AI and Deep Learning

CNN, Convolutional Neural Network

Jeju National University
Yung-Cheol Byun

컨볼루션
(곱하고 합친 후 이동하는 것)

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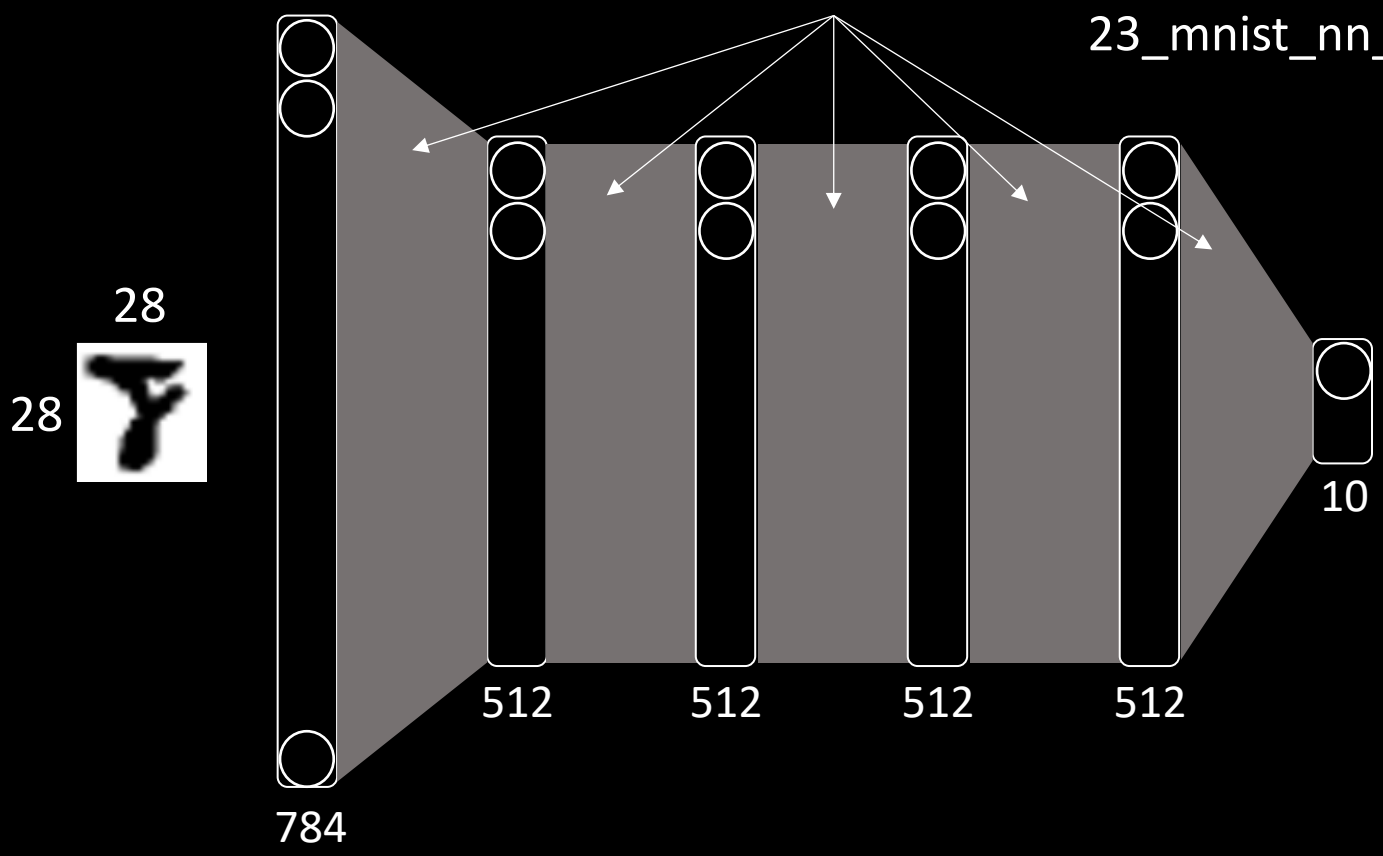
차례

- 요즘 인공지능 이야기
- 생활 속 인공지능
- 인공지능과 4차산업혁명
- 인공지능 어떻게?
- 뉴런과 학습, 그리고 신경망
- 선형회귀와 논리회귀
- 딥러닝
- CNN과 RNN 이해하기

이제까지 배운
신경망의 단점은?

Fully connected

23_mnist_nn_deep.py



784(28x28) pixels as inputs to NN

Different inputs according to the size, location, skewness, and distortion

이미지는 같은데 이미지 회전, 위치, 확대/축소 등에 따라 픽셀이 달라지고, 따라서 신경망 입력층으로 주어지는 입력 값이 확연히 달라짐.


4 → 9
116
2 → 7
322
5 → 3
341
6 → 0
446
3 → 5
450
8 → 2
583
4 → 9
741
3 → 5
939
8 → 9
948
1 → 3
957
6 → 0
1015
4 → 6
1113
7 → 2
1227
9 → 4
1233
9 → 5
1248
7 → 1
1261
8 → 2
1365
5 → 3
1394
8 → 7
1531
9 → 5
1710
5 → 2
1738
8 → 3
1879
9 → 4
1902
5 → 3
2036
4 → 9
2054
2 → 0
2099
6 → 0
2119
4 → 9
2131
9 → 8
2294
9 → 1
2388
9 → 4
2407
2 → 0
2463
2 → 4
2489
5 → 3
2598
6 → 1
2655
8 → 0
2897
9 → 5
2940
3 → 5
2954
6 → 0
3031
8 → 9
3290
6 → 0
3423
6 → 4
3521
5 → 0
3559
8 → 9
3728
4 → 6
3781
7 → 8
3808
1 → 3
3907
7 → 1
4028
9 → 8
4079
1 → 7
4202
2 → 7
4206
9 → 7
4225
7 → 3
4239
2 → 8
4249
9 → 5
4285
3 → 2
4444
6 → 8
4572
3 → 5
4741
9 → 8
4762
8 → 0
4808
6 → 0
4815
8 → 6
4880
8 → 2
5750
5 → 3
5938
3 → 8
5956
3 → 0
6012
8 → 9
6556
1 → 8
6573
7 → 1
6577
8 → 3
6626
2 → 1
8060
8 → 5
8409
7 → 2
9010
7 → 2
9016
6 → 4
9680
9 → 7
9693
5 → 6
9730
4 → 9
9793
2 → 7
9840

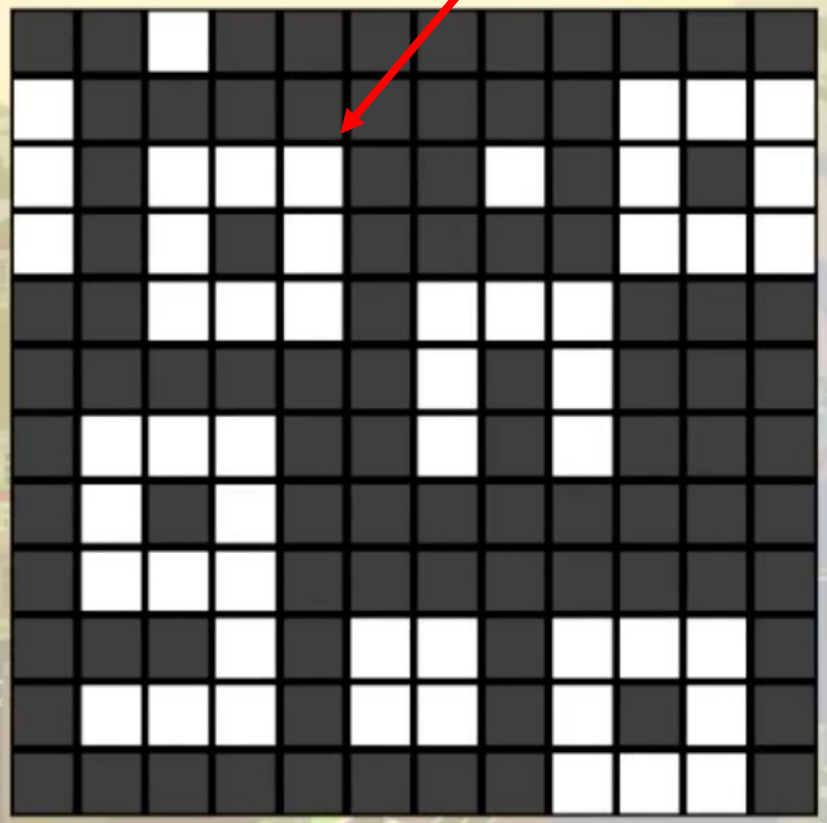
모양, 위치, 크기, 기울기에 따라
신경망 입력이 달라짐

따라서 이미지를 바로 신경망에
넣지 말고 중요한 정보만
걸러서(필터링해서) 주자.

거를 때 쓰는 것 : 필터(filter)

도넛을 찾아라!

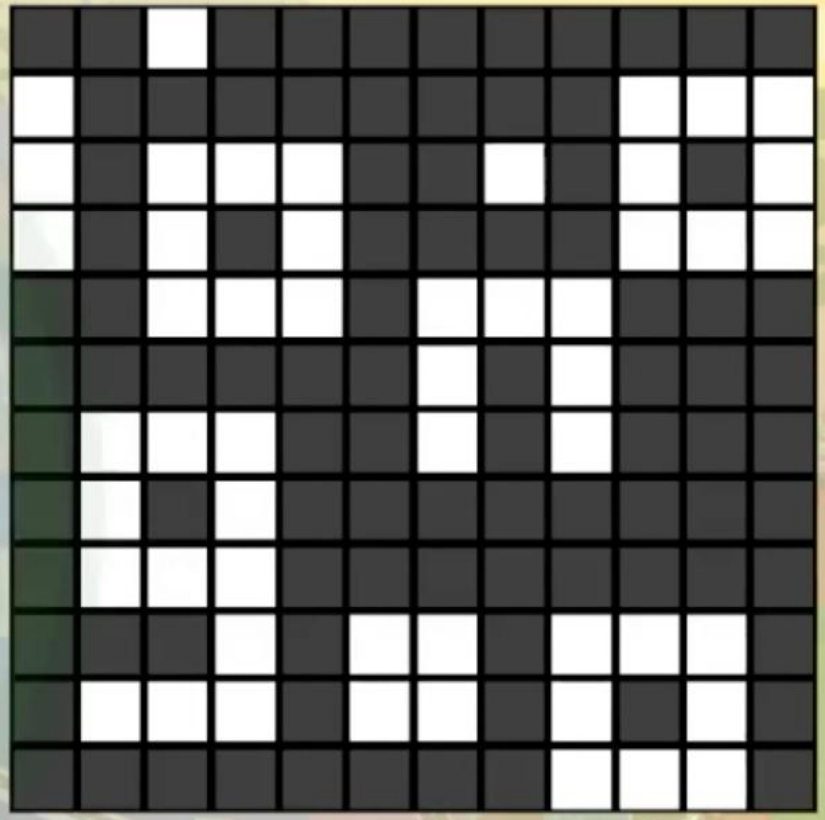
"도넛이 될 조건을 말해보자"



