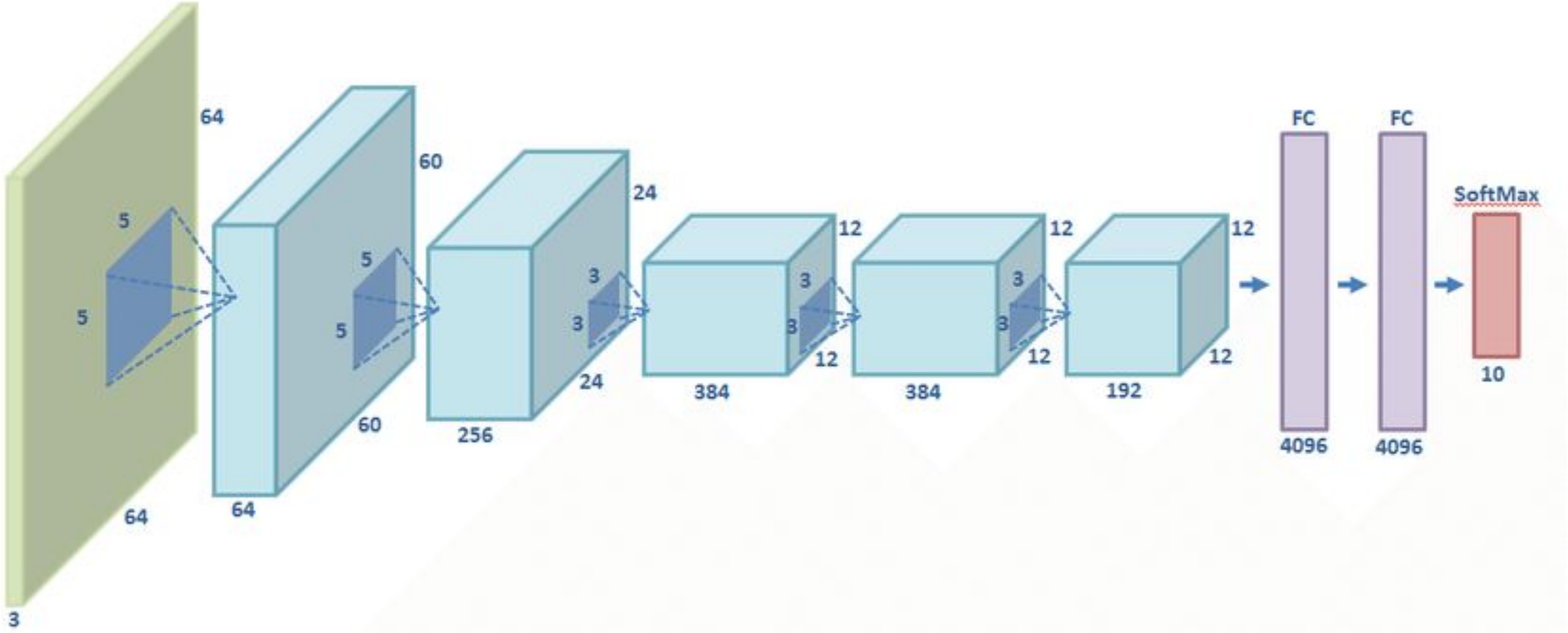
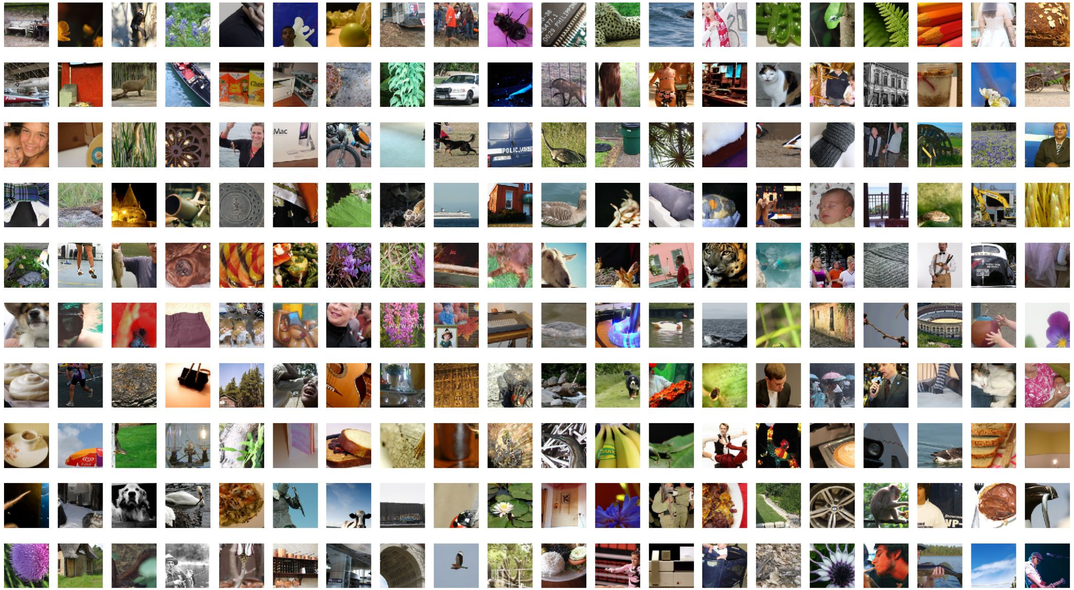
History of Convolutional Neural Networks



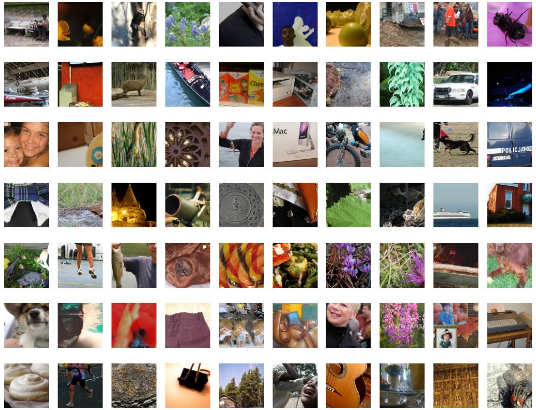
ImageNet dataset



Dataset size:
14,000,000 + images
30,000+ classes

Image size 224x224

ImageNet Large Scale Visual Recognition Challenge (ILSVRC)



Dataset size:
20,000 images
1000 classes

Task:
Predict which class picture belongs to.

