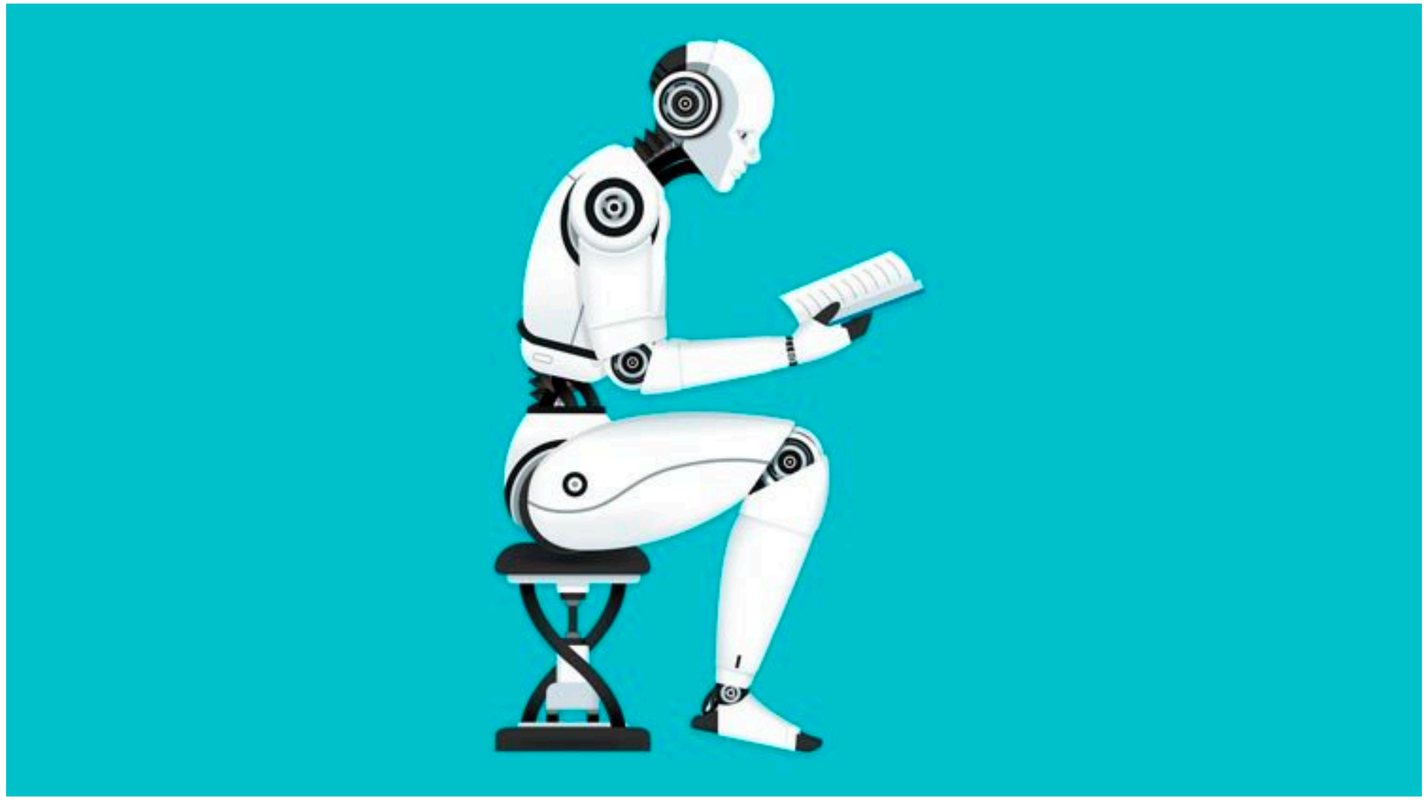
UNIVERSITAT DE BARCELONA



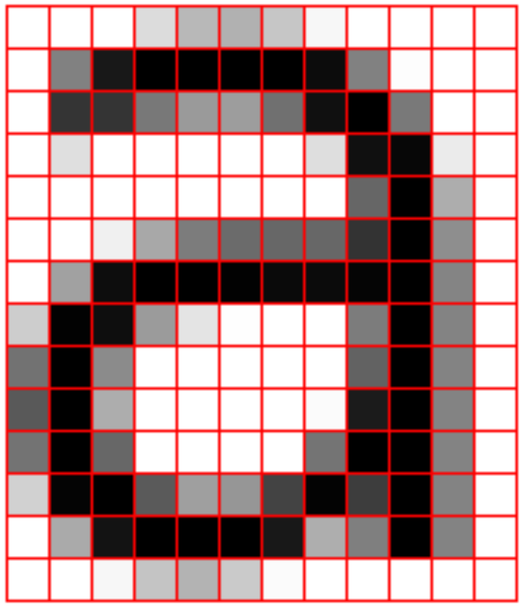
Neural Networks

Machine Learning | Enginyeria Informàtica

Santi Seguí | 2021-2022

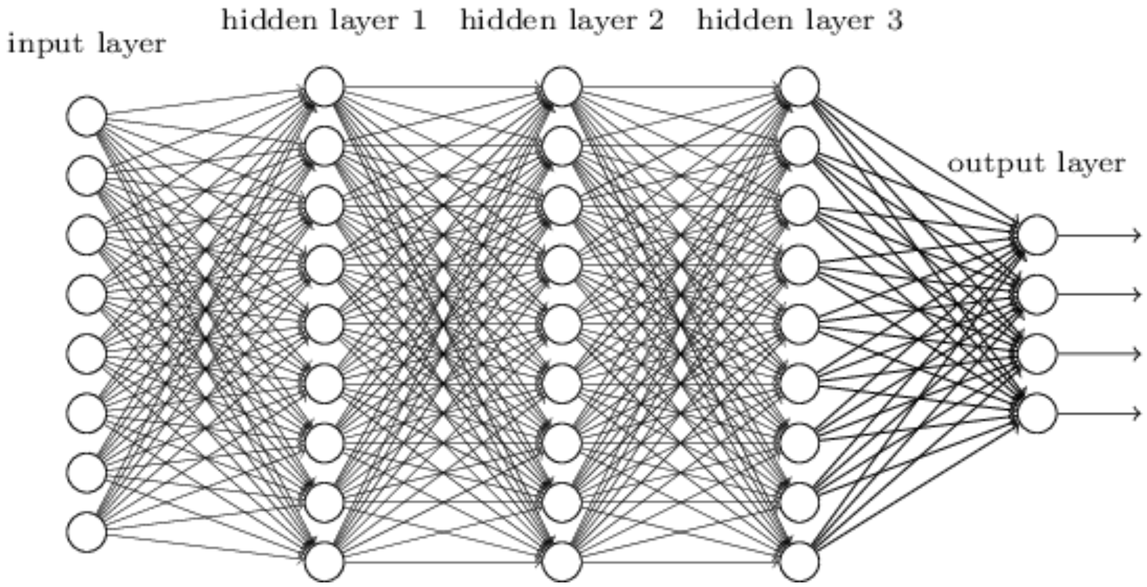
Neural Networks for Images?

An image is a matrix of size **mxnxc** pixels



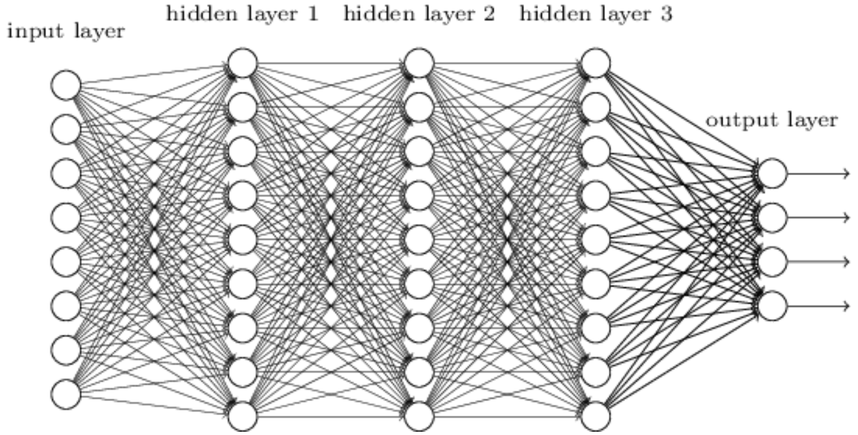
1.0	1.0	1.0	0.9	0.6	0.6	0.6	1.0	1.0	1.0	1.0	1.0
1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	1.0	1.0
1.0	0.2	0.2	0.5	0.6	0.6	0.5	0.0	0.0	0.5	1.0	1.0
1.0	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.0	0.0	0.9	1.0
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0
1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.4	0.0	0.5	1.0
1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0
0.9	0.0	0.0	0.6	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0
0.5	0.0	0.6	1.0	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0
0.5	0.0	0.7	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.5	1.0
0.6	0.0	0.6	1.0	1.0	1.0	1.0	0.5	0.0	0.0	0.5	1.0
0.9	0.1	0.0	0.6	0.7	0.7	0.5	0.0	0.5	0.0	0.5	1.0
1.0	0.7	0.1	0.0	0.0	0.0	0.1	0.9	0.8	0.0	0.5	1.0
1.0	1.0	1.0	0.8	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0

Neural Networks for Images?

