13x13x256] MAX POOL2: 3x3 filters at stride 2
[13x13x256] NORM2: Normalization layer
[13x13x384] CONV3: 384 3x3 filters at stride 1, pad 1
[13x13x384] CONV4: 384 3x3 filters at stride 1, pad 1
[13x13x256] CONV5: 256 3x3 filters at stride 1, pad 1
[6x6x256] MAX POOL3: 3x3 filters at stride 2
[4096] FC6: 4096 neurons
[4096] FC7: 4096 neurons
[1000] FC8: 1000 neurons (class scores)



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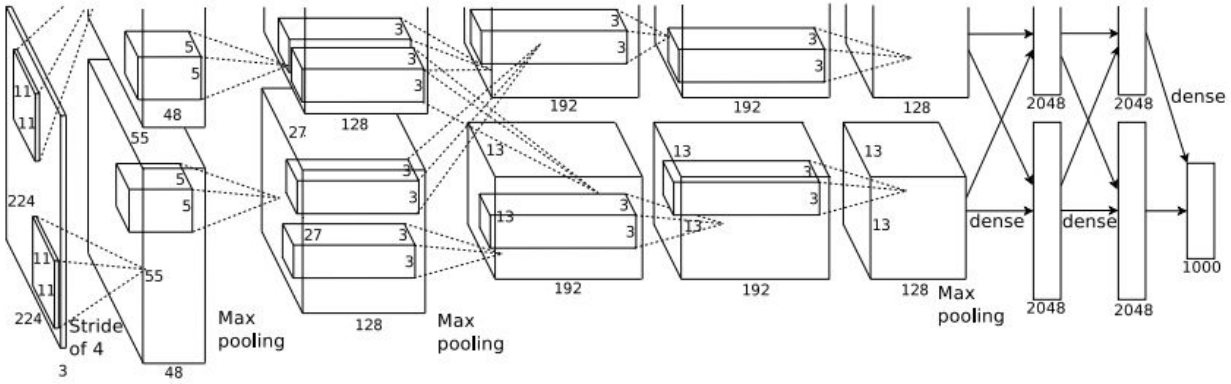