IMAGE

"DONUT FILTER"

DOESN'T MATTER	MUST BE BLACK	MUST BE BLACK	MUST BE BLACK	DOESN'T MATTER
MUST BE BLACK	MUST BE WHITE	MUST BE WHITE	MUST BE WHITE	MUST BE BLACK
MUST BE BLACK	MUST BE WHITE	MUST BE BLACK	MUST BE WHITE	MUST BE BLACK
MUST BE BLACK	MUST BE WHITE	MUST BE WHITE	MUST BE WHITE	MUST BE BLACK
DOESN'T MATTER	MUST BE BLACK	MUST BE BLACK	MUST BE BLACK	DOESN'T MATTER

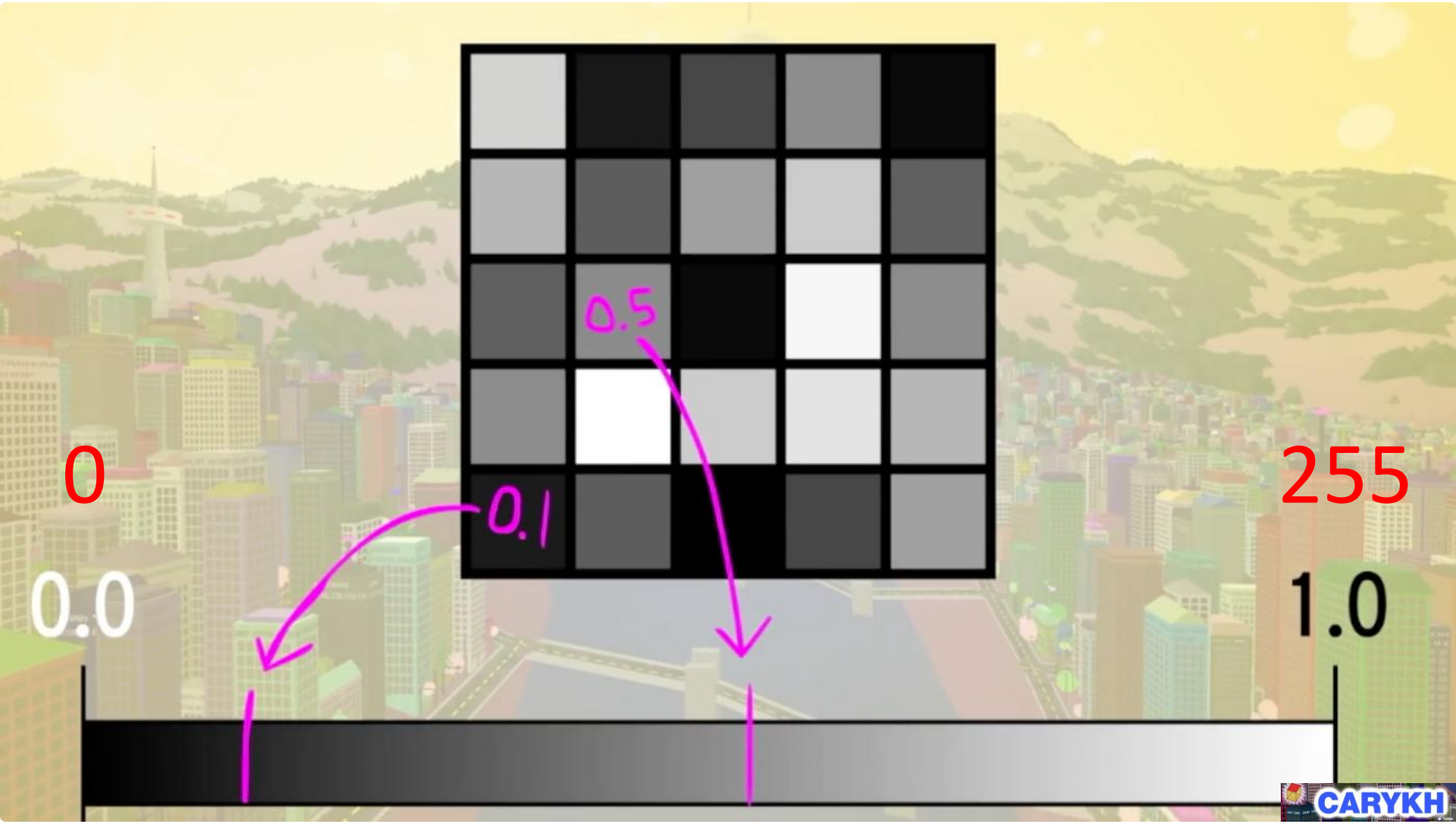


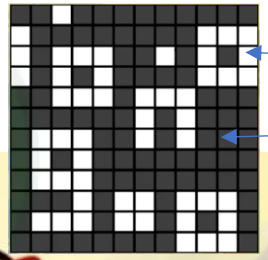

"DONUT FILTER"
upper-left pixel
DOESN'T MATTER
MUST BE BLACK
MUST BE WHITE
CARYKH

“우리가 정한 조건을 모두 만족하는가?”


"Is every condition of the filter satisfied?"
It's not a donut.
DOESN'T MATTER Yes
MUST BE BLACK Yes
MUST BE BLACK Yes
MUST BE BLACK Yes
DOESN'T MATTER Yes
MUST BE BLACK Yes
MUST BE WHITE No
MUST BE WHITE No
MUST BE WHITE No
MUST BE BLACK Yes
MUST BE BLACK Yes
MUST BE WHITE No
MUST BE BLACK Yes
MUST BE WHITE No
MUST BE BLACK No
MUST BE BLACK Yes
MUST BE WHITE No
MUST BE WHITE Yes
MUST BE WHITE No
MUST BE BLACK Yes
DOESN'T MATTER Yes
MUST BE BLACK Yes
MUST BE BLACK No
MUST BE BLACK Yes
DOESN'T MATTER Yes
바깥 부분은 black으로 간주하여 확인
→ 9개 조건 만족하지 않아 도넛이 아님.
CARYKH

블랙 & 화이트 vs. Gray vs. 컬러


0.5
0.1
0
255
0.0
1.0
CARYKH



DONUT FILTER

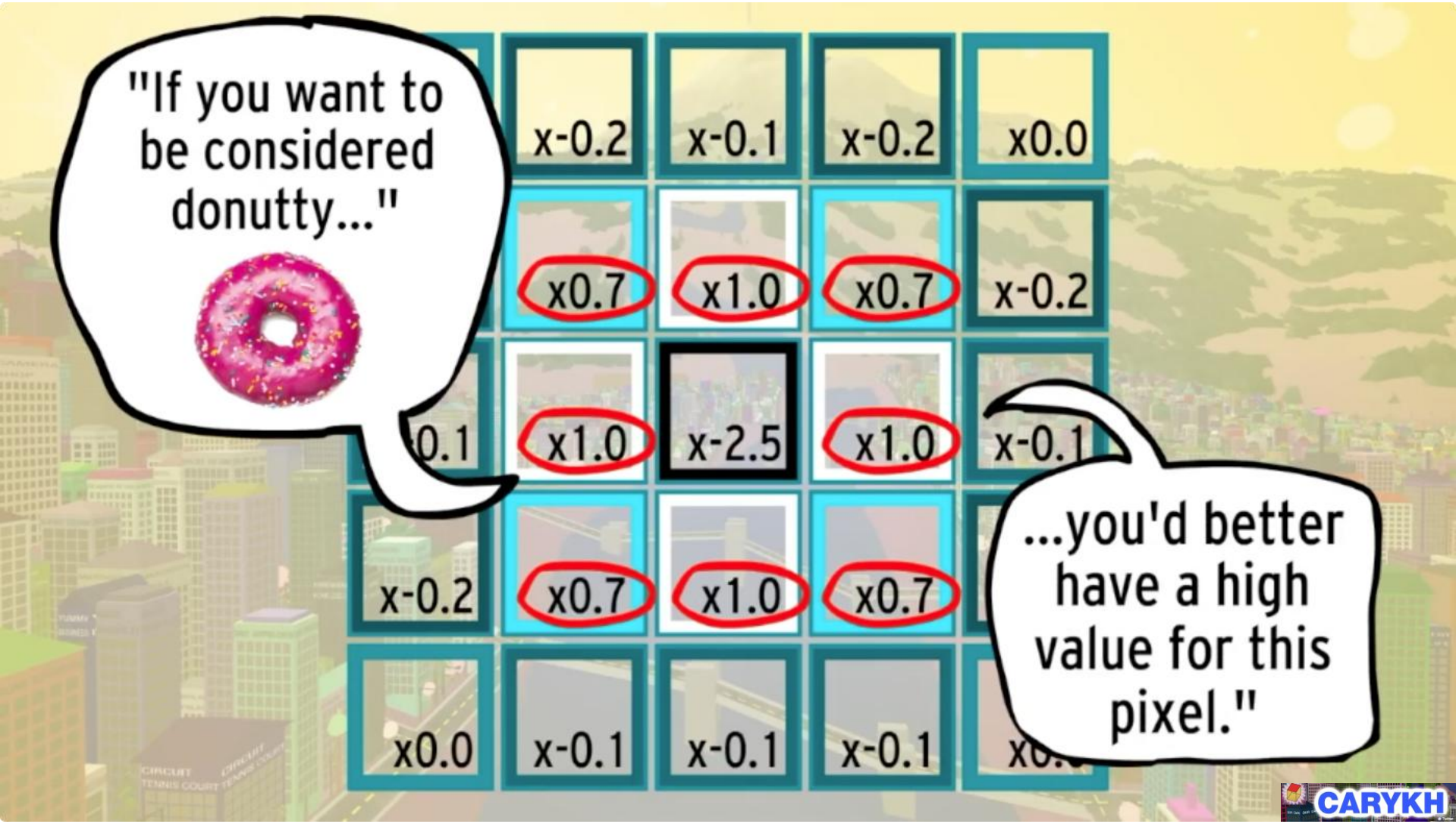
DOESN'T MATTER	MUST BE BLACK	MUST BE BLACK	MUST BE BLACK	DOESN'T MATTER
MUST BE BLACK	MUST BE WHITE	MUST BE WHITE	MUST BE WHITE	MUST BE BLACK
MUST BE BLACK	MUST BE WHITE	MUST BE BLACK	MUST BE WHITE	MUST BE BLACK
MUST BE BLACK	MUST BE WHITE	MUST BE WHITE	MUST BE WHITE	MUST BE BLACK
DOESN'T MATTER	MUST BE BLACK	MUST BE BLACK	MUST BE BLACK	DOESN'T MATTER