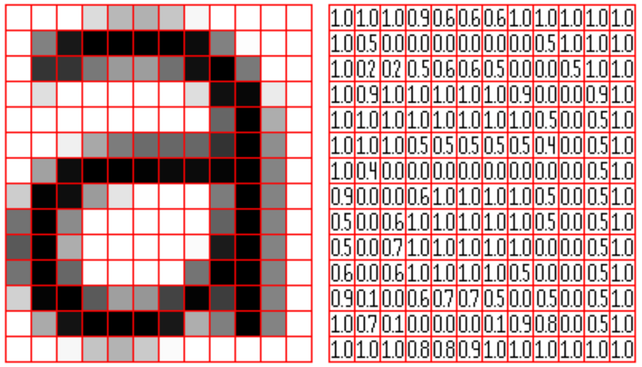


How many parameter does this MLP has?

Neural Networks for Images?



What happens if your data is an image like this one?



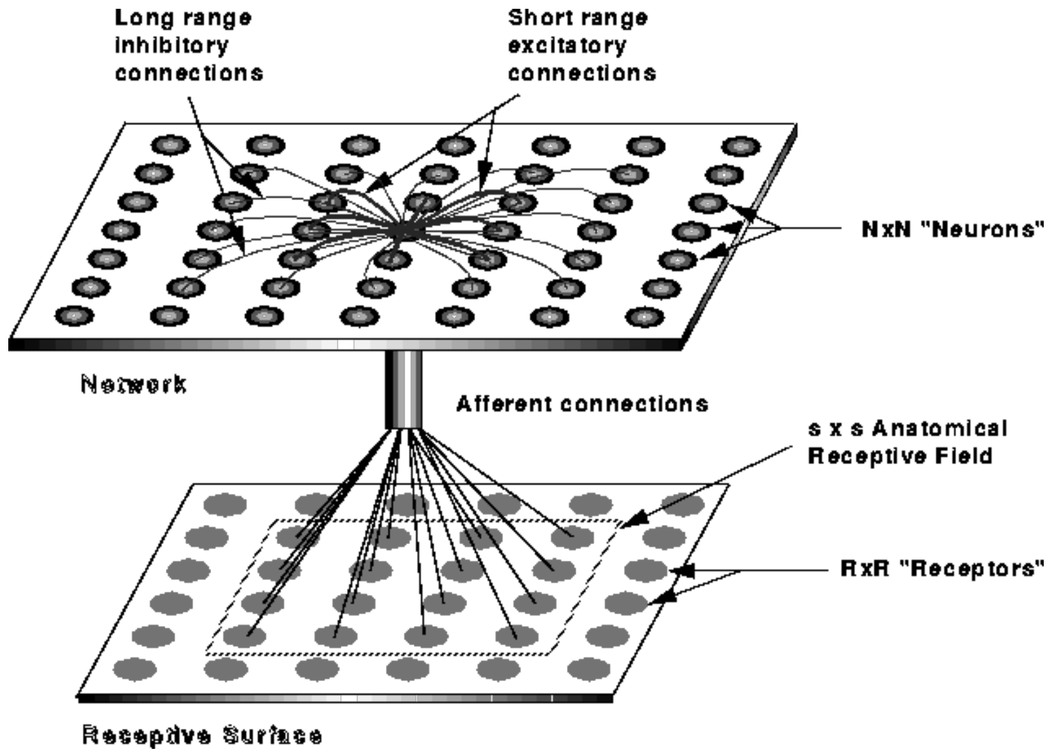
1.0	1.0	1.0	0.9	0.6	0.6	0.6	1.0	1.0	1.0	1.0	1.0			
1.0	0.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0	1.0	1.0		
1.0	0.2	0.2	0.5	0.6	0.6	0.5	0.0	0.0	0.0	0.5	1.0	1.0		
1.0	0.9	1.0	1.0	1.0	1.0	1.0	0.9	0.0	0.0	0.0	0.9	1.0		
1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0			
1.0	1.0	1.0	0.5	0.5	0.5	0.5	0.5	0.4	0.0	0.5	1.0			
1.0	0.4	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.5	1.0			
0.9	0.0	0.0	0.6	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0			
0.5	0.0	0.6	1.0	1.0	1.0	1.0	1.0	0.5	0.0	0.5	1.0			
0.5	0.0	0.7	1.0	1.0	1.0	1.0	1.0	0.0	0.0	0.5	1.0			
0.6	0.0	0.6	1.0	1.0	1.0	1.0	0.5	0.0	0.0	0.5	1.0			
0.9	0.1	0.0	0.6	0.7	0.7	0.5	0.0	0.5	0.0	0.5	1.0			
1.0	0.7	0.1	0.0	0.0	0.0	0.1	0.9	0.8	0.0	0.5	1.0			
1.0	1.0	1.0	0.8	0.8	0.9	1.0	1.0	1.0	1.0	1.0	1.0			

Neural Networks for Images?

Neural Networks for Images

- Input is a standard vector of size N x M x C
  - Imagine an medium resolution color image of 256x256 pixels
  - If we think on a Multi Layer Perceptron with just one hidden layer of 256 neurons + an output layer of 1 neuron it will have more than **48 million** parameters.
    - **Does it make sense? Can we do it better?**

Local Receptive Fields



David Hunter Hubel and Torsten Nils Wiesel, 1968

But, in an image:

A dog can appear **anywhere** in the image!

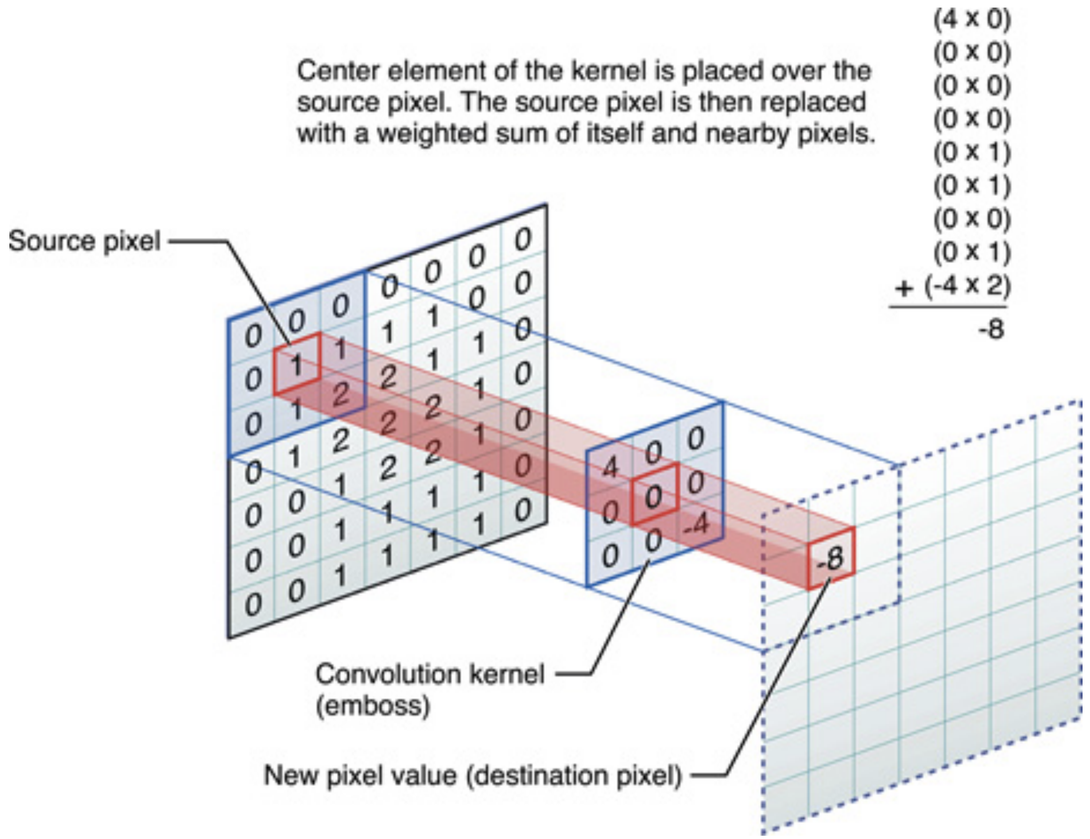
Doesn’t matter where they appear,
they look similar anywhere!

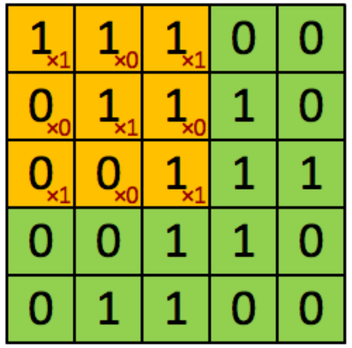
Convolutional Neural Networks (CNNs)

- Three main ideas:

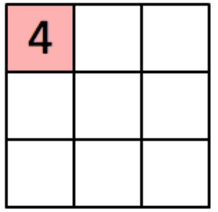
    1. **local receptive fields**,
    2. **shared weights**,
    3. **sub-sampling**

What is an image convolution?