Evaluation types:

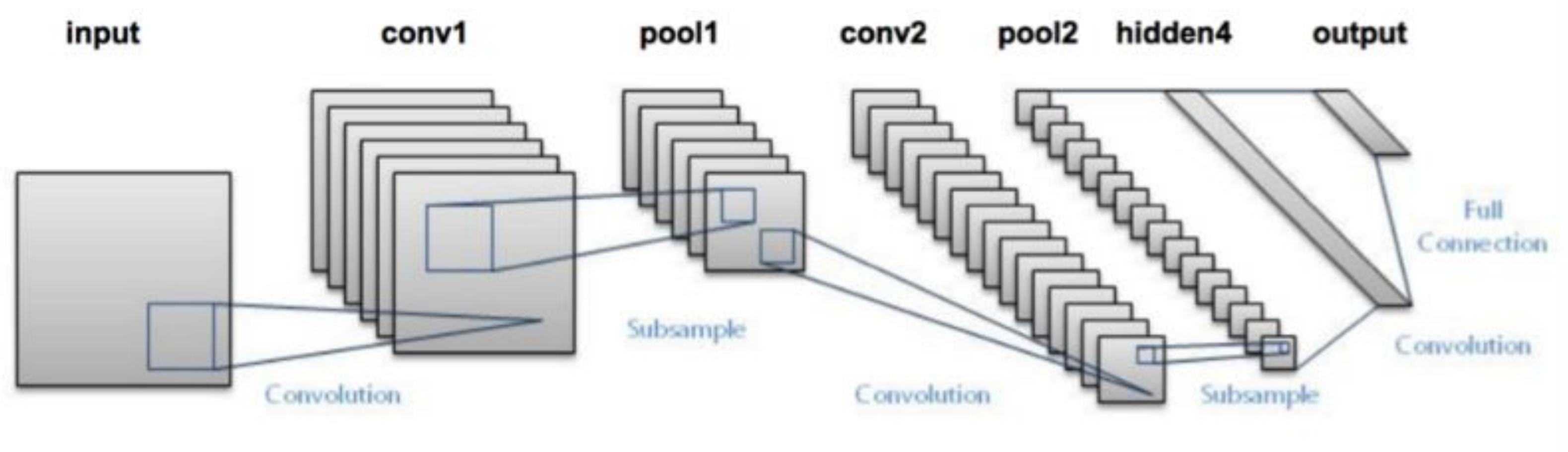
1. Top 5 error.

The percentage of the images that the classifier did not include the correct class among its top 5 guesses.

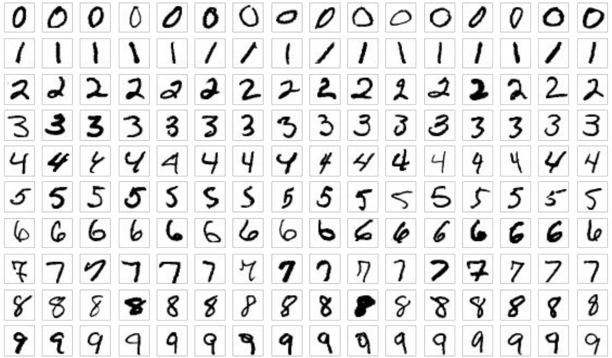
2. Top 1 error.

The percentage of the images that the classifier did not give the correct class the highest score.

LeNet-5 (1998)

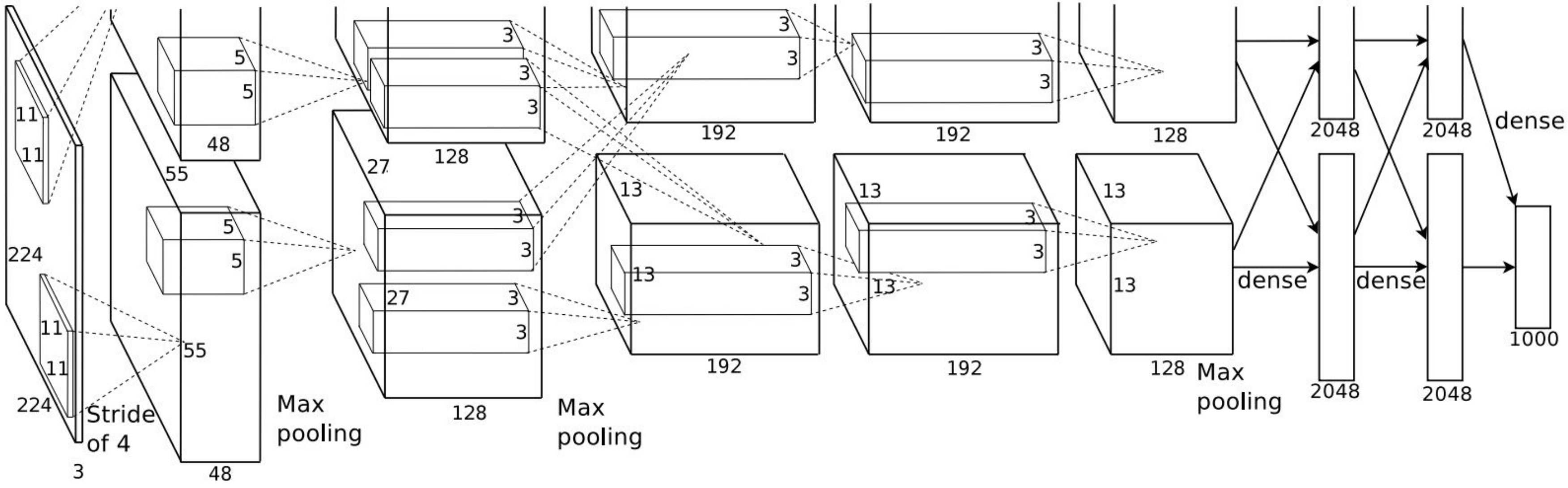

input
conv1
pool1
conv2
pool2
hidden4
output
Convolution
Subsample
Convolution
Subsample
Convolution
Full
Connection

LeNet-5 (1998)



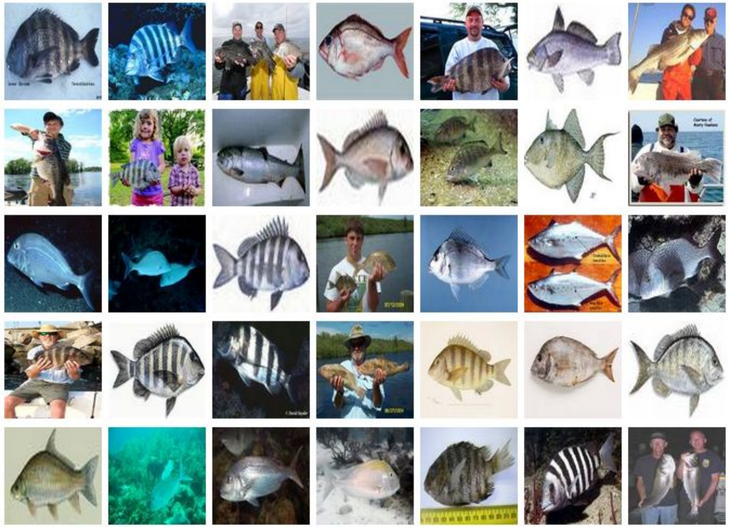
- Small 7 layers network developed by Yann Lecun.
- Used for recognizing 32x32 hand-written numbers.
- It required a lot of resources for training that were not available in 1998.