New improved filter

x0.0	x-0.2	x-0.1	x-0.2	x0.0
x-0.2	x0.7	x1.0	x0.7	x-0.2
x-0.1	x1.0	x-2.5	x1.0	x-0.1
x-0.2	x0.7	x1.0	x0.7	x-0.2
x0.0	x-0.1	x-0.1	x-0.1	x0.0

"set of multipliers"

“흰색이 있어야 할 곳에 흰색이 있으면 큰 점수를 더하고”
“흰색이 있어야 할 곳에 검정색이 오면 큰 점수를 빼고”

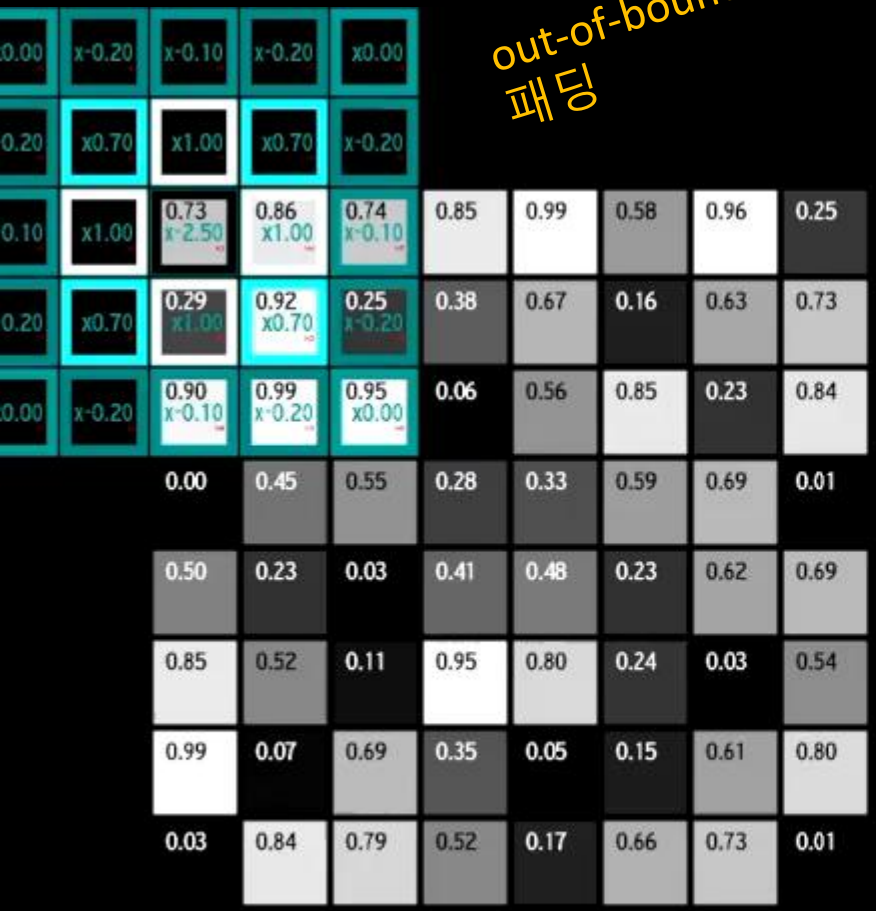


컨볼루션
(곱하고 합치는 것)

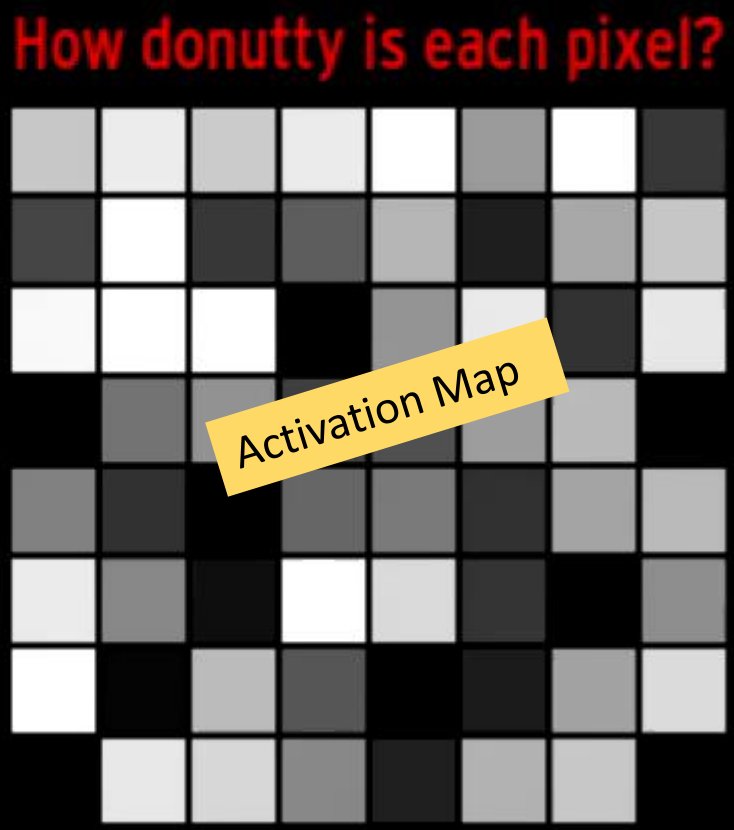
0.73	0.86	0.74	0.85	0.99	0.58	0.96	0.25
0.29	0.92	0.25	0.38	0.67	0.16	0.63	0.73
0.90	0.99	0.95	0.06	0.56	0.85	0.23	0.84
0.00	0.45	0.55	0.28	0.33	0.59	0.69	0.01
0.50	0.23	0.03	0.41	0.48	0.23	0.62	0.69
0.85	0.52	0.11	0.95	0.80	0.24	0.03	0.54
0.99	0.07	0.69	0.35	0.05	0.15	0.61	0.80
0.03	0.84	0.79	0.52	0.17	0.66	0.73	0.01

Filter size : 5 X 5

out-of-bound 패딩



컨볼루션
(곱하고 합친 후 이동하는 것)



CARYKH

"필터로 이미지에 대해 합성곱(곱한 후 합치는 것) 수행"

Convolve the filter with the image

slide over the image spatially, computing dot product

"이미지에서 공간적으로 필터를 이동하면서 dot product를 수행"

A filter containing a group of synapsis (parameters)

shared by the whole neurons

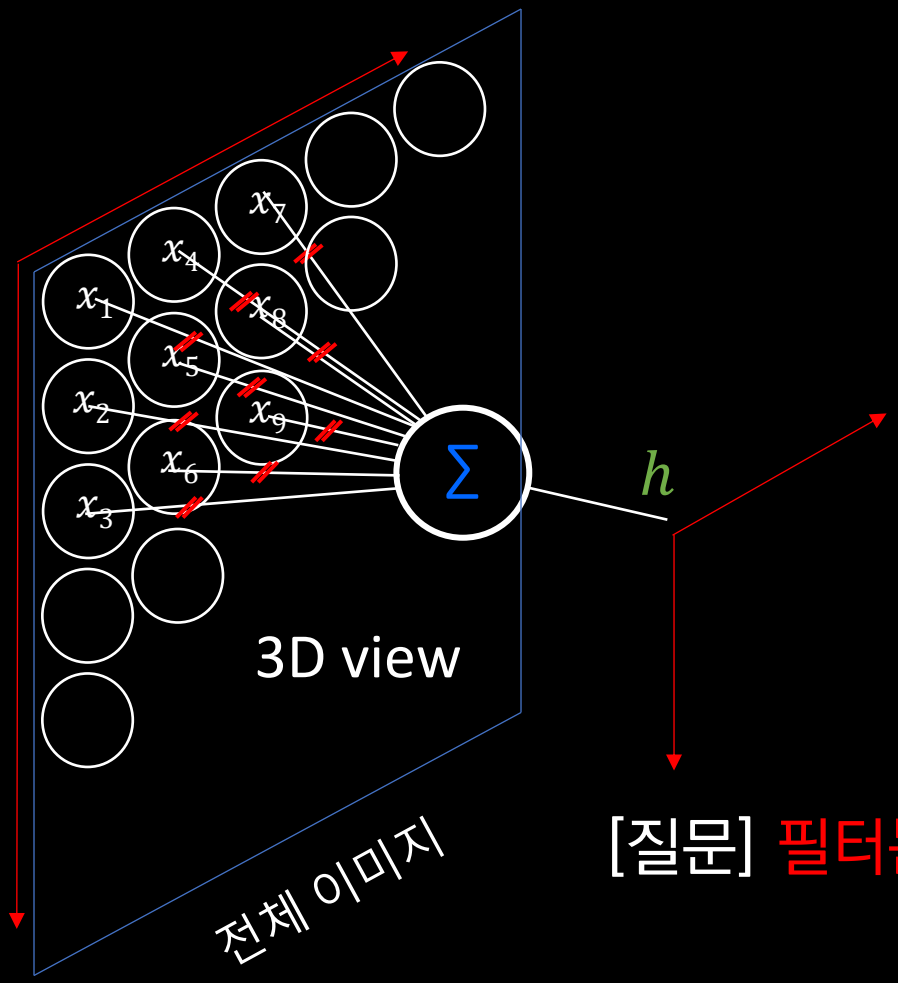
하나의 필터로

입력 이미지 전체에 대하여

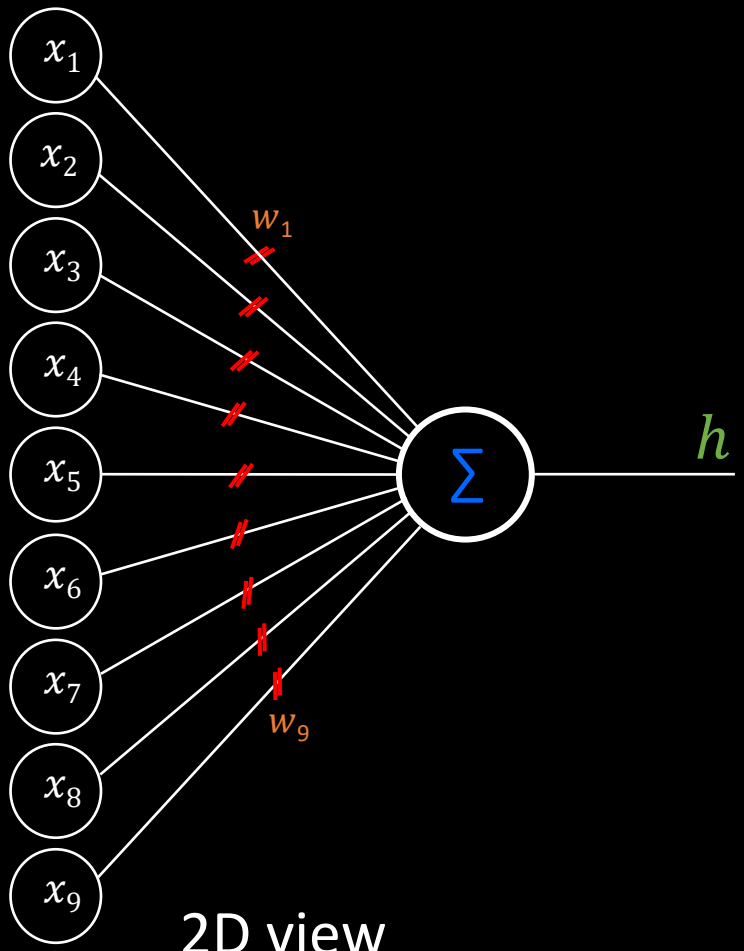
컨볼루션 수행하여 결과 만듬


x1.0
x-1.5
x1.0
x-0.4
x0.7
x1.0
x0.7
x-0.6
x-0.4
x-0.4
x-0.4
x0.0
0.73 0.86 0.74 0.85 0.99 0.58 0.96 0.25
0.29 0.92 0.25 0.38 0.67 0.16 0.63 0.73
0.90 0.99 0.95 0.06 0.56 0.85 0.23 0.84
0.00 0.45 0.55 0.28 0.33 0.59 0.69 0.01
0.50 0.23 0.03 0.41 0.48 0.23 0.62 0.69
0.85 0.52 0.11 0.95 0.80 0.24 0.03 0.54
0.99 0.07 0.69 0.35 0.05 0.15 0.61 0.80
0.03 0.84 0.79 0.52 0.17 0.66 0.73 0.01