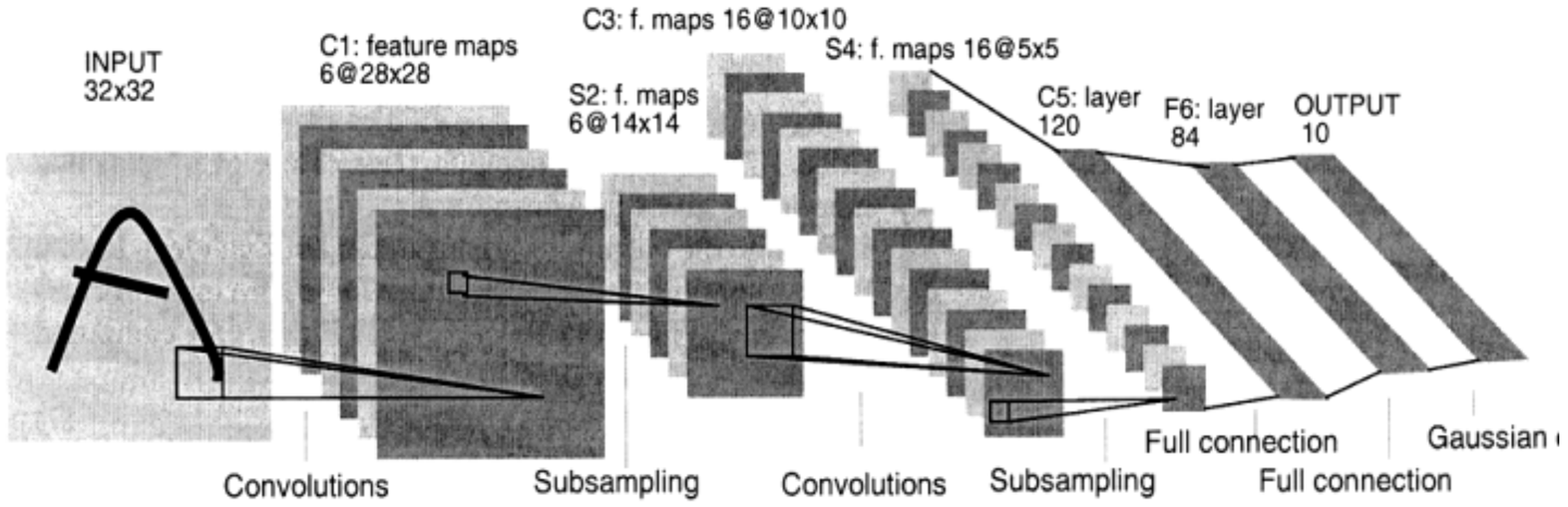
Image



Convolved Feature

What is an image convolution?

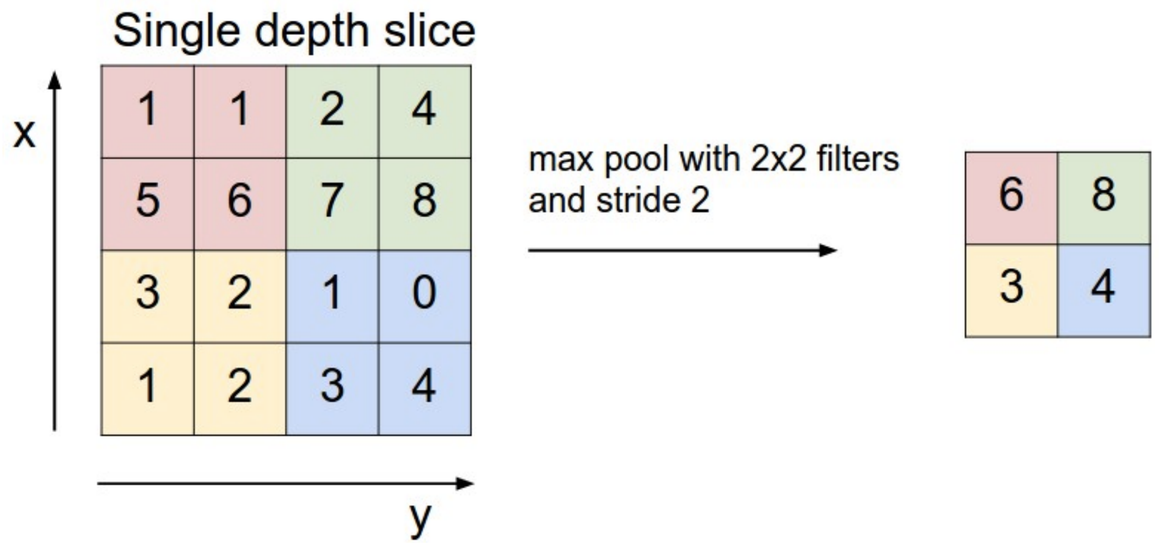
"Nothing New"



LeCun et al. 1998

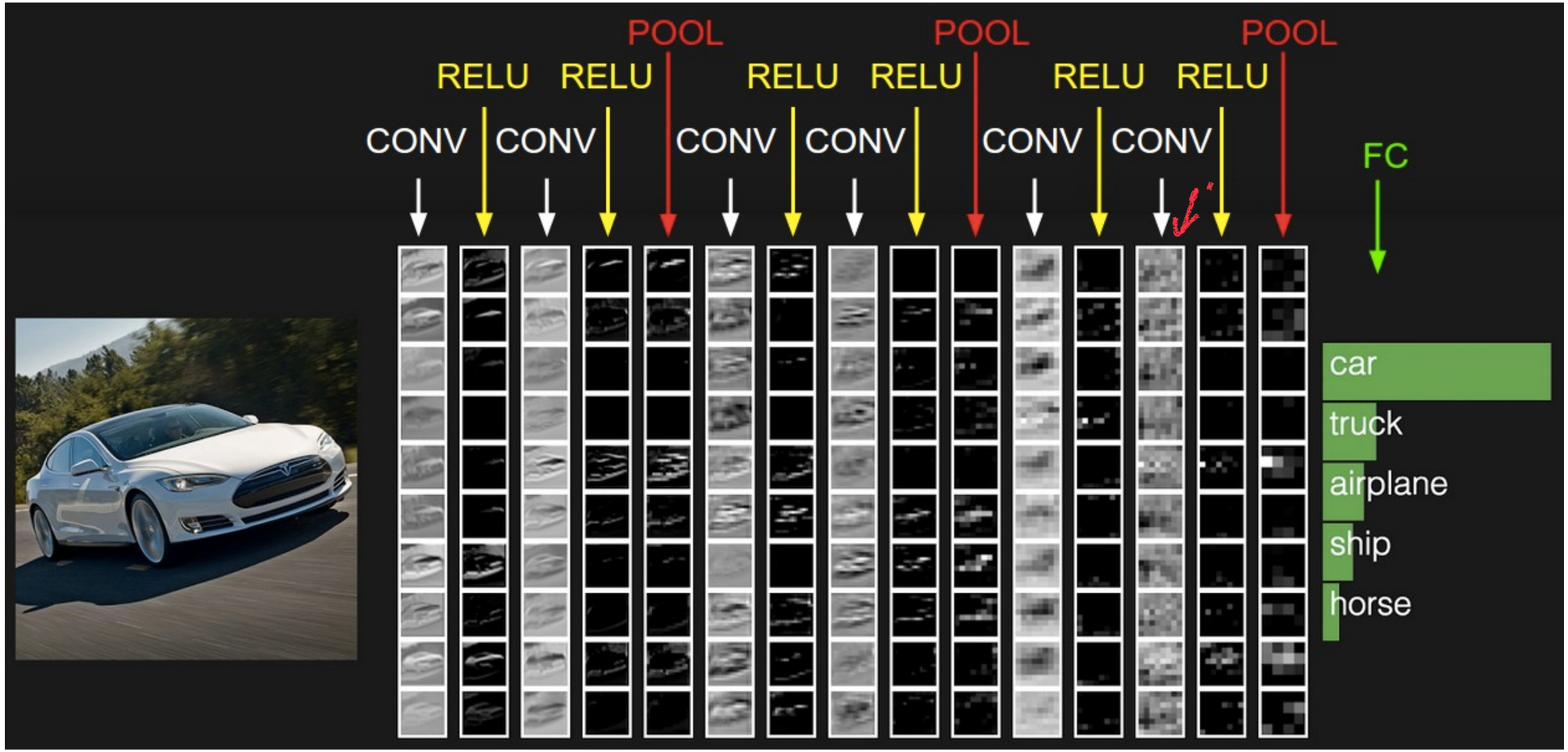
Max pooling

Pooling is a way of sub-sampling, i.e. reducing the dimension of the input (or at some hidden layer).
It is usually done after some of the convolutional layers