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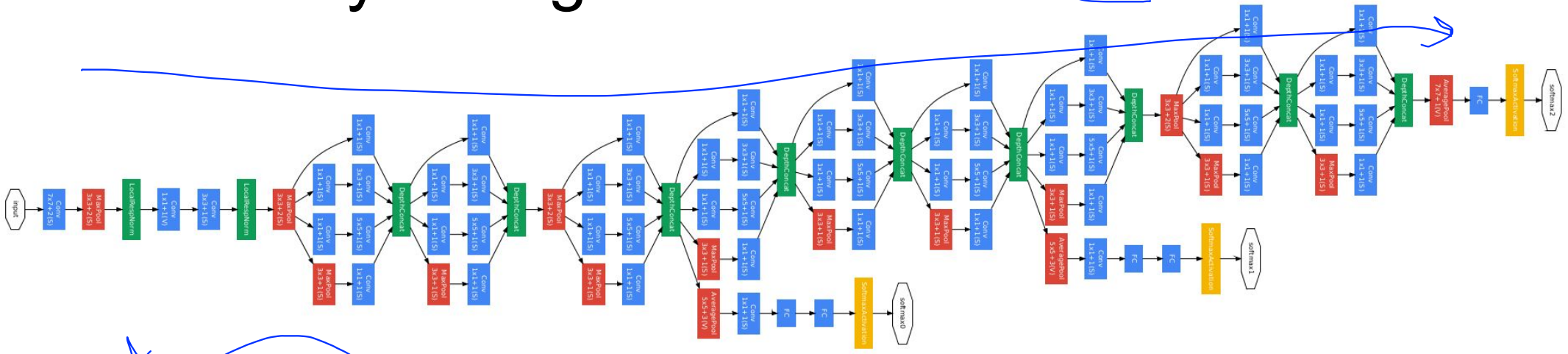
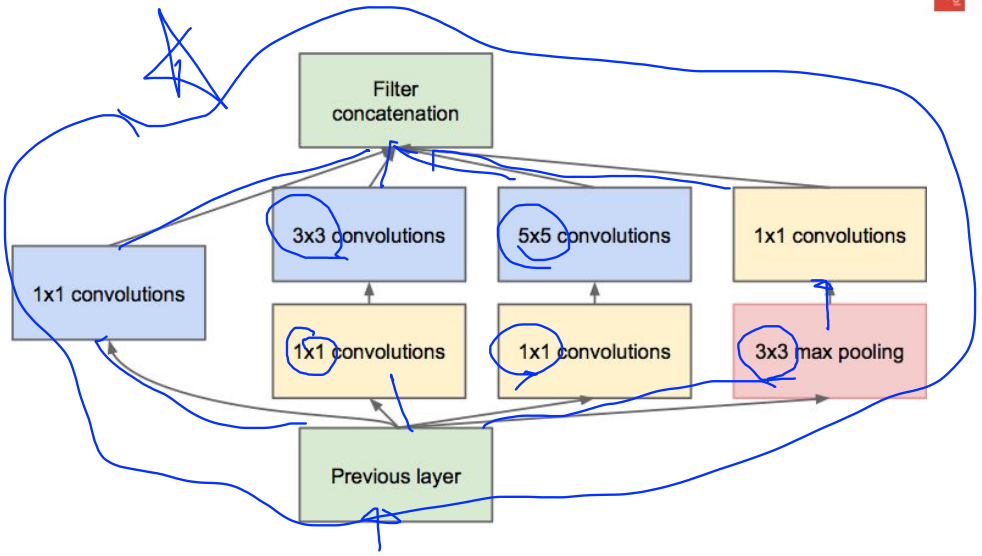
Details/Retrospectives:
- first use of ReLU
- used Norm layers (not common anymore)
- heavy data augmentation
- dropout 0.5
- batch size 128
- SGD Momentum 0.9
- Learning rate 1e-2, reduced by 10 manually when val accuracy plateaus
- L2 weight decay 5e-4
- 7 CNN ensemble: 18.2% -> 15.4%

Case Study: GoogLeNet

[Szegedy et al., 2014]