9 connections = 9 synaps (values)

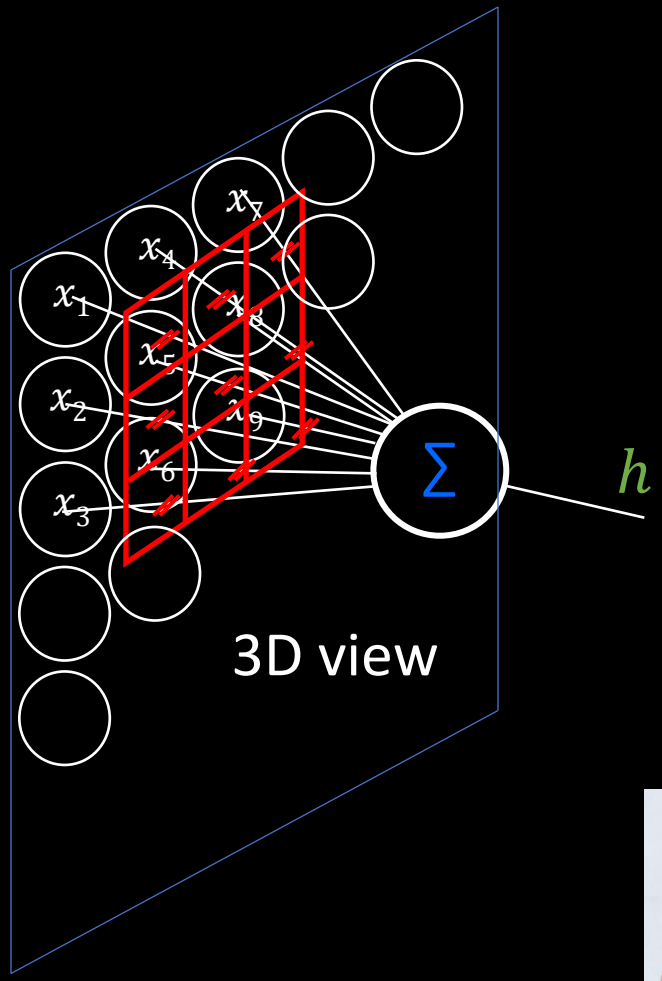


[질문] 필터는 어디에?



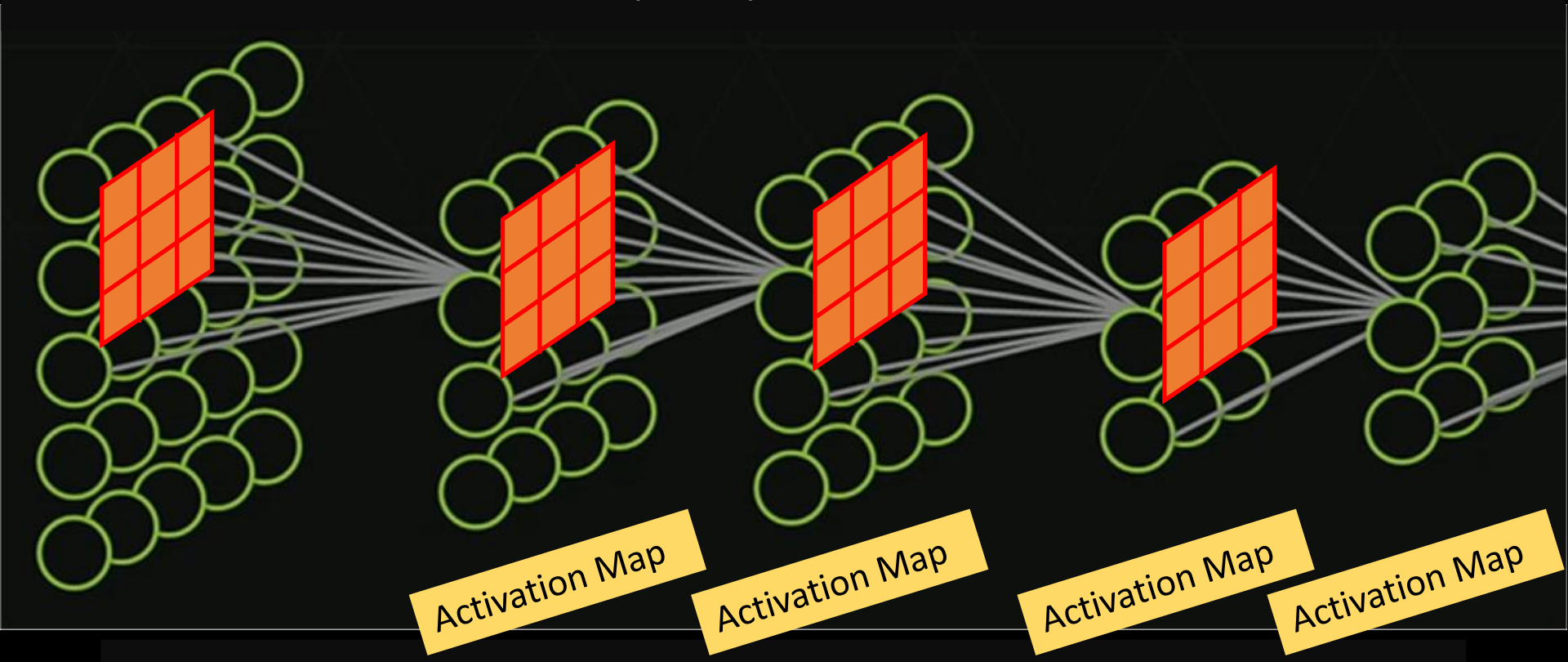
2D view

9 connections = 9 synaps (values) -> 필터



sess.run(train)

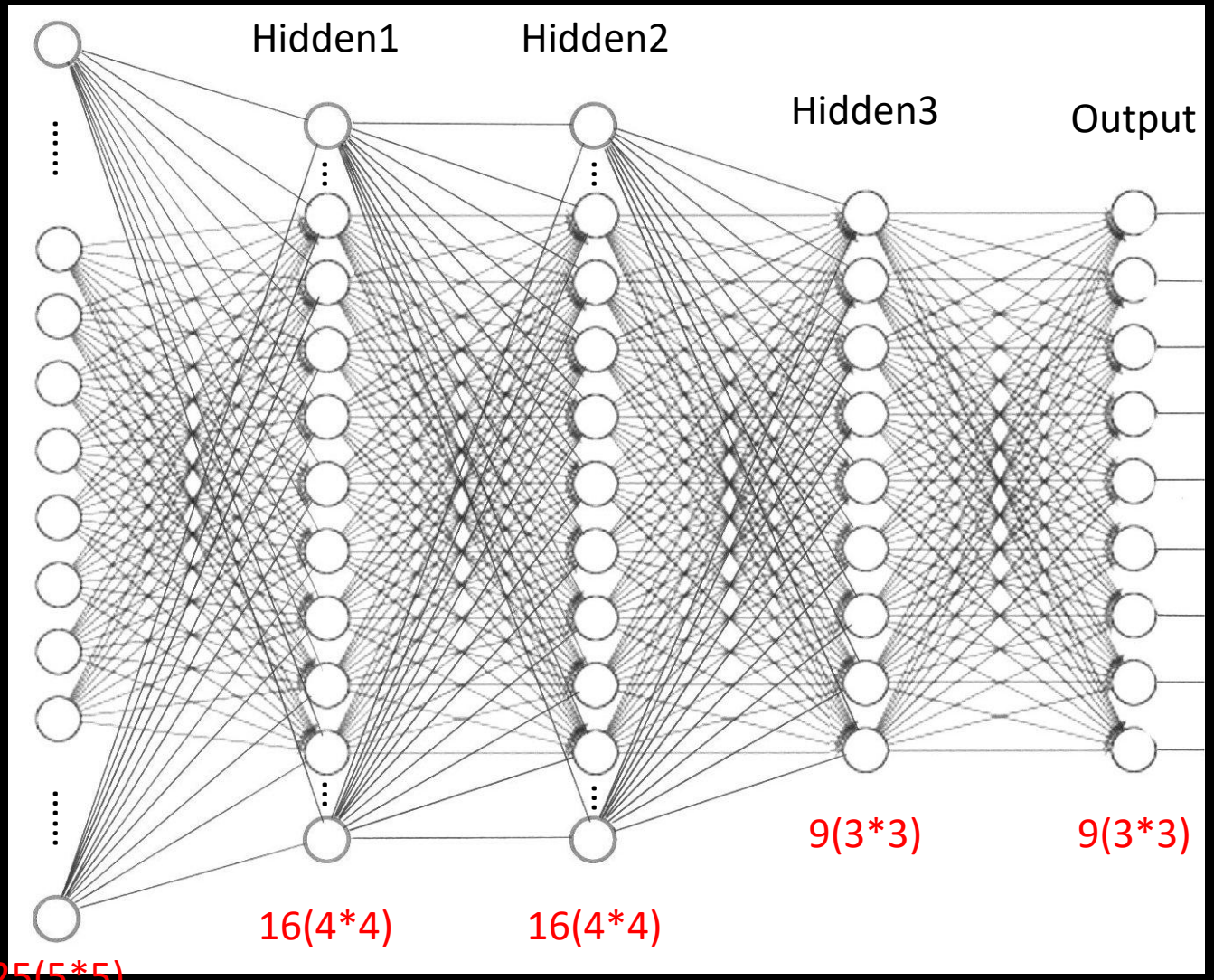
Filter size : 3x3, 1 filter for each convolution,
then how many parameters to be tuned?
(3 * 3) * 4 = 36