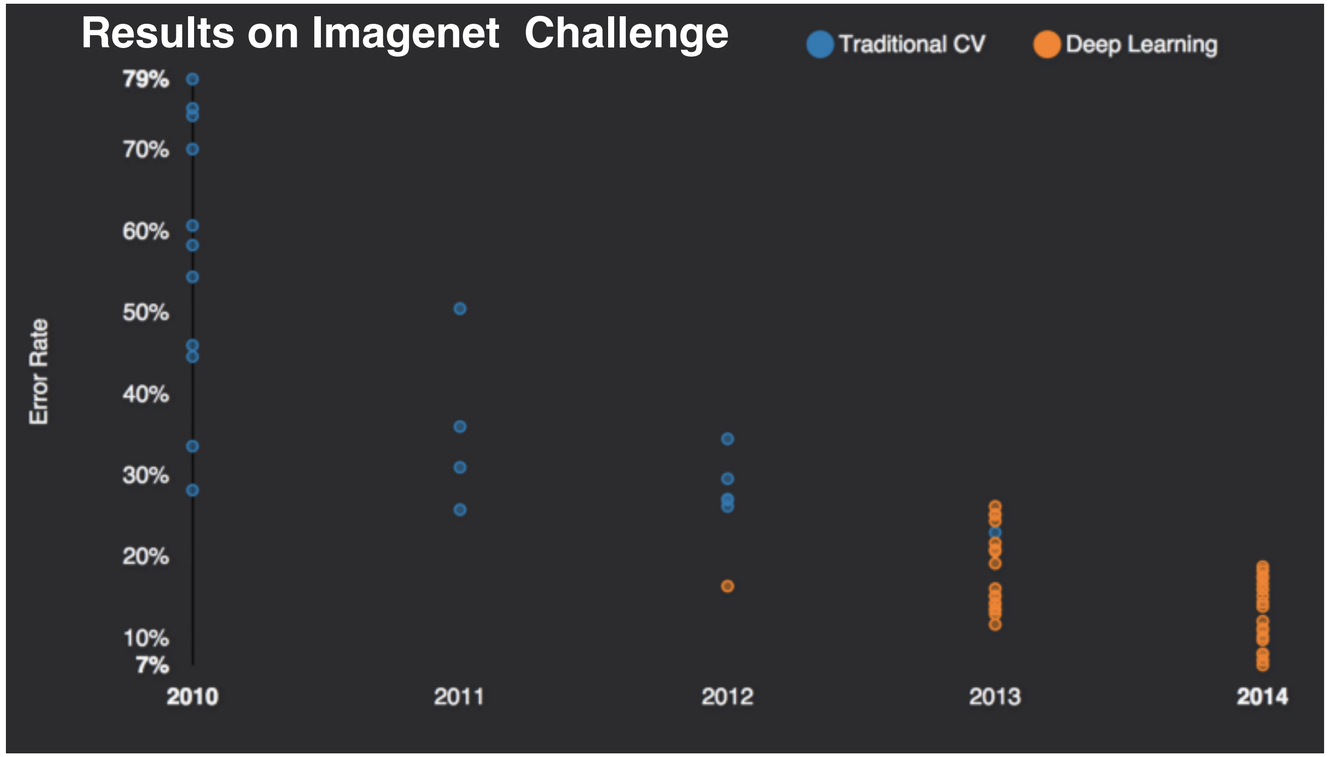
But it is also useful since it provides a form of translation **invariance**

Finally..


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

Convolutional Neural Networks (CNNs)

In computer Vision the breakthrough resulted in 2011 when Ciresan et.al introduced an algorithm to train these networks by using graphical cards (GPUs)



AlexNet

Similar framework to LeCun'98 but:

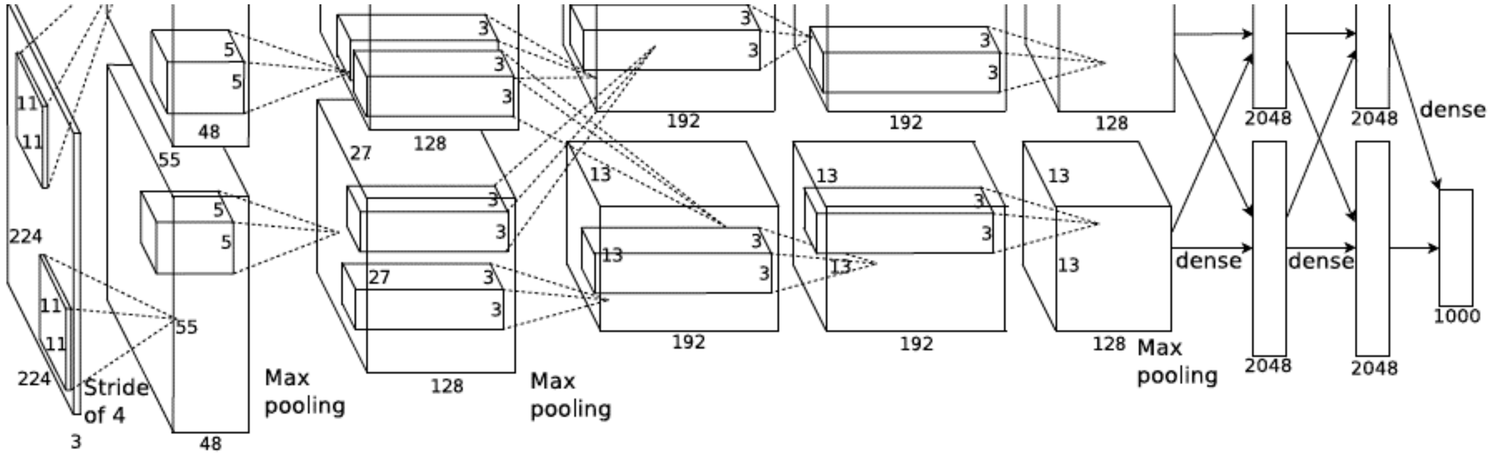
Bigger model:

7 hidden layers, 650.000 units, 60 million parameter

More Data:

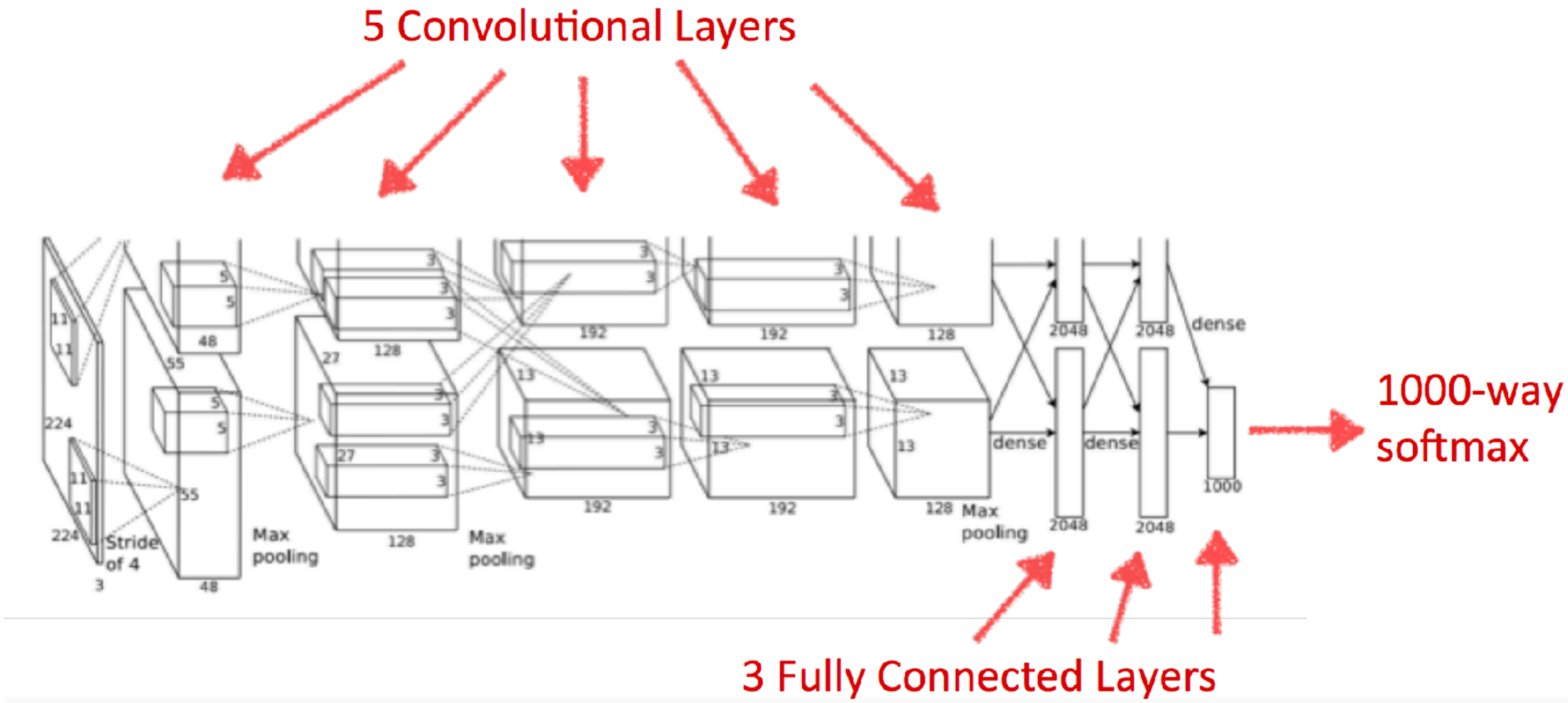
10^6 vs 10^3 images

GPU implementation (50x speedup over CPU)