Alexnet (2012)

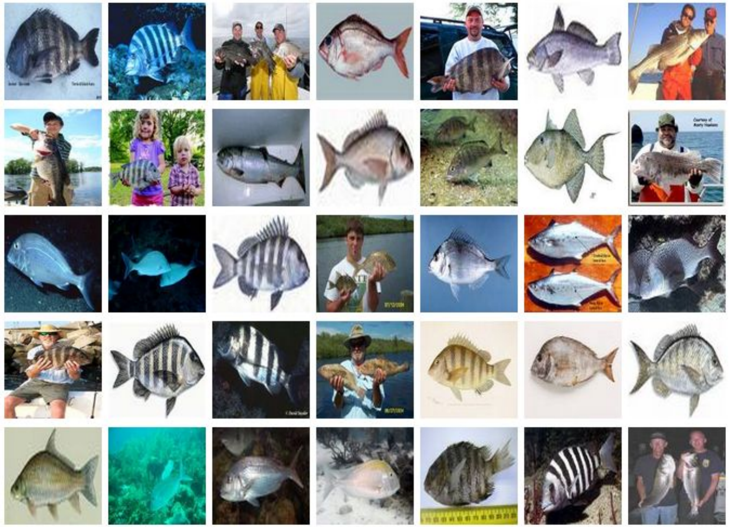


Alexnet (2012)

- Winner of ILSVRC 2012 with 15.3% of top 5 error.
- Deeper architecture with huge convolutions 11x11.
- Was trained on 2 GPU for 6 days.
- 60 million parameters.



Alexnet (2012)



- Winner of ILSVRC 2012 with 15.3% of top 5 error.
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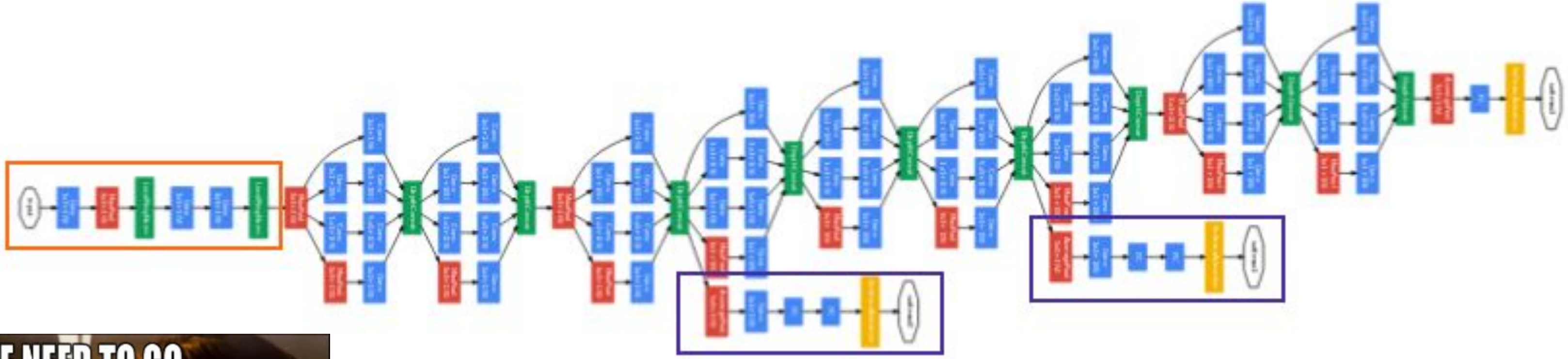
Drawbacks:

- Huge convolutions with a lots of weights.

GoogLeNet or Inception v1 (2014)



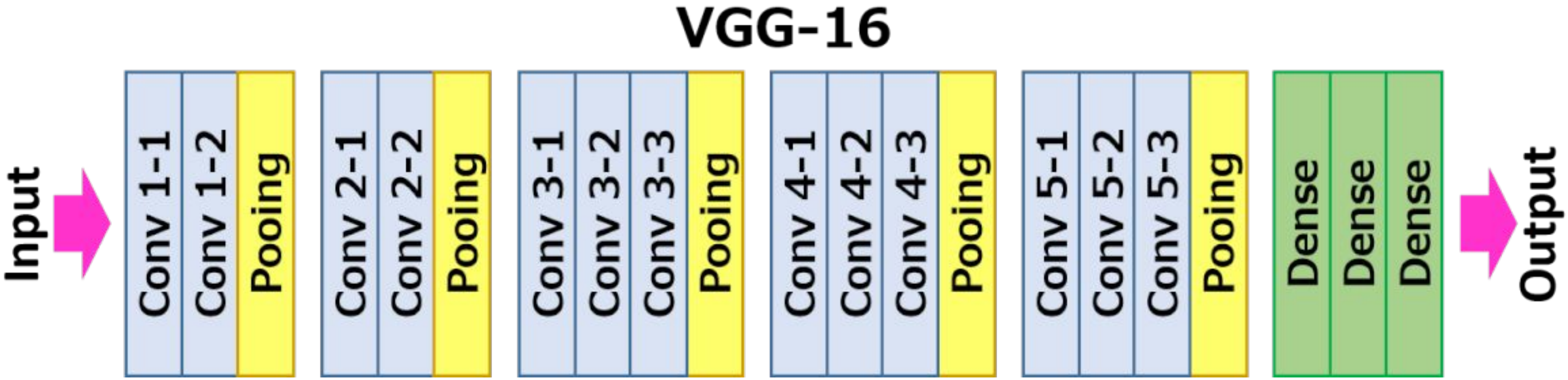
GoogLeNet or Inception v1 (2014)

- Winner of ILSVRC 2014 with 6.67% of top 5 error.
  (Right now it is better than human)
- Huge block structure with 22 layers.
- Small number of parameters. (4 million)

Drawbacks:

- Need a lot of time to reach a good quality.

VGG (2014)


VGG-16
Input
Conv 1-1
Conv 1-2
Pooing
Conv 2-1
Conv 2-2
Pooing
Conv 3-1
Conv 3-2
Conv 3-3
Pooing
Conv 4-1
Conv 4-2
Conv 4-3
Pooing
Conv 5-1
Conv 5-2
Conv 5-3
Pooing
Dense
Dense
Dense
Output

ConvNet Configuration					
A	A-LRN	B	C	D	E
11 weight layers	11 weight layers	13 weight layers	16 weight layers	16 weight layers	19 weight layers
input (224 × 224 RGB image)					
conv3-64	conv3-64 **LRN**	conv3-64 **conv3-64**	conv3-64 conv3-64	conv3-64 conv3-64	conv3-64 conv3-64
maxpool					
conv3-128	conv3-128	conv3-128 **conv3-128**	conv3-128 conv3-128	conv3-128 conv3-128	conv3-128 conv3-128
maxpool					
conv3-256 conv3-256	conv3-256 conv3-256	conv3-256 conv3-256	conv3-256 conv3-256 **conv1-256**	conv3-256 conv3-256 **conv3-256**	conv3-256 conv3-256 conv3-256 **conv3-256**
maxpool					
conv3-512 conv3-512	conv3-512 conv3-512	conv3-512 conv3-512	conv3-512 conv3-512 **conv1-512**	conv3-512 conv3-512 **conv3-512**	conv3-512 conv3-512 conv3-512 **conv3-512**
maxpool					
conv3-512 conv3-512	conv3-512 conv3-512	conv3-512 conv3-512	conv3-512 conv3-512 **conv1-512**	conv3-512 conv3-512 **conv3-512**	conv3-512 conv3-512 conv3-512 **conv3-512**
maxpool					
FC-4096					
FC-4096					
FC-1000					
soft-max					

Table 2: **Number of parameters** (in millions).