If *fully* connected, 25*16+16*16+16*9+9*9 = 881

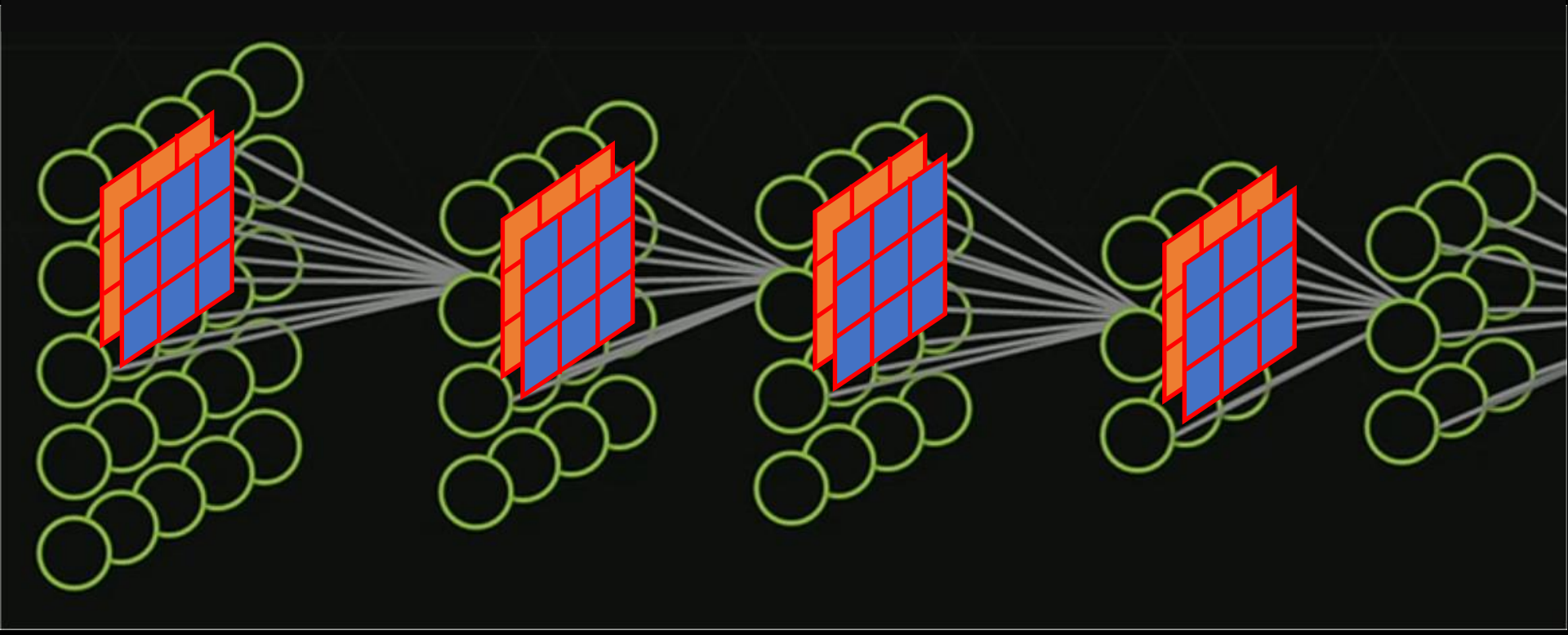
따라서 이미지를 바로 신경망에
넣지 말고 중요한 정보만
걸러서(필터링해서) 주자.

거를 때 쓰는 것 : 필터(filter)

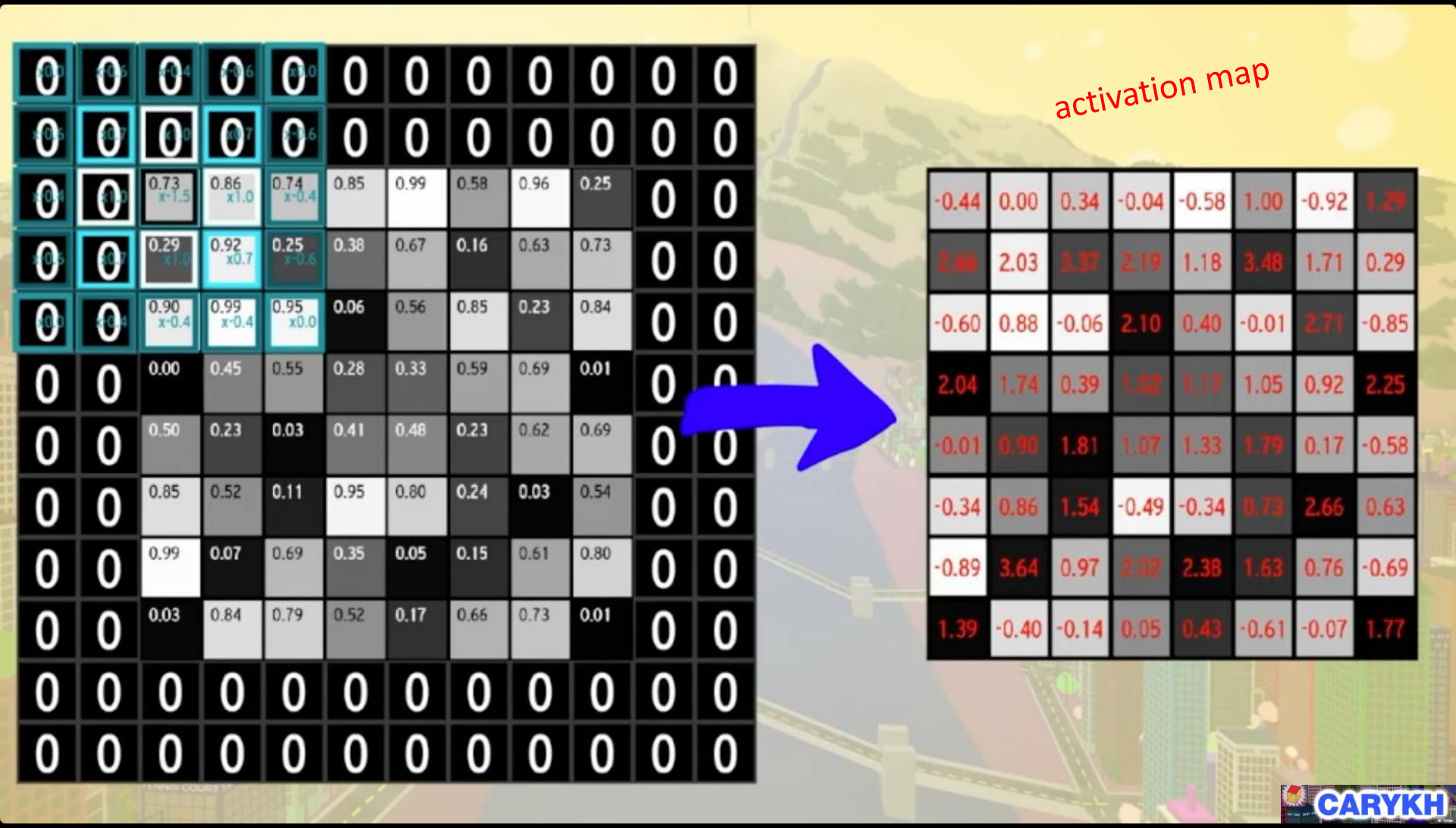

Hidden1
Hidden2
Hidden3
Output
25(5*5)
16(4*4)
16(4*4)
9(3*3)
9(3*3)

필터가 2개라면

(3 * 3 * 2) * 4 = 72



out-of-bound,
패딩



activation map

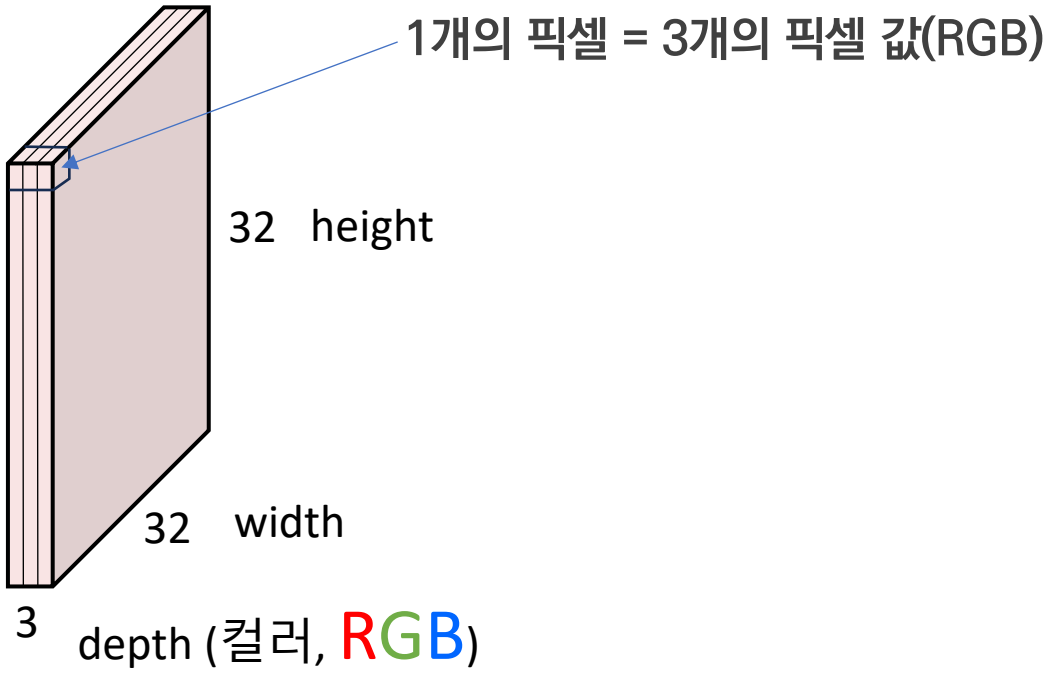
-0.44	0.00	0.34	-0.04	-0.58	1.00	-0.92	1.29
2.66	2.03	3.37	2.19	1.18	3.48	1.71	0.29
-0.60	0.88	-0.06	2.10	0.40	-0.01	2.71	-0.85
2.04	1.74	0.39	1.02	1.17	1.05	0.92	2.25
-0.01	0.90	1.81	1.07	1.33	1.79	0.17	-0.58
-0.34	0.86	1.54	-0.49	-0.34	0.73	2.66	0.63
-0.89	3.64	0.97	2.02	2.38	1.63	0.76	-0.69
1.39	-0.40	-0.14	0.05	0.43	-0.61	-0.07	1.77