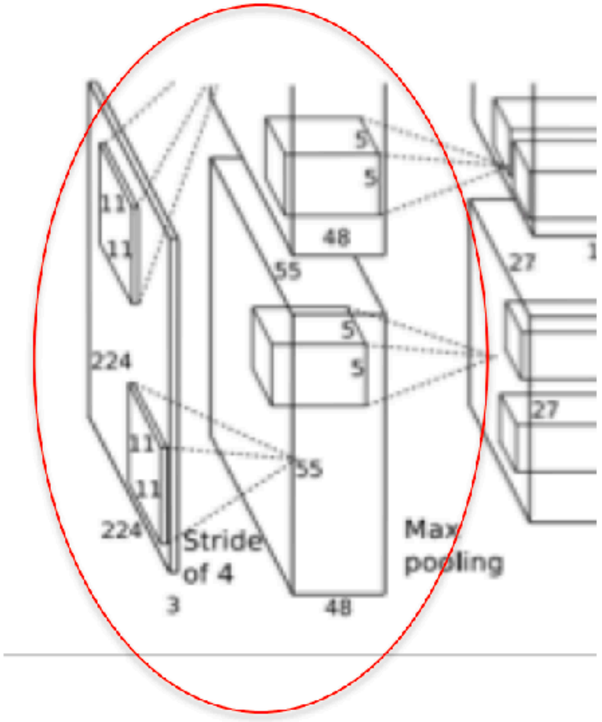


ImageNet Classification with Deep Convolutional Neural Networks. Alex Krizhevsky, Ilya Sutskever, Geoffrey E. Hinton

AlexNet

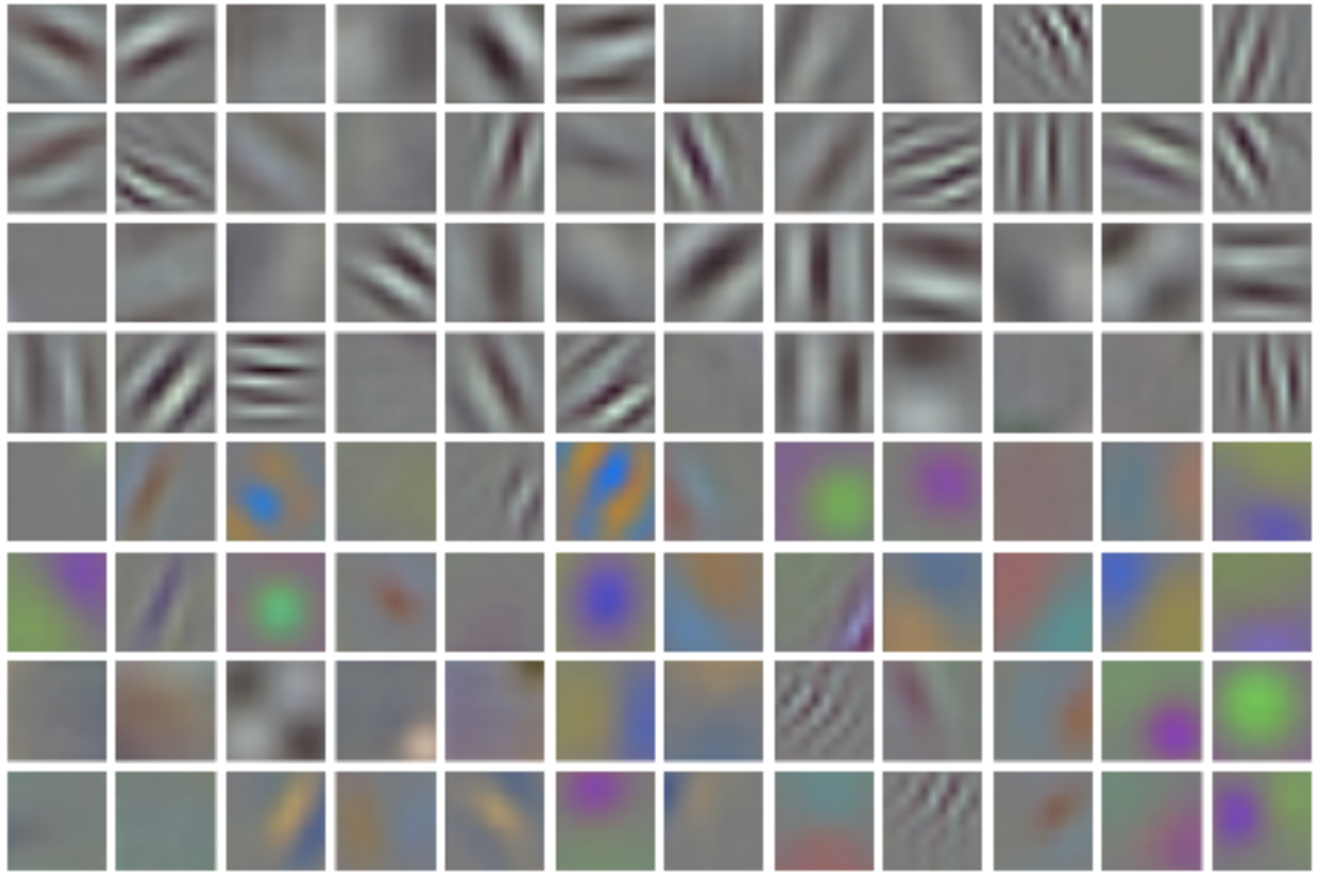

5 Convolutional Layers
1000-way softmax
3 Fully Connected Layers
Stride of 4
Max pooling
Max pooling
Max pooling
dense
dense
dense
2048
2048
2048
2048
1000
224
55
27
13
48
128
192
3

AlexNet
1st Convolution Layer

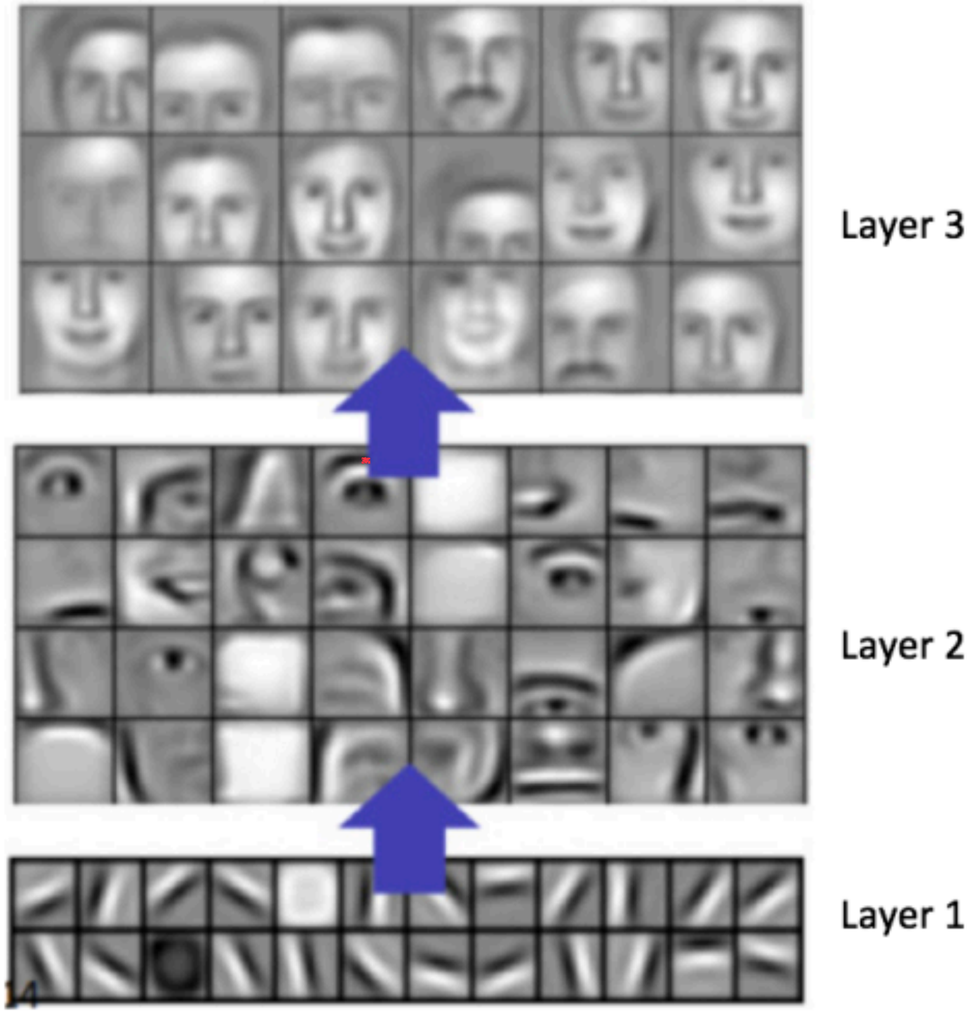


- Images: 227x227x3
- F (receptive field size): 11
- S (stride) = 4
- Conv layer output: 55x55x96