Network	A,A-LRN	B	C	D	E
Number of parameters	133	133	134	138	144

VGG (2014)

- 2d place on ILSVRC 2014 with 7.32% of top 5 error.
- Only 3x3 convolutions and poolings!
- There are a lot of different versions from small VGG7 to huge VGG19. (133 - 144 million parameters)

Drawbacks:

- All parameters in fully connected layers in the end of the network.
- Vanishing gradients.

Vanishing gradients

Reminder about weights update process

$$w_{new} = w_{old} - \alpha \frac{\partial L(w,x)}{\partial w}$$

$$\frac{\partial L}{\partial w} = \frac{\partial L}{f_{out}} * \frac{\partial f_{out}}{W_N} * \ldots * \frac{\partial f_1}{W_1} X$$

< 1

Vanishing gradients

Reminder about weights update process

$$w_{new} = w_{old} - \alpha \frac{\partial L(w,x)}{\partial w}$$

< 1 < 1

$$\frac{\partial L}{\partial w} = \frac{\partial L}{f_{out}} * \frac{\partial f_{out}}{W_N} * \dots * \frac{\partial f_1}{W_1} X$$

Vanishing gradients

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$$w_{new} = w_{old} - \alpha \frac{\partial L(w,x)}{\partial w}$$

< 1 $\quad$ < 1

$$\frac{\partial L}{\partial w} = \frac{\partial L}{f_{out}} * \frac{\partial f_{out}}{W_N} \underbrace{* \dots *}_{\text{A lot of parameters!}} \frac{\partial f_1}{W_1} X$$

≈ 0

Vanishing gradients

Reminder about weights update process

$$w_{new} = w_{old} - \alpha \frac{\partial L(w,x)}{\partial w}$$

$$\underbrace{\frac{\partial L}{\partial w}}_{\approx 0} = \frac{\partial L}{f_{out}} * \overbrace{\frac{\partial f_{out}}{W_N}}^{<1} \underbrace{* \ldots *}_{\text{A lot of parameters!}} \overbrace{\frac{\partial f_1}{W_1} X}^{<1}$$

Thus,

$$w_{new} = w_{old} - \alpha \cancelto{0}{\frac{\partial L(w,x)}{\partial w}}$$

$$w_{new} = w_{old}$$ Almost no updates!

Vanishing gradients

Reminder about weights update process

$$w_{new} = w_{old} - \alpha \frac{\partial L(w,x)}{\partial w}$$

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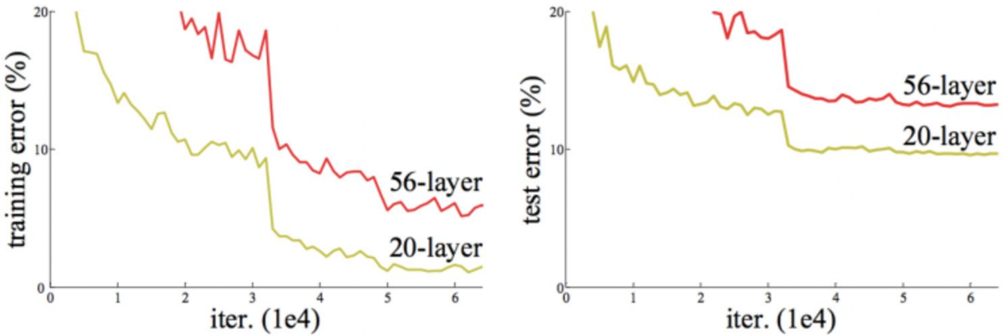
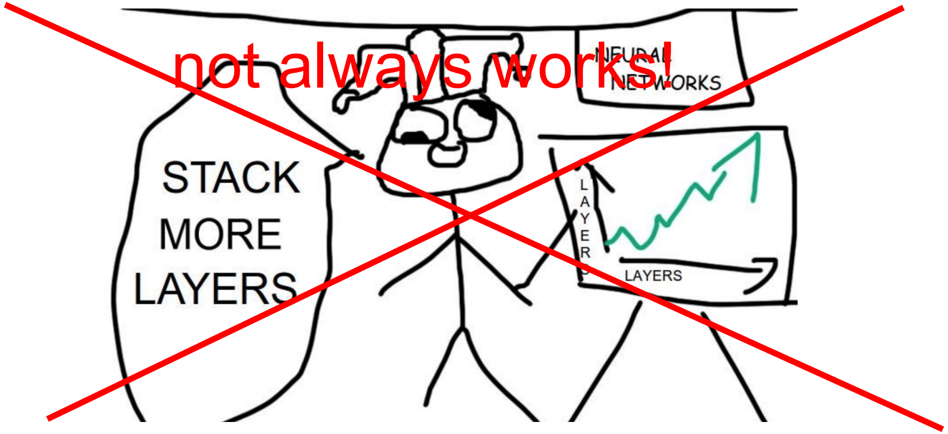


It means that networks with huge number of layers will be train very slowly.

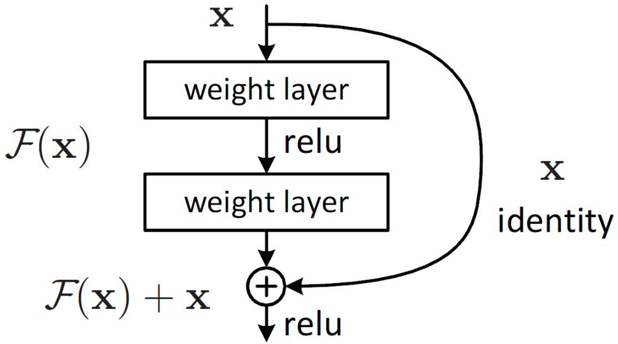
Thus,

$$w_{new} = w_{old} - \alpha \cancelto{0}{\frac{\partial L(w,x)}{\partial w}}$$

$$w_{new} = w_{old}$$ Almost no updates!