Some questions

- Fully connected? (Yes/No)
- How many connections for each pixels?
- Where are the parameters to be tuned?
- What happens if we have 2 filters?
- What happens if no padding(out-of-bound)?
- Convolution again with the resulting activation map

Convolution Layer

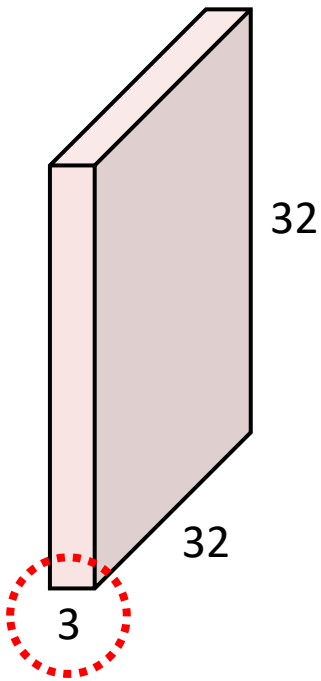
32x32x3 pixels image

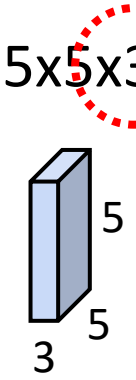


https://youtu.be/LxfUGhug-iQ?list=PLkt2uSq6rBVctENoVBg1TpCC7OQi31AlC&t=119

Convolution Layer

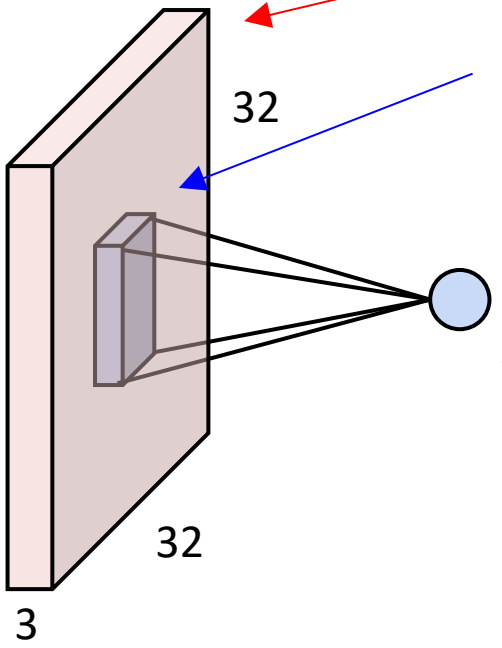
필터도 RGB 각각에 대해 존재:
따라서 3개





Convolve the filter with the image
i.e. “slide over the image spatially, computing dot products”

Convolution Layer



32x32x3 image

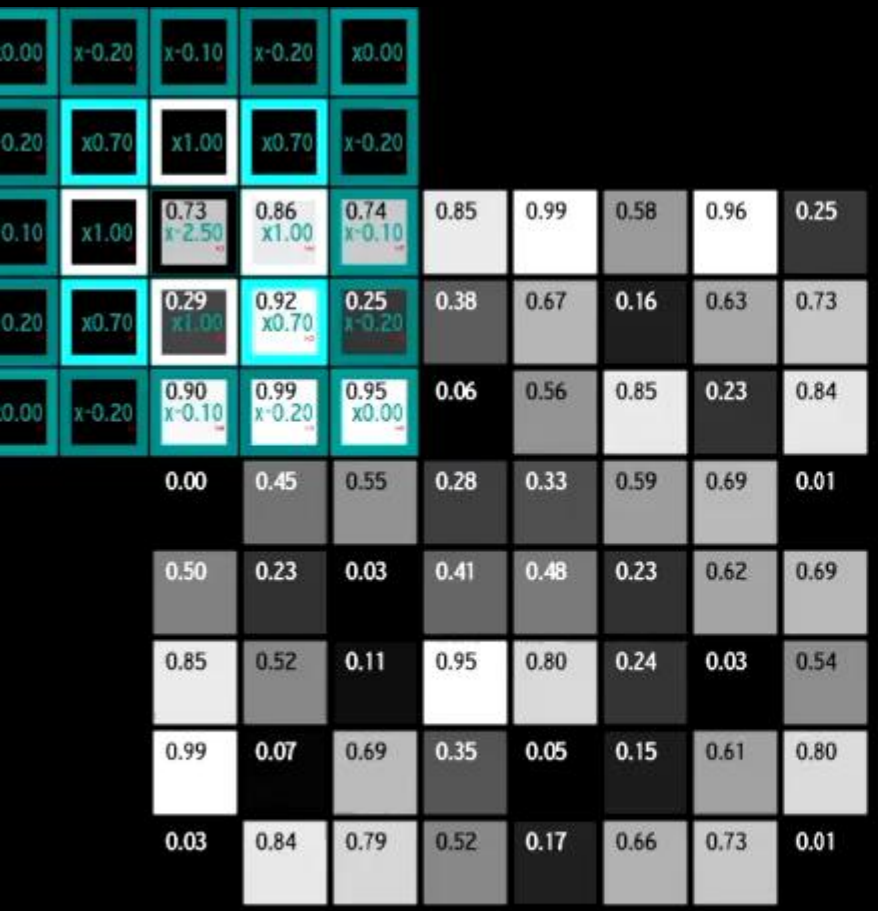
5x5x3 filter w

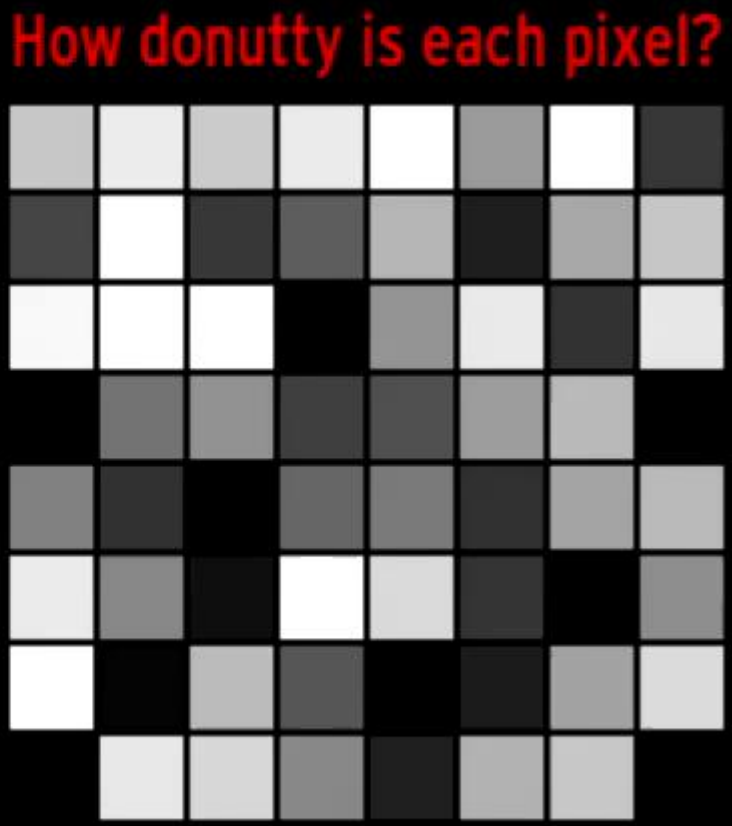
시냅스(연결)은 어디에?

1 number:
the result of taking a dot product between the filter and a small 5x5x3 chunk of the image
(i.e. 5*5*3 = 75-dimensional dot product + bias)

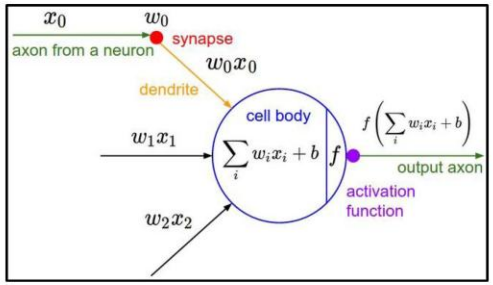
$$w^T x + b$$

RGB라면 어떻게 동작할까?

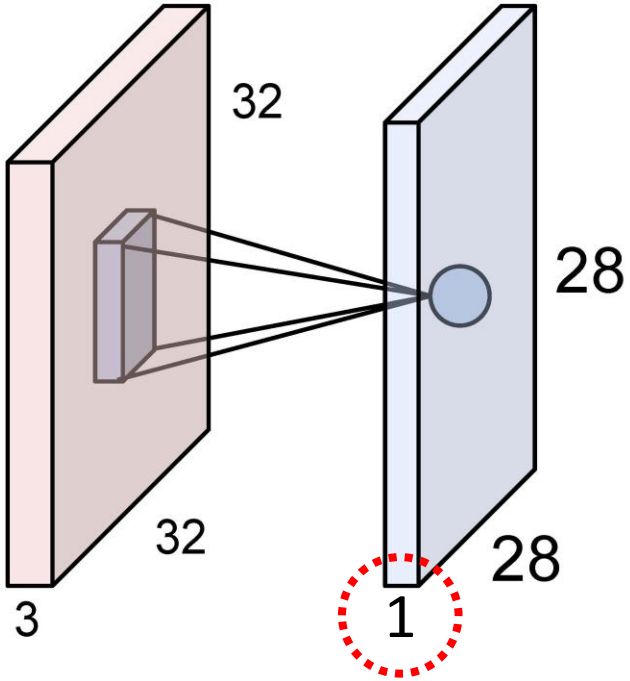




The brain/neuron view of CONV Layer



시냅스(연결)은 어디에?