Alexnet 1st Conv Filters

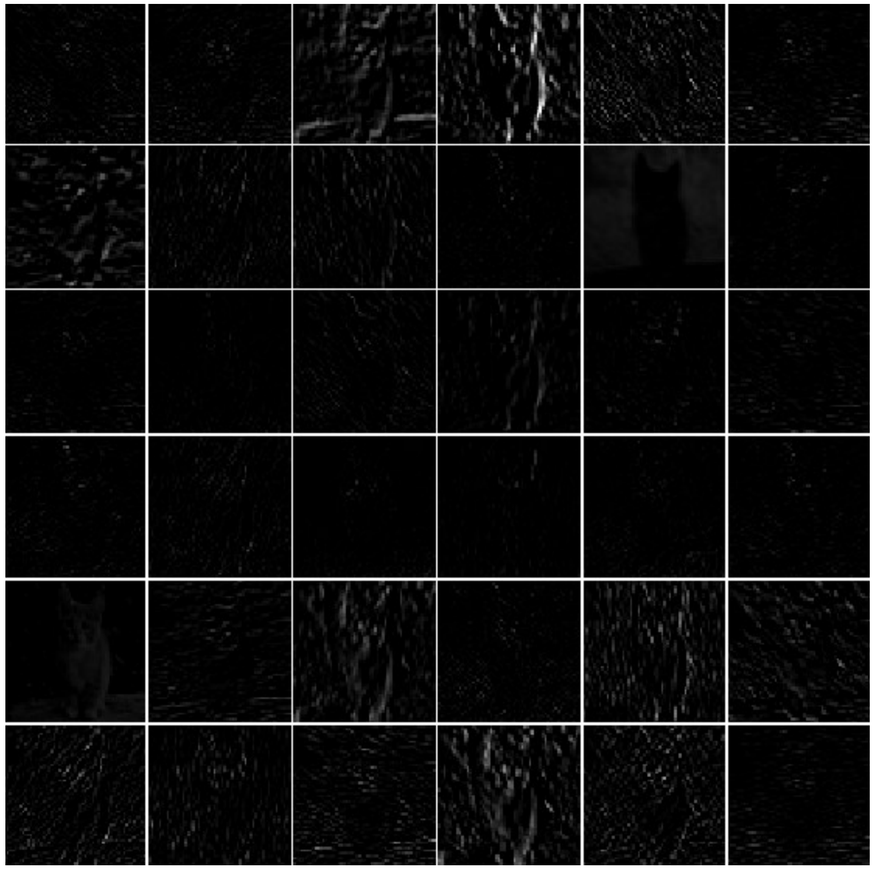


Alexnet

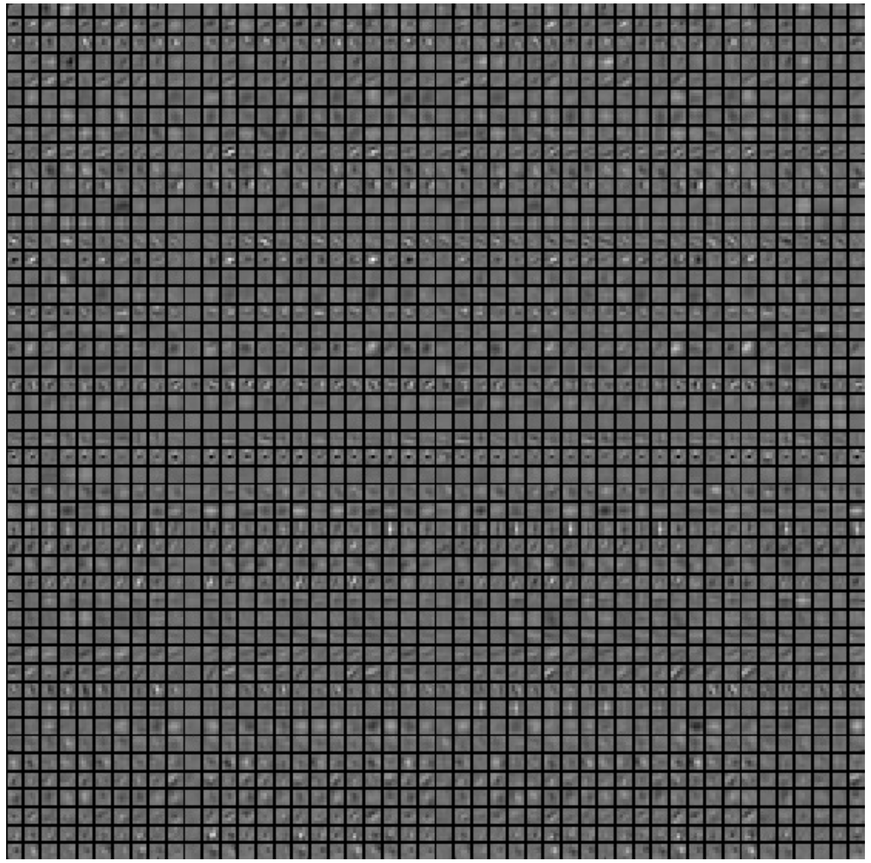


Alexnet

Feature Map Conv1

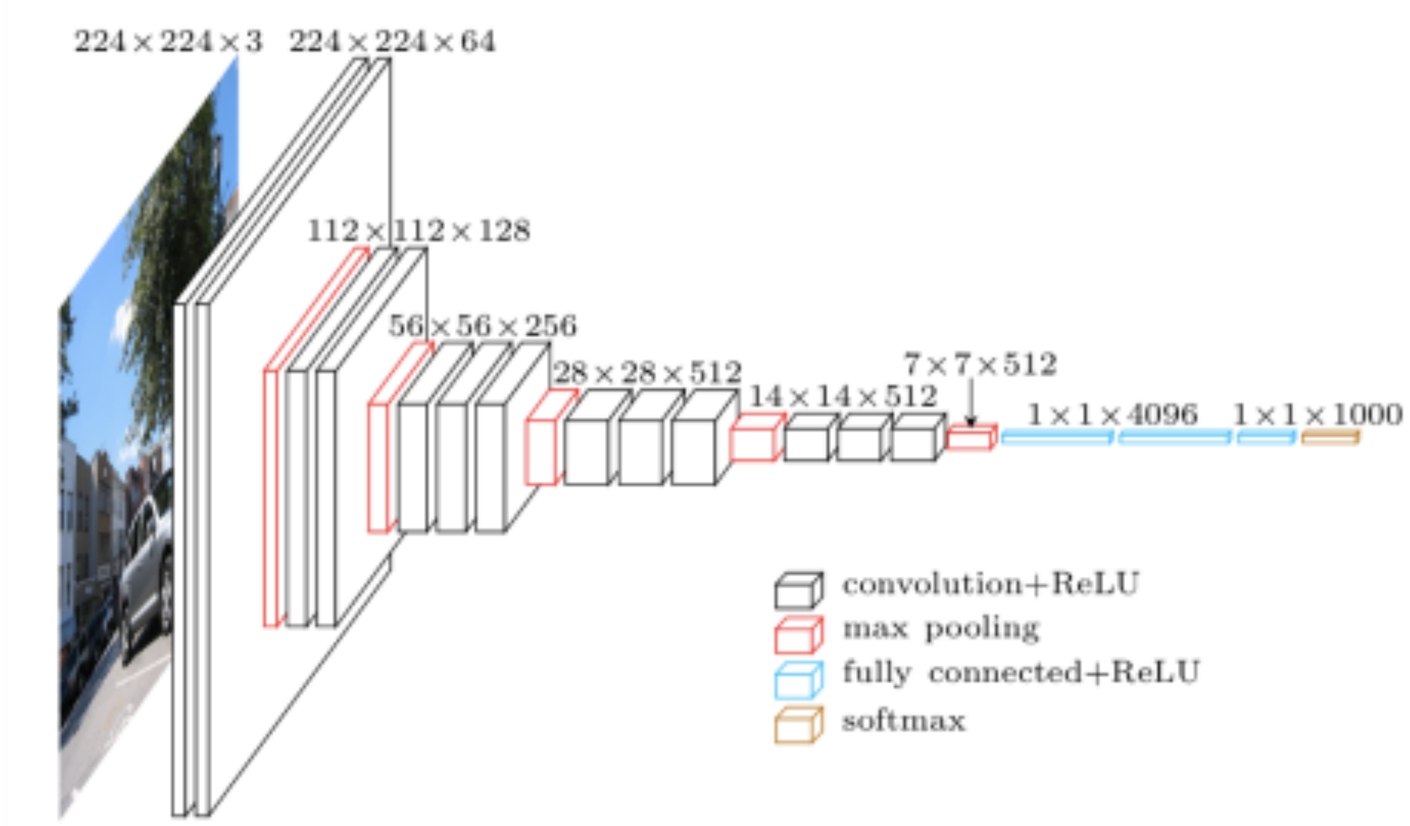


Conv2



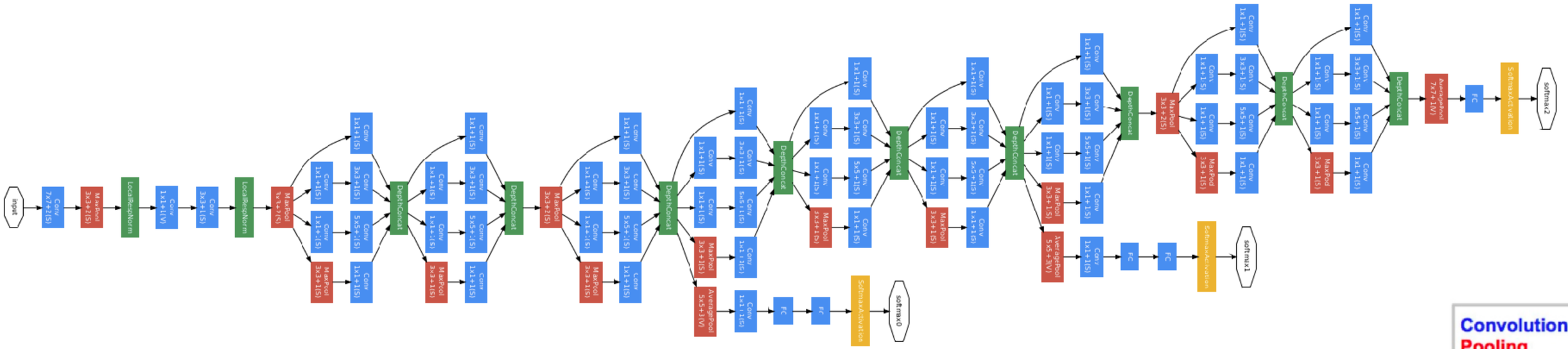

WE NEED TO GO
DEEPER
troll-face.ru

VGG Net

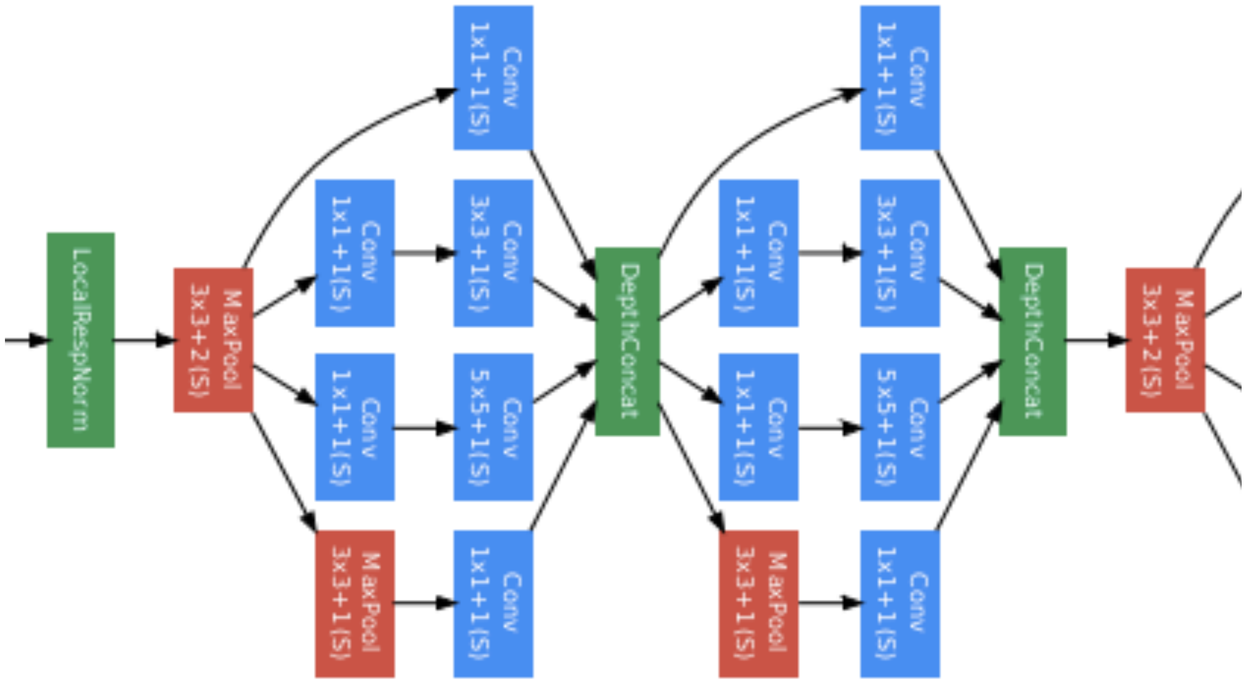

224 × 224 × 3
224 × 224 × 64
112 × 112 × 128
56 × 56 × 256
28 × 28 × 512
14 × 14 × 512
7 × 7 × 512
1 × 1 × 4096
1 × 1 × 1000
convolution+ReLU
max pooling
fully connected+ReLU
softmax

GoogleNet

22 layers, but 12 times less parameters than AlexNet

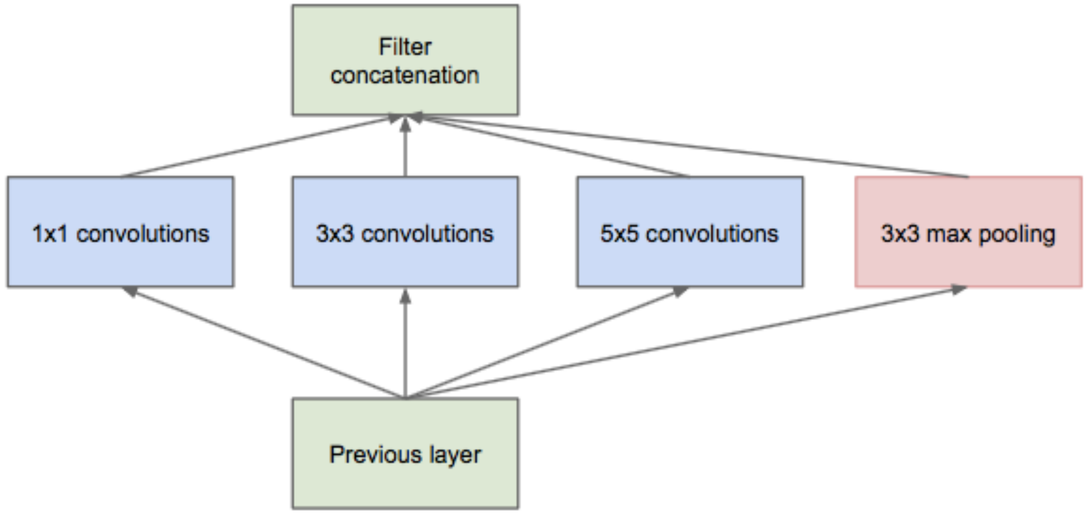


GoogleNet


LocalRespNorm
MaxPool 3x3+2(S)
Conv 1x1+1(S)