ResNet (2015)



$\mathbf{x}$
weight layer
$\mathcal{F}(\mathbf{x})$
relu
weight layer
$\mathbf{x}$
identity
$\mathcal{F}(\mathbf{x}) + \mathbf{x}$
relu

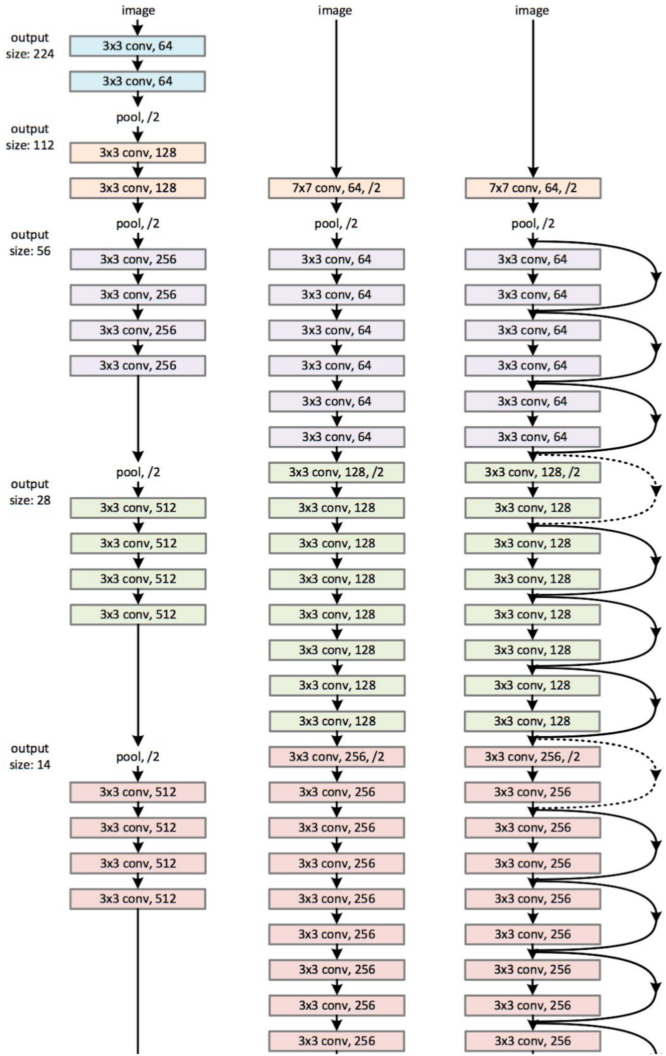
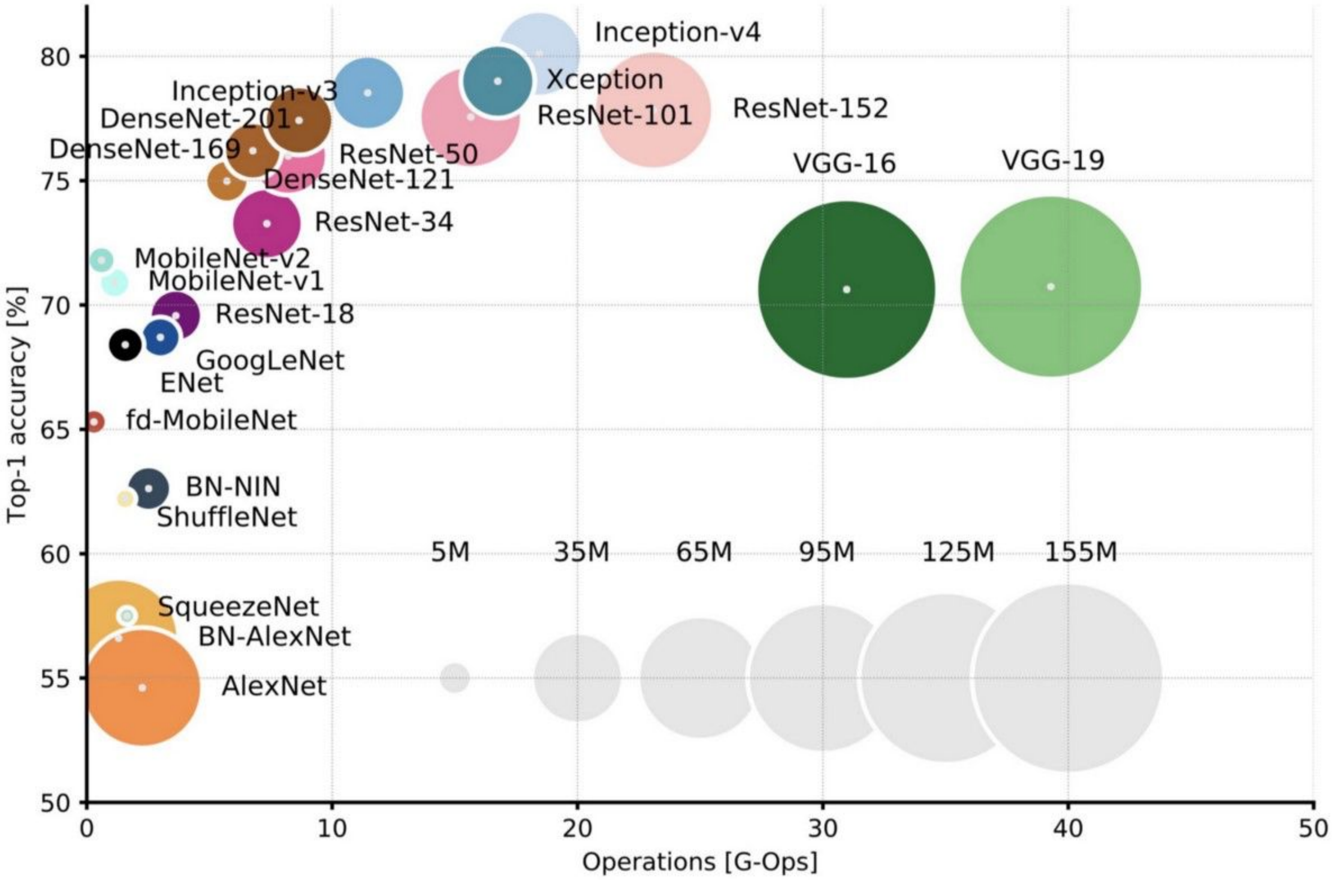


image
output size: 224
3x3 conv, 64
3x3 conv, 64
pool, /2
output size: 112
3x3 conv, 128
3x3 conv, 128
pool, /2
output size: 56
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
pool, /2
output size: 28
3x3 conv, 512
3x3 conv, 512
3x3 conv, 512
3x3 conv, 512
pool, /2
output size: 14
3x3 conv, 512
3x3 conv, 512
3x3 conv, 512
3x3 conv, 512
image
7x7 conv, 64, /2
pool, /2
3x3 conv, 64
3x3 conv, 64
3x3 conv, 64
3x3 conv, 64
3x3 conv, 64
3x3 conv, 64
3x3 conv, 128, /2
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 256, /2
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
image
7x7 conv, 64, /2
pool, /2
3x3 conv, 64
3x3 conv, 64
3x3 conv, 64
3x3 conv, 64
3x3 conv, 64
3x3 conv, 64
3x3 conv, 128, /2
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 128
3x3 conv, 256, /2
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256
3x3 conv, 256

ResNet (2015)