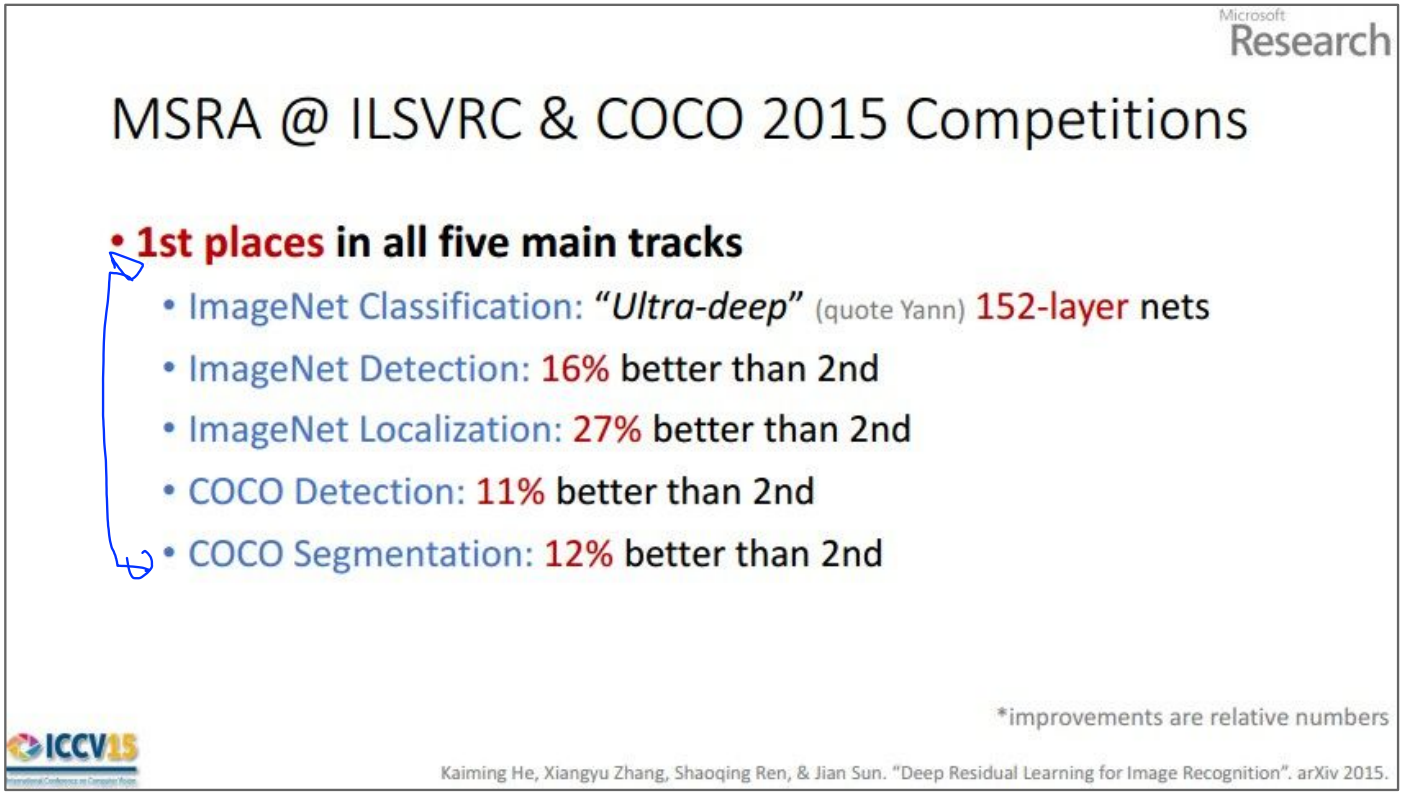


Inception module

ILSVRC 2014 winner (6.7% top 5 error)

Case Study: ResNet [He et al., 2015]