Conv 1x1+1(S)
Conv 3x3+1(S)
Conv 1x1+1(S)
Conv 5x5+1(S)
MaxPool 3x3+1(S)
Conv 1x1+1(S)
DepthConcat
Conv 1x1+1(S)
Conv 1x1+1(S)
Conv 3x3+1(S)
Conv 1x1+1(S)
Conv 5x5+1(S)
MaxPool 3x3+1(S)
Conv 1x1+1(S)
DepthConcat
MaxPool 3x3+2(S)

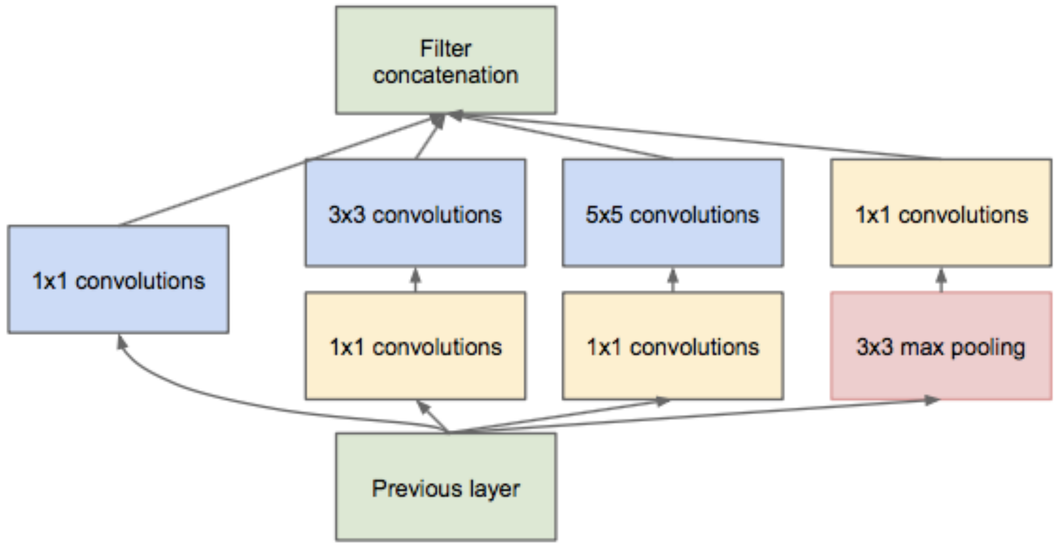
Inception Module: Naive Version

Convolutional filters with different sizes can cover different clusters of information.
By finding the optimal local construction and repeating it spatially, they approximate the optimal sparse structure with dense components.
For convenience of computation, they use 1 x 1, 3 x 3 and 5 x 5 filters + pooling.
Together these made up the naive Inception module.