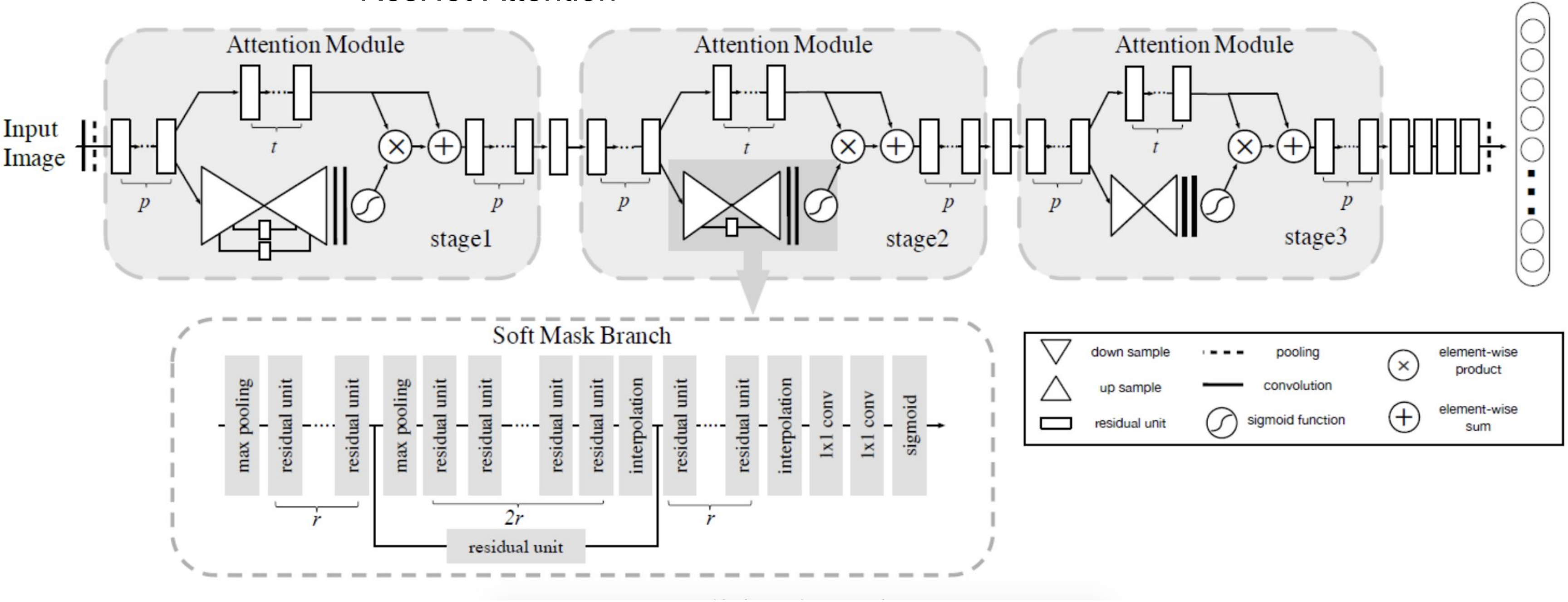
- Winner of ILSVRC 2015 with top 5 error 3.5%
- No vanishing gradients
- Really huge networks, started from ResNet18 to ResNet152.

A lots of other architectures here..

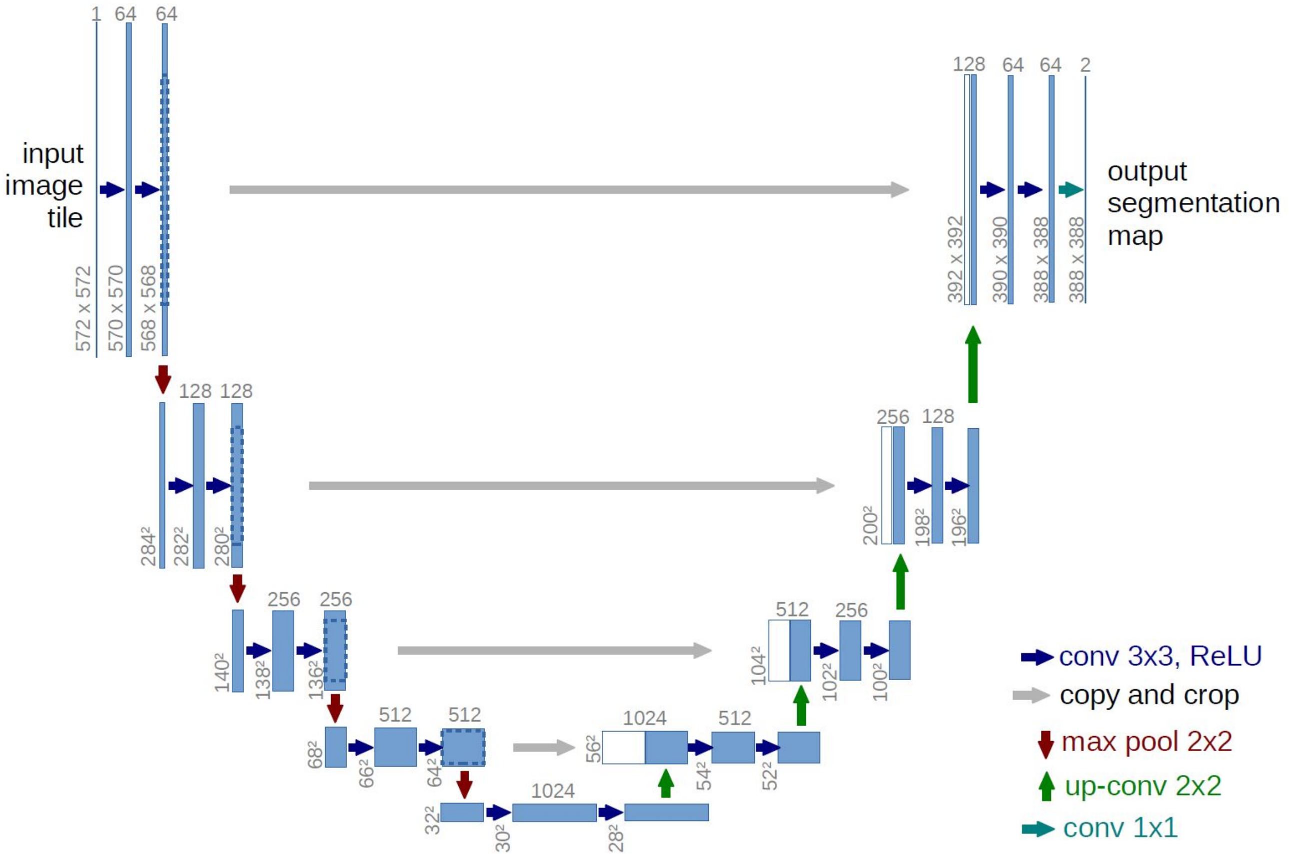


Attention models

ResNet-Attention



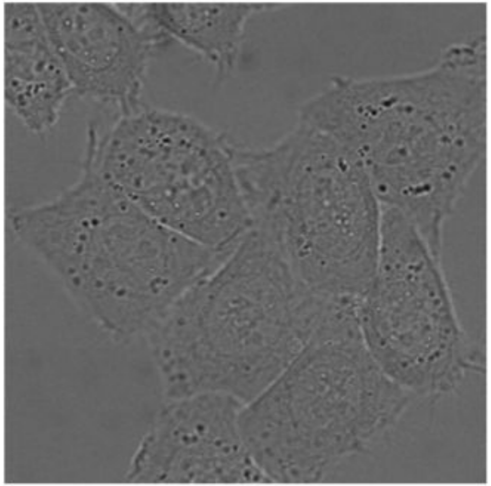
UNet (2015)