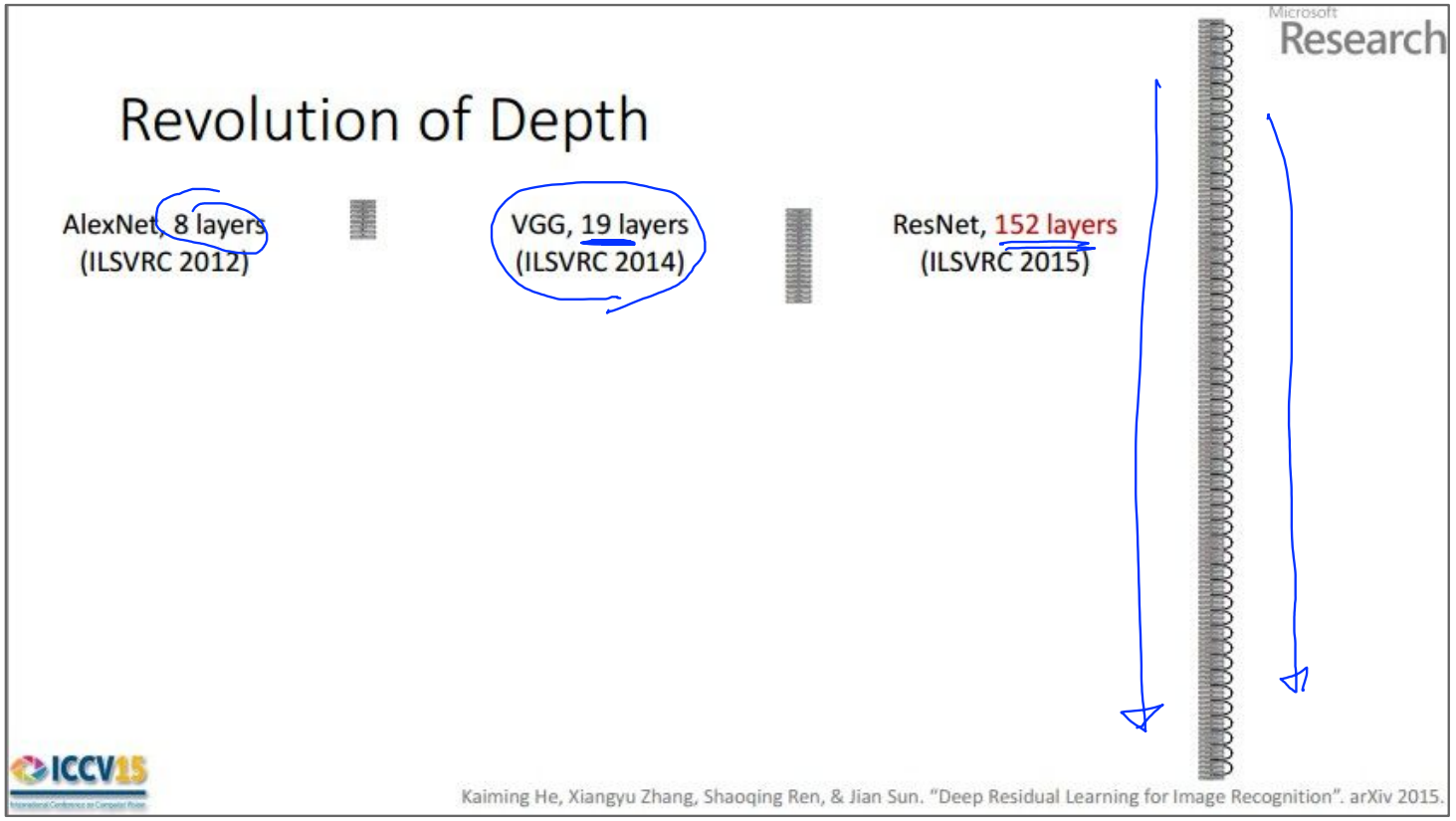
ILSVRC 2015 winner (3.6% top 5 error)



Slide from Kaiming He's recent presentation https://www.youtube.com/watch?v=1PGLj-uKT1w

Case Study: ResNet *[He et al., 2015]*

ILSVRC 2015 winner (3.6% top 5 error)