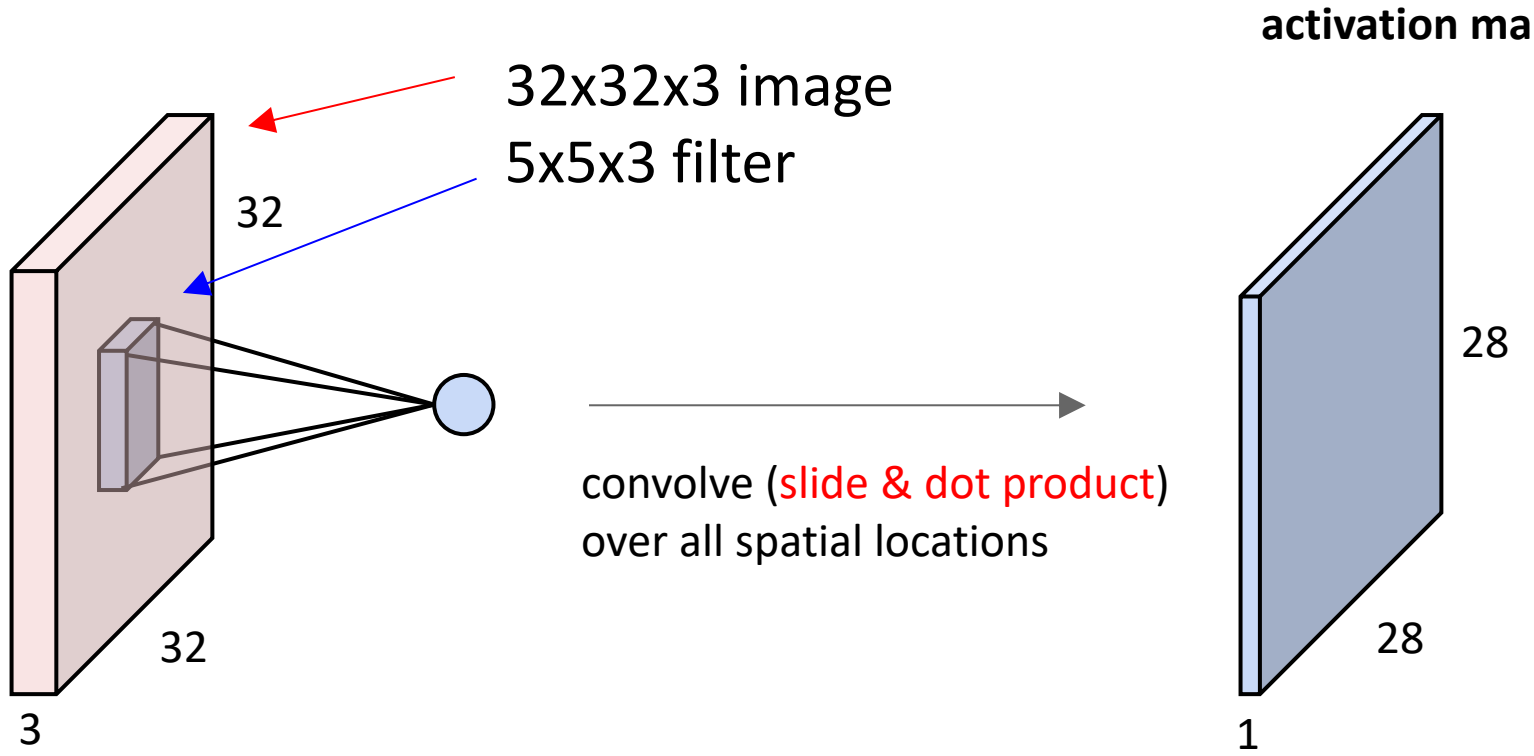
An activation map is a 28x28 sheet of neuron outputs:

1. Each is connected to a small region in the input
2. All of them share parameters

"5x5 filter" -> "5x5 receptive field for each neuron"

Convolution Layer

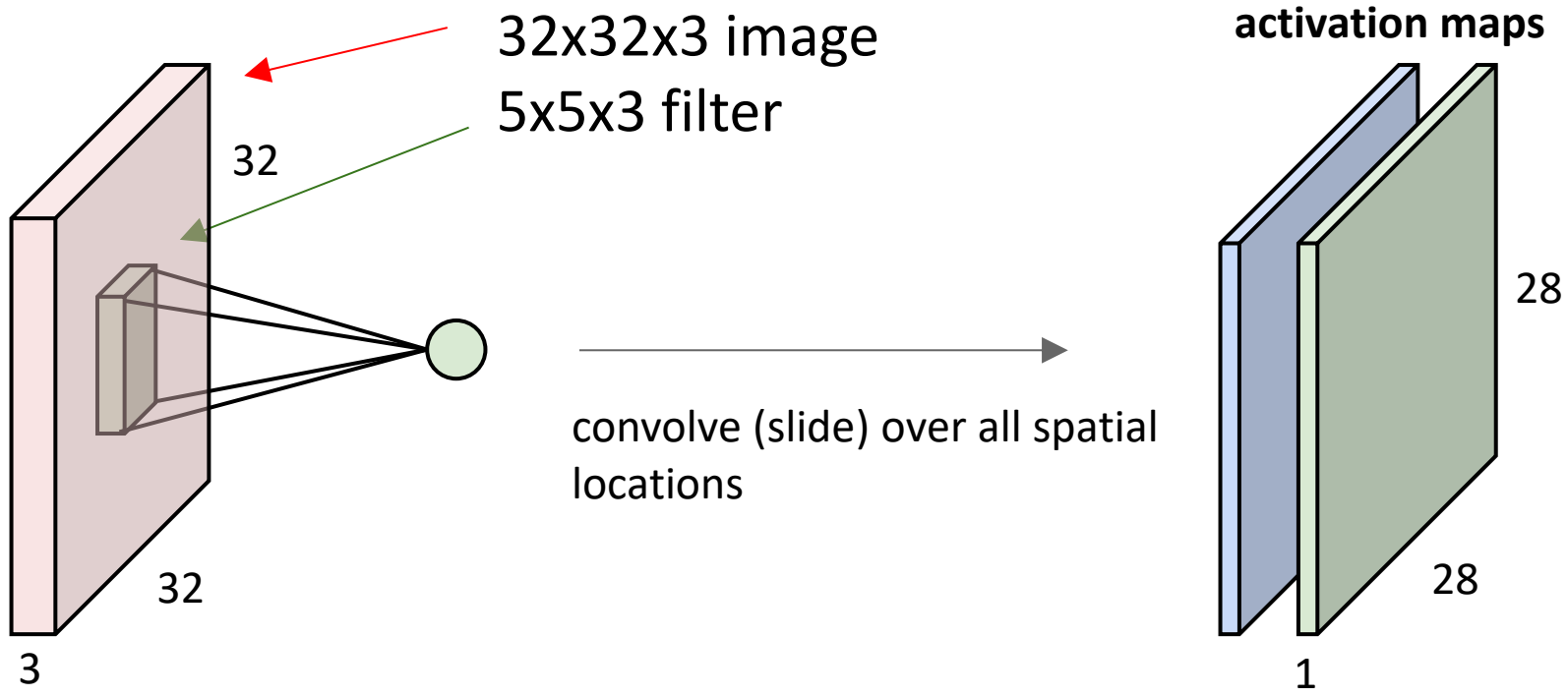
필터의 수가 1개라면



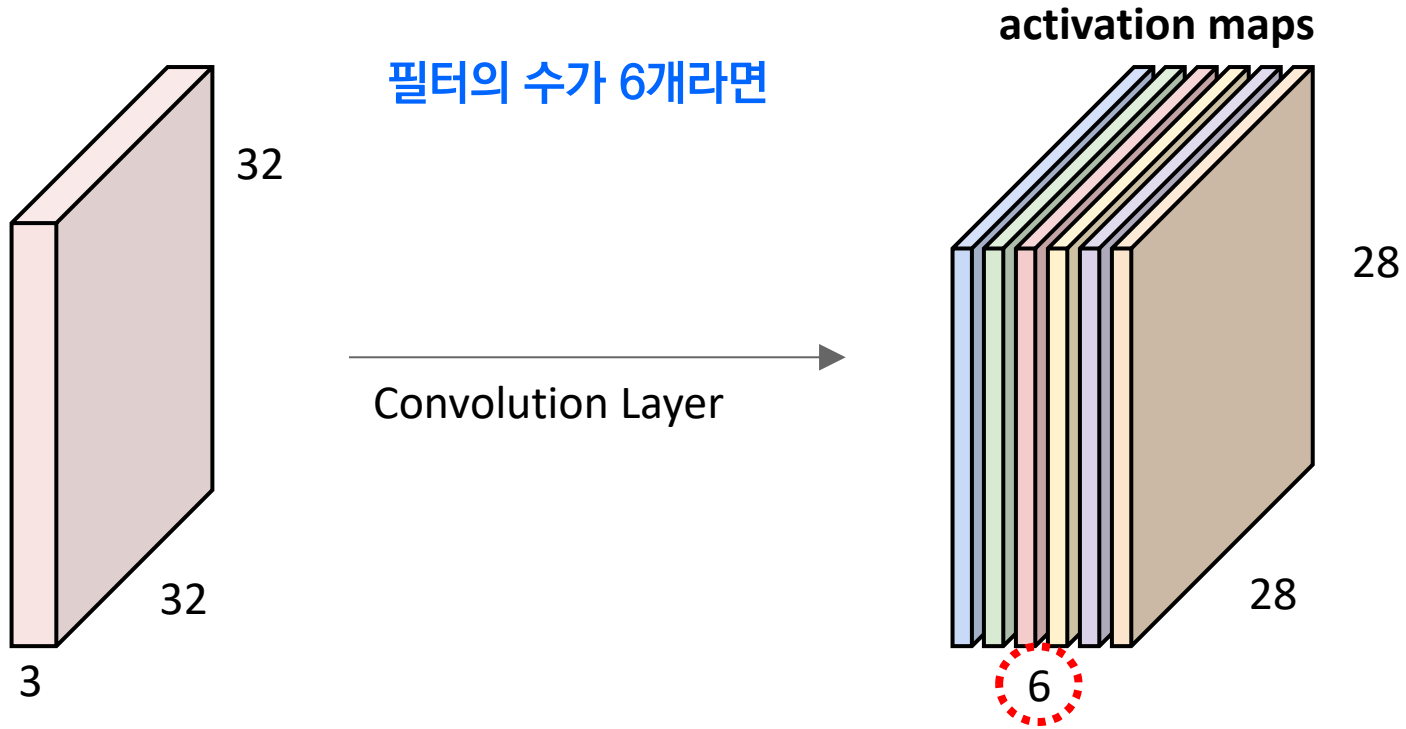
시냅스(연결)은 어디에?