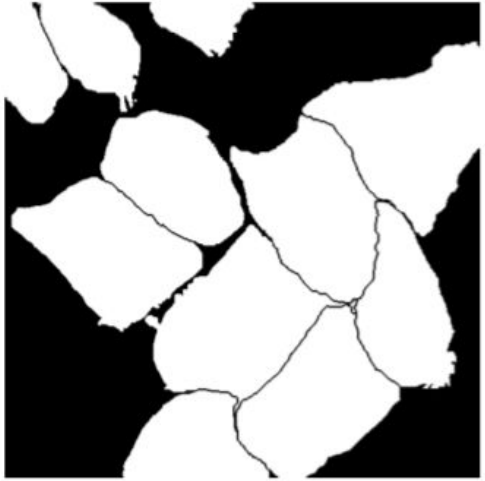


1
64
64
input
image
tile
572 x 572
570 x 570
568 x 568
128
128
284^2
282^2
280^2
256
256
140^2
138^2
136^2
512
512
68^2
66^2
64^2
1024
32^2
30^2
28^2
1024
512
56^2
54^2
52^2
512
256
104^2
102^2
100^2
256
128
200^2
198^2
196^2
128
64
64
2
392 x 392
390 x 390
388 x 388
388 x 388
output
segmentation
map
conv 3x3, ReLU
copy and crop
max pool 2x2
up-conv 2x2
conv 1x1

UNet (2015)

Binary segmentation

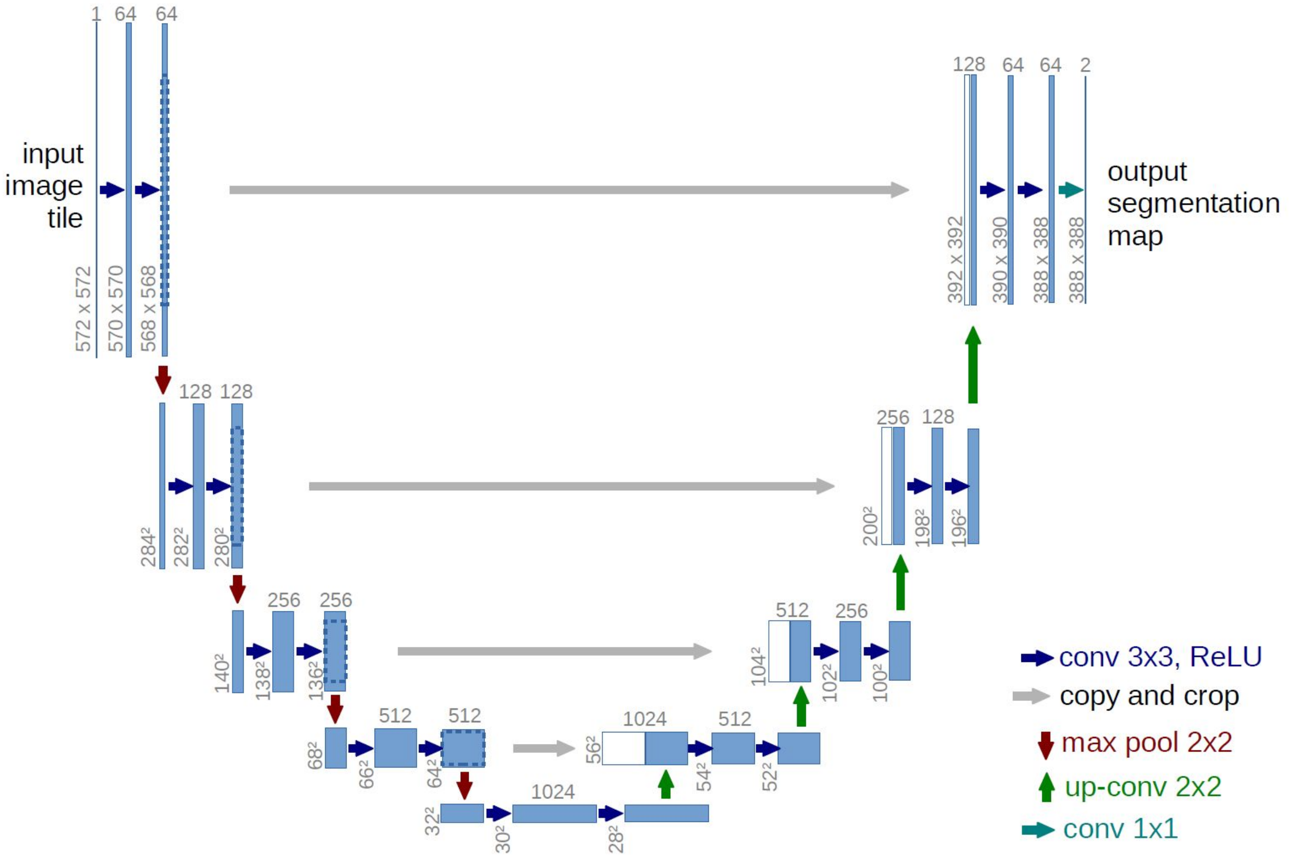




UNet (2015)

2015? To old!

What should we do then?