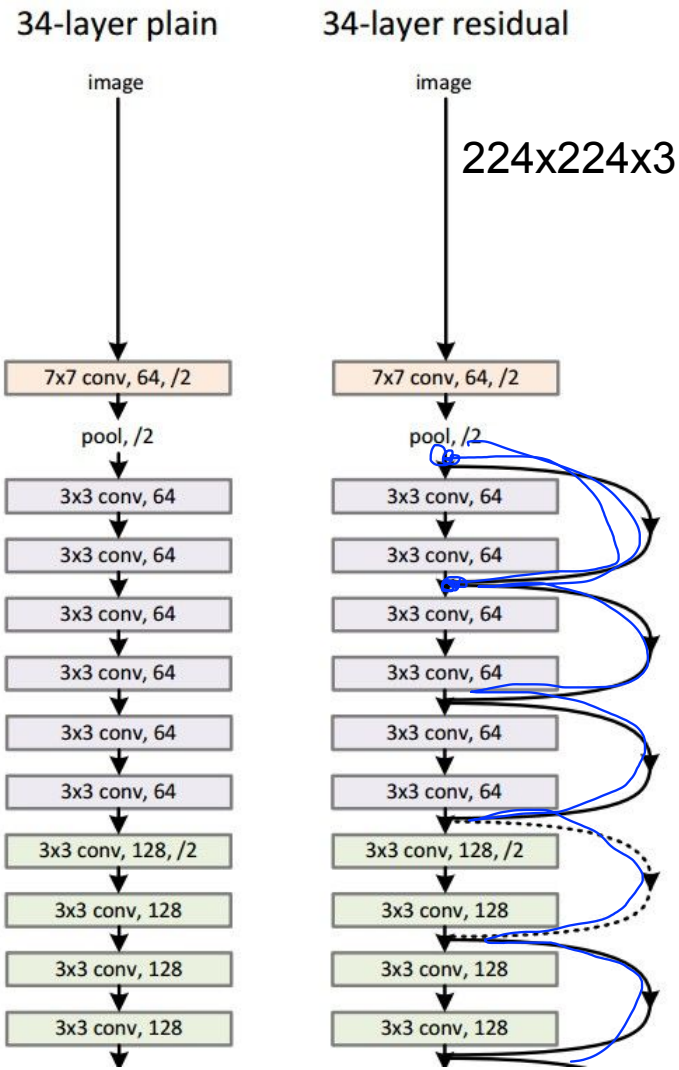
2-3 weeks of training on 8 GPU machine

at runtime: faster than a VGGNet! (even though it has 8x more layers)

(slide from Kaiming He's recent presentation)