Inception Module: Naive Version

Stacking these inception modules on top of each would lead to an exploding number of outputs
Solution: inspired by "Network in Network" add 1x1 convolutions for dimensionality reduction



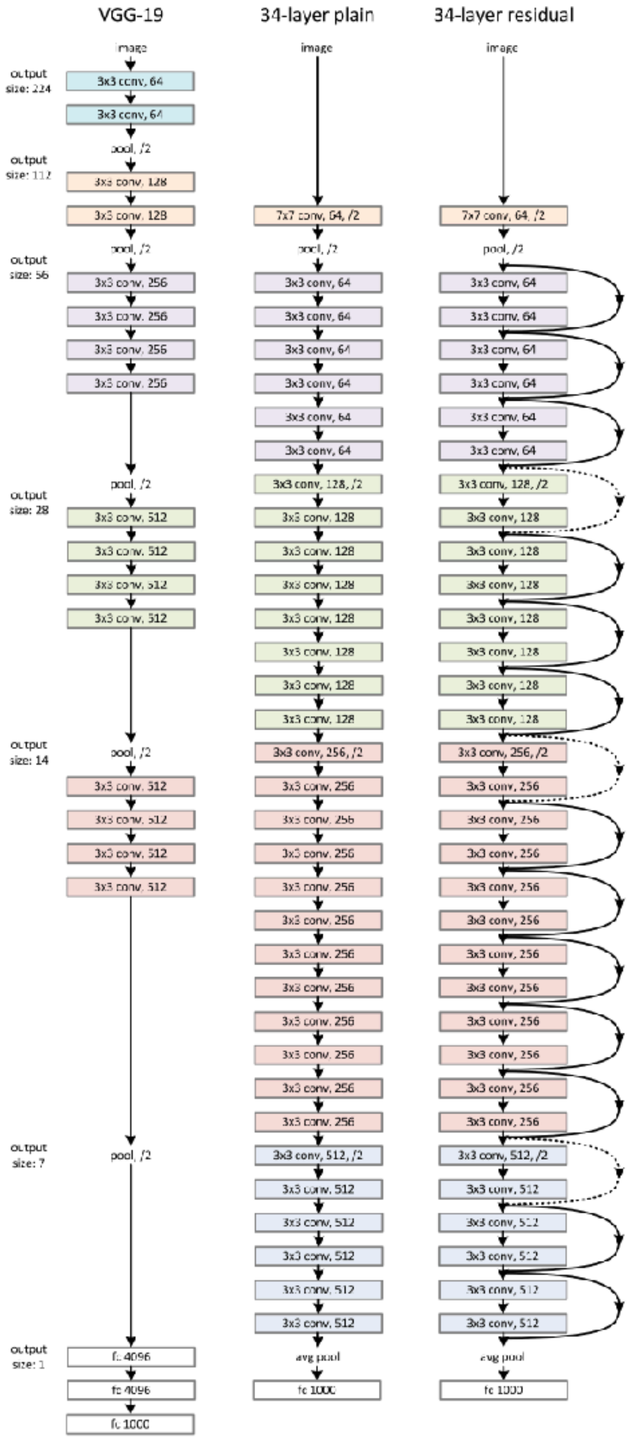
GoogleNet

type	patch size/ stride	output size	depth	#1×1	#3×3 reduce	#3×3	#5×5 reduce	#5×5	pool proj	params	ops
convolution	7×7/2	112×112×64	1							2.7K	34M
max pool	3×3/2	56×56×64	0								
convolution	3×3/1	56×56×192	2		64	192				112K	360M
max pool	3×3/2	28×28×192	0								
inception (3a)		28×28×256	2	64	96	128	16	32	32	159K	128M
inception (3b)		28×28×480	2	128	128	192	32	96	64	380K	304M
max pool	3×3/2	14×14×480	0								
inception (4a)		14×14×512	2	192	96	208	16	48	64	364K	73M
inception (4b)		14×14×512	2	160	112	224	24	64	64	437K	88M
inception (4c)		14×14×512	2	128	128	256	24	64	64	463K	100M
inception (4d)		14×14×528	2	112	144	288	32	64	64	580K	119M
inception (4e)		14×14×832	2	256	160	320	32	128	128	840K	170M
max pool	3×3/2	7×7×832	0								
inception (5a)		7×7×832	2	256	160	320	32	128	128	1072K	54M
inception (5b)		7×7×1024	2	384	192	384	48	128	128	1388K	71M
avg pool	7×7/1	1×1×1024	0								
dropout (40%)		1×1×1024	0								
linear		1×1×1000	1							1000K	1M
softmax		1×1×1000	0								

ImageNet Challenge 2012-2014

Team	Year	Place	Error (top-5)	External data
SuperVision – Toronto (7 layers)	2012	-	16.4%	no
SuperVision	2012	1st	15.3%	ImageNet 22k
Clarifai – NYU (7 layers)	2013	-	11.7%	no
Clarifai	2013	1st	11.2%	ImageNet 22k
VGG – Oxford (16 layers)	2014	2nd	7.32%	no
GoogLeNet (19 layers)	2014	1st	6.67%	no
Human expert*			5.1%	

ResNet


VGG-19
34-layer plain
34-layer residual
image
output size: 224
3x3 conv, 64
3x3 conv, 64
pool, /2
output size: 112
3x3 conv, 128
3x3 conv, 128
pool, /2
output size: 56
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
pool, /2
output size: 28
3x3 conv, 512
3x3 conv, 512
3x3 conv, 512
3x3 conv, 512
pool, /2
output size: 14
3x3 conv, 512
3x3 conv, 512
3x3 conv, 512
3x3 conv, 512
pool, /2
output size: 7
fc 4096
fc 4096
fc 1000
7x7 conv, 64, /2
pool, /2
3x3 conv, 64
3x3 conv, 128, /2
3x3 conv, 256, /2
3x3 conv, 512, /2
avg pool
fc 1000
7x7 conv, 64, /2
pool, /2
3x3 conv, 64
3x3 conv, 128, /2
3x3 conv, 256, /2
3x3 conv, 512, /2
avg pool
fc 1000

Training a CNN

- Back-propagation + stochastic gradient descent with momentum
- Dropout
- Data Augmentation
- Batch Normalization
- Initialization
  - Transfer Learning
- The make use of **GPU's** in order to optimize the weights.

Reducing Overfitting

Data Augmentation

60 million parameters, 650,000 neurons
-> overfits a lot

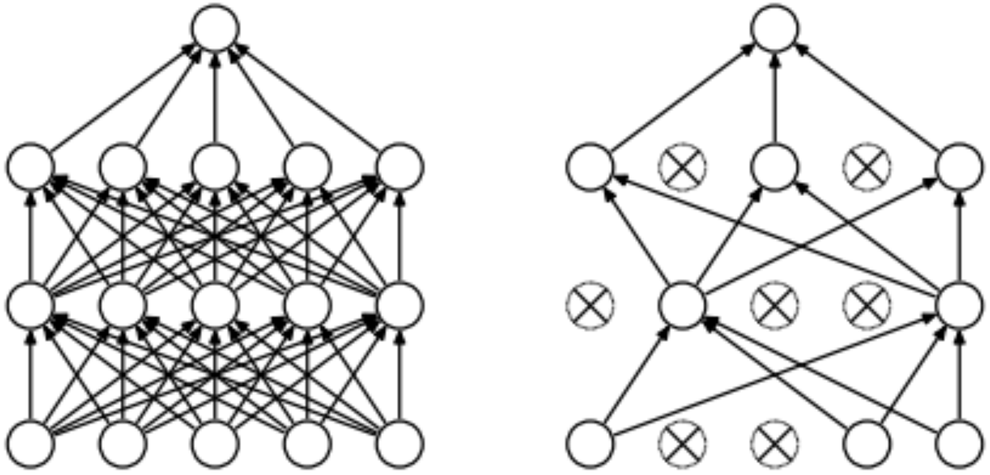
Crop 224x224 patches (and their horizontal reflections)

Data Augmentation at test
average the predictions on the 10 patches.

Reducing Overfitting

Dropout: A Simple Way to Prevent Neural Networks from Overfitting

Journal of Machine Learning Research 15 (2014) 1929-1958



(a) Standard Neural Net

(b) After applying dropout.

Exercice

- How many parameter do the model has if:
  - it has 10 input values
  - 2 neurons in one hidden layer
  - 1 neuron in the output layer

Exercice

- How many parameter do the model has if:
  - it has 10 input values
  - 2 neurons in one hidden layer
  - 1 neuron in the output layer

- How many parameter do the model has if:
  - it has 10 input values
  - 25 neurons in the first hidden layer
  - 25 neurons in the second hidden layer
  - 1 neuron in the output layer

Exercice

- How many parameter do the model is a RGB image of 50x50:
  - 1 convolution layer with10 filters of size 5x5
  - Max-pooling 2x2 with stride 2
  - 1 convolution layer with20 filters of size 3x3
  - Dense Layer with 100 neurons
  - Dense Layer with 10 neuros

Learning algorithm

- Learning the parameters is a complex and time-comsuming task.
  - **Huge amount** of **data** is needed.
  - **Back progragation** method is used.
  - Great **packages** like Caffe, Theano or TensorFlow.
  - The make use of **GPU's** in order to optimize the weights.