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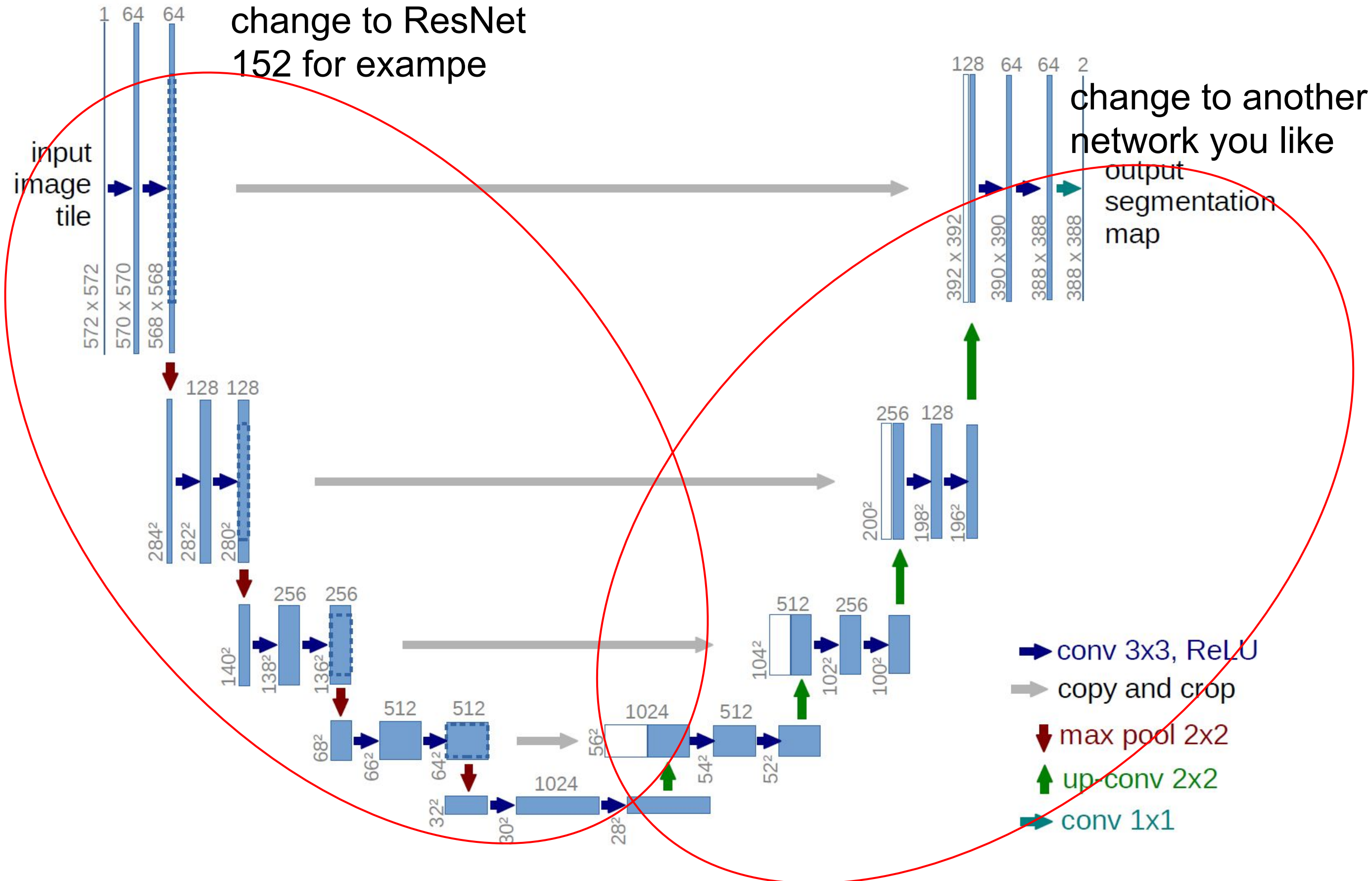


What tasks we can solve by CNN?

- regression
- classification
- segmentation
- detection

What tasks we can solve by CNN?

- regression
- classification
- segmentation
- detection

What is the output of the network?

CNN with regression

CNN

Prediction

4

number of
dogs

CNN with classification

f :

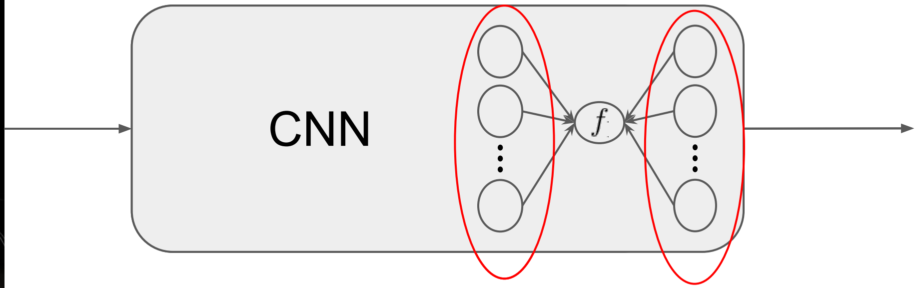
$$\sigma(z)_i = \frac{e^{z_i}}{\sum_{k=1}^{K} e^{z_k}}$$

Softmax

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

Sigmoid

Probability for each class

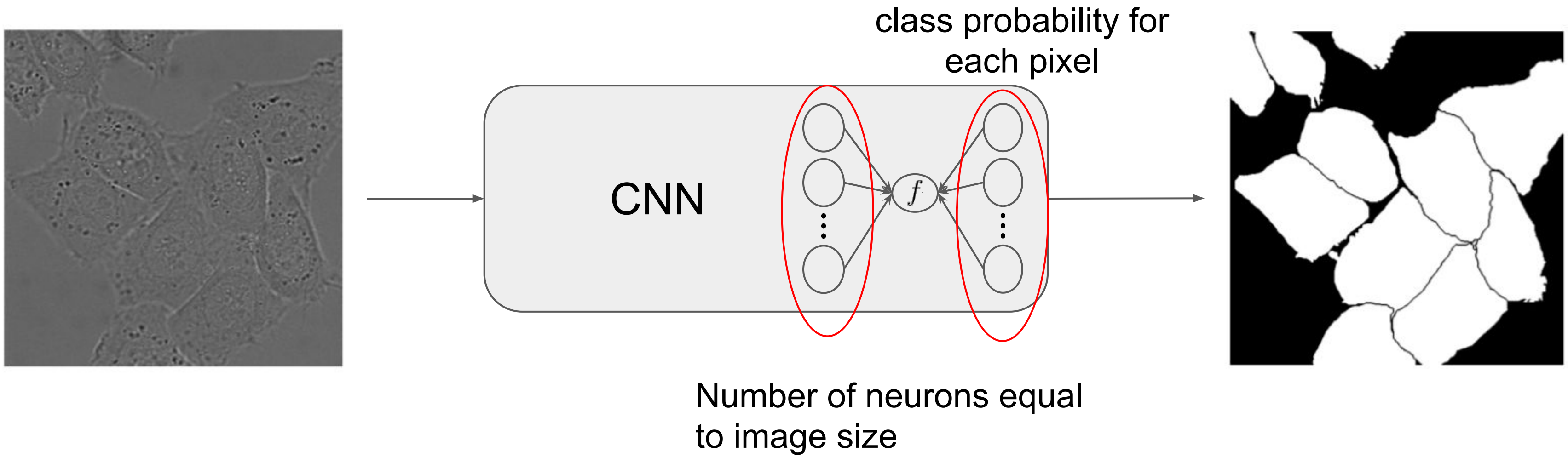


class (cat)

Number of neurons equal
to number of classes

CNN with classification

CNN with segmentation



CNN with detection one object

4 neurons:

- length of bb
- width of bb
- x
- y

CNN with detection for several objects

Number of neurons in output layer is 5xWxH.

CNN with detection for several objects

Number of neurons in output layer is WxHx(5+NumClass).

- confidence in this bb
- length of bb
- width of bb
- x
- y
- probability for each class