Case Study: ResNet

[He et al., 2015]



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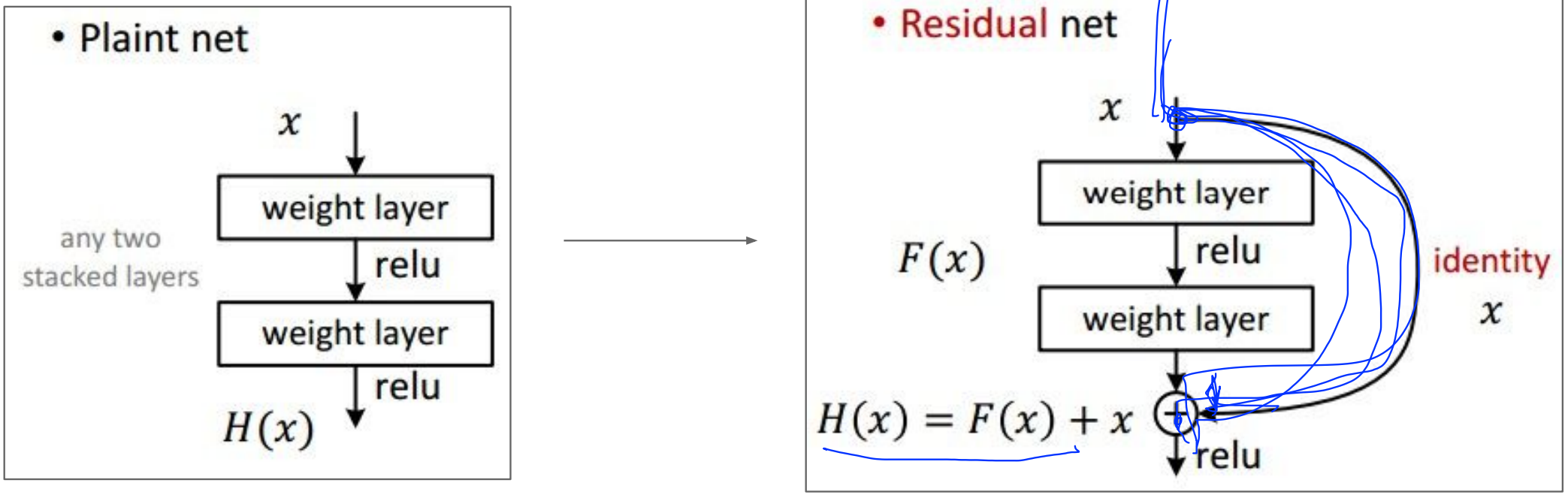
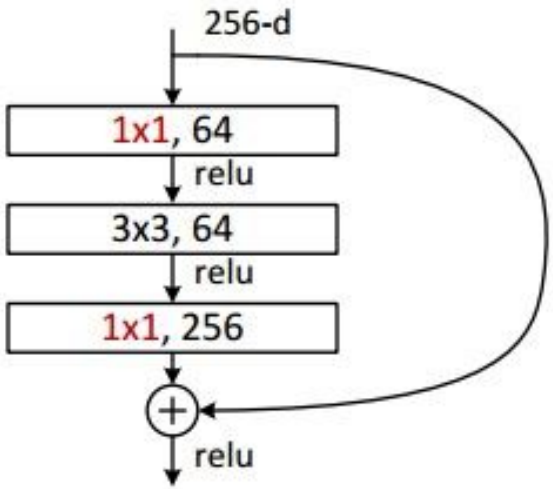
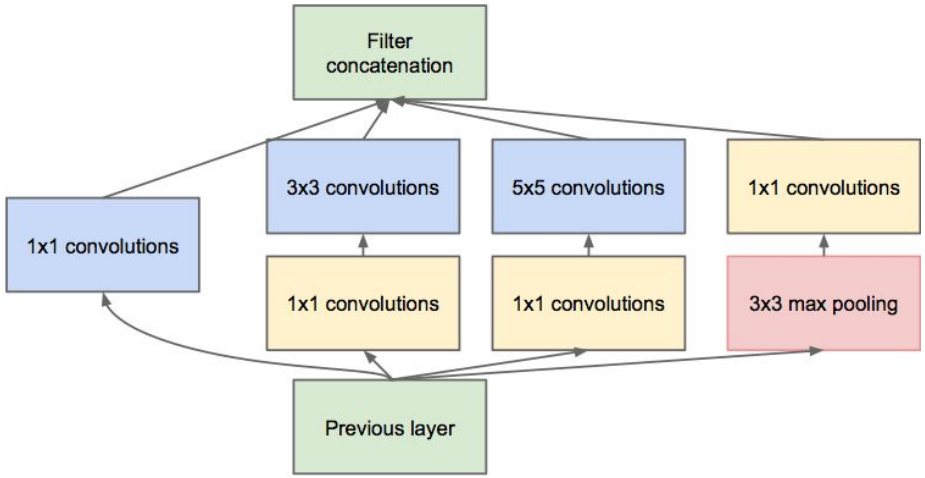


Case Study: ResNet *[He et al., 2015]*





Convolutional Neural Networks for Sentence Classification

[Yoon Kim, 2014]

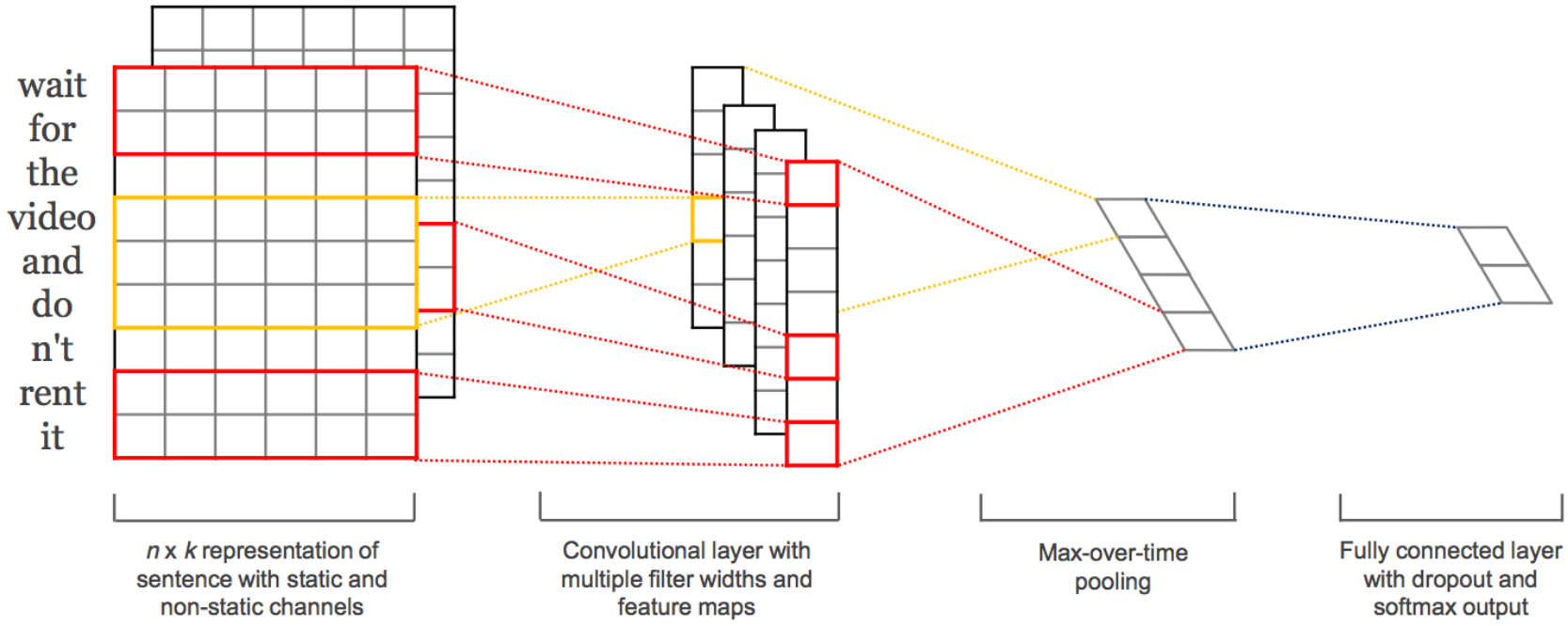
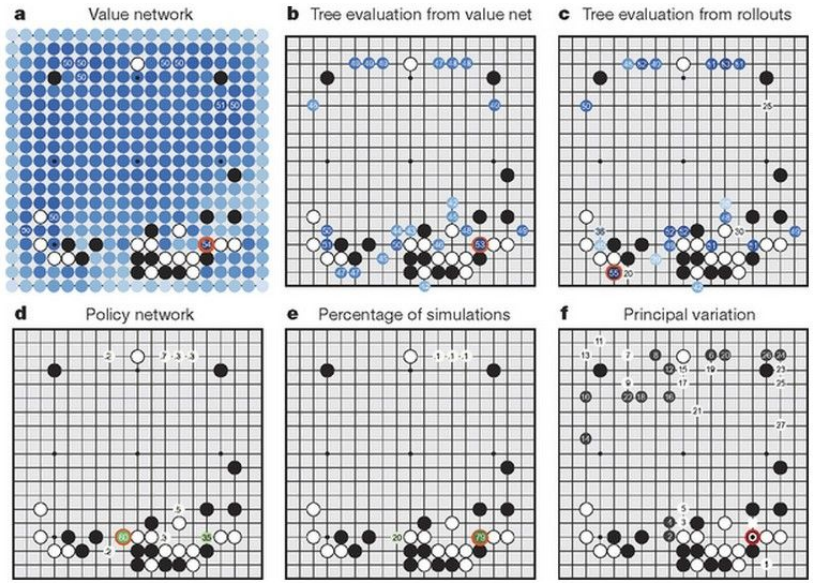


Figure 1: Model architecture with two channels for an example sentence.

Case Study Bonus: DeepMind's AlphaGo



The input to the policy network is a 19 × 19 × 48 image stack consisting of 48 feature planes. The first hidden layer zero pads the input into a 23 × 23 image, then convolves *k* filters of kernel size 5 × 5 with stride 1 with the input image and applies a rectifier nonlinearity. Each of the subsequent hidden layers 2 to 12 zero pads the respective previous hidden layer into a 21 × 21 image, then convolves *k* filters of kernel size 3 × 3 with stride 1, again followed by a rectifier nonlinearity. The final layer convolves 1 filter of kernel size 1 × 1 with stride 1, with a different bias for each position, and applies a softmax function. The match version of AlphaGo used $k = 192$ filters; Fig. 2b and Extended Data Table 3 additionally show the results of training with $k = 128$, 256 and 384 filters.

policy network:

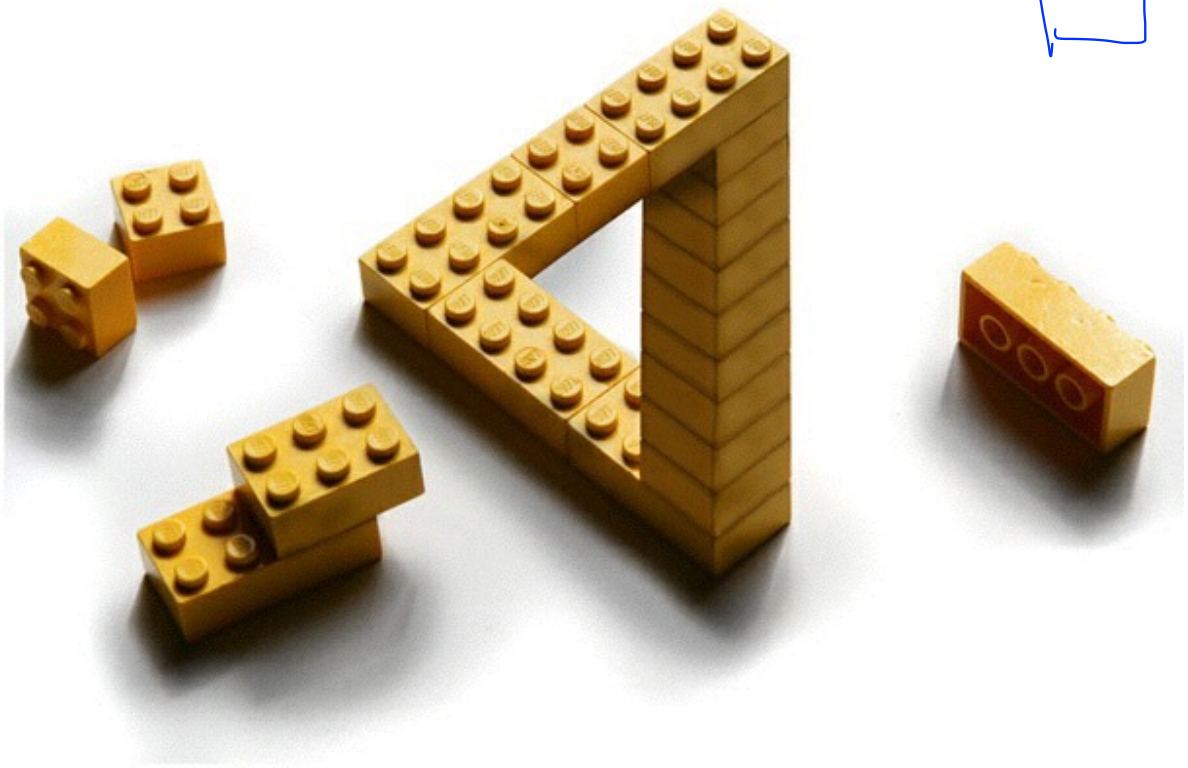
[19x19x48] Input

CONV1: 192 5x5 filters , stride 1, pad 2 => [19x19x192]

CONV2..12: 192 3x3 filters, stride 1, pad 1 => [19x19x192]

CONV: 1 1x1 filter, stride 1, pad 0 => [19x19] *(probability map of promising moves)*

'The only limit is your imagination'



http://itchyi.squarespace.com/thelatest/2012/5/17/the-only-limit-is-your-imagination.html

Next

Recurrent
Neural Nets (RNN)