Convolution Layer

필터의 수가 2개라면 (초록색 필터 추가)



For example, if we had 6 5x5 filters, we'll get 6 separate activation maps:

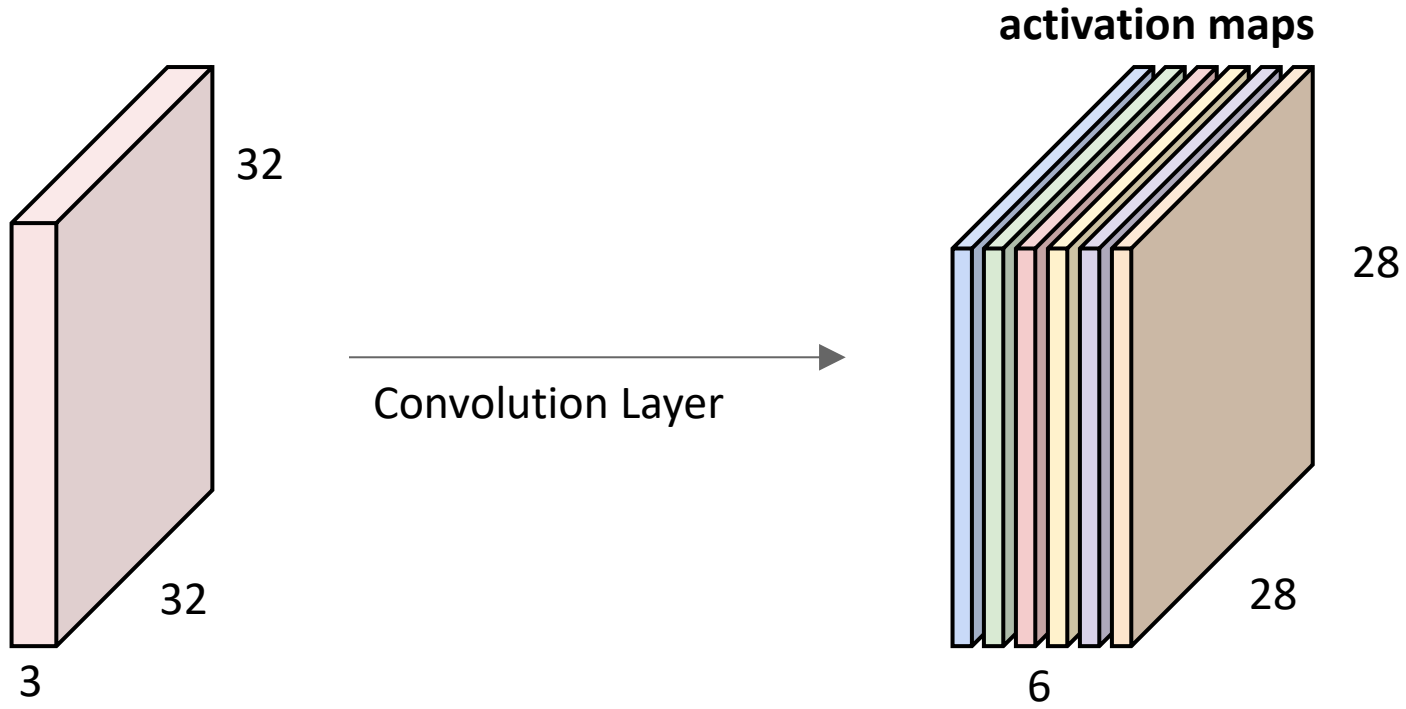


We processed [32x32x3] volume into [28x28x6] volume.

Q: how many parameters would this be if we used a fully connected layer instead?

A: (32*32*3)*(28*28*6) = **14.5M parameters**, **~14.5M multiplies**

For example, if we had 6 5x5 filters, we'll get 6 separate activation maps:



We processed [32x32x3] volume into [28x28x6] volume.

Q: how many parameters are used instead?

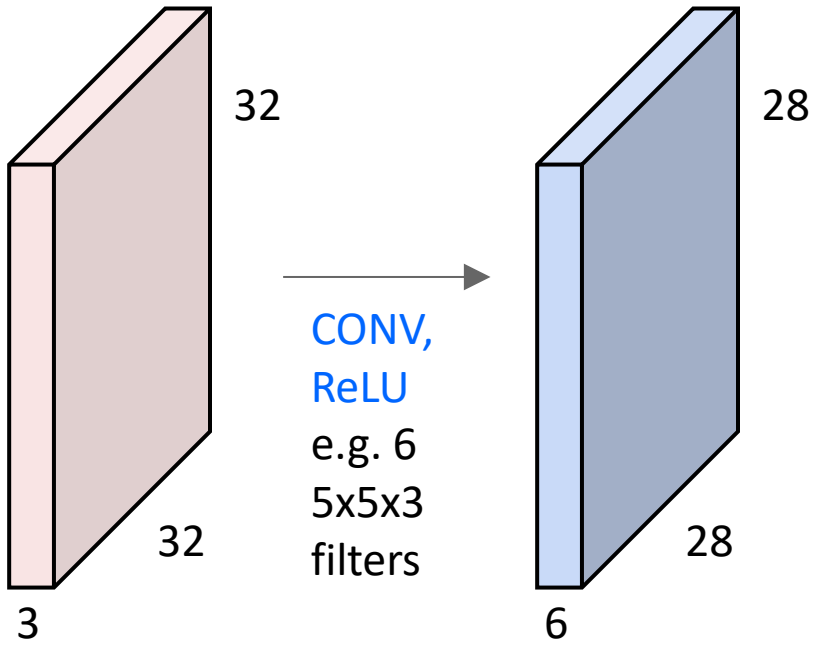
A: (5*5*3)*6 = **450 parameters**, (5*5*3)*(28*28*6) = **~350K multiplies**

5*5 RGB(3) 필터 가 움직이면서 28*28 맵을 6개 만들어 냄.

1 Filter -> 1 Activation Map

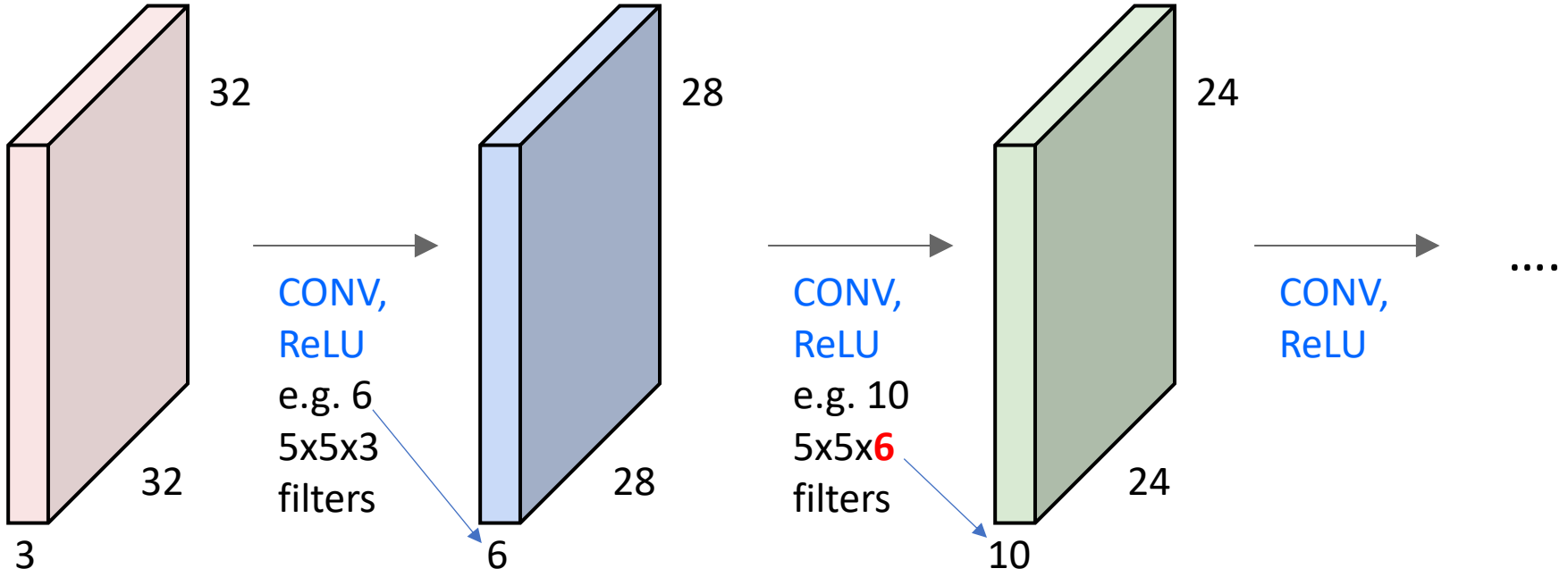
6 Filters -> 6 Activation Maps

Preview: ConvNet is a sequence of Convolution Layers, interspersed with activation functions

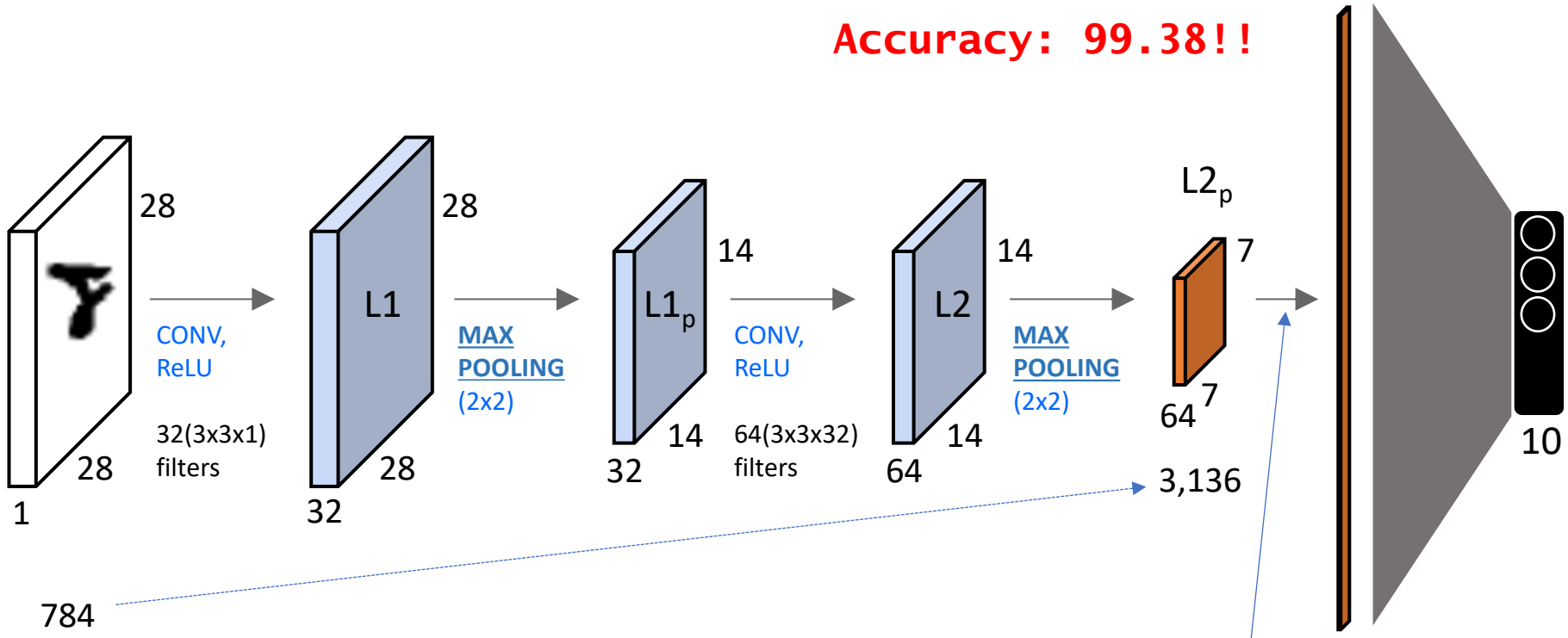


Preview: ConvNet is a sequence of Convolutional Layers, interspersed with activation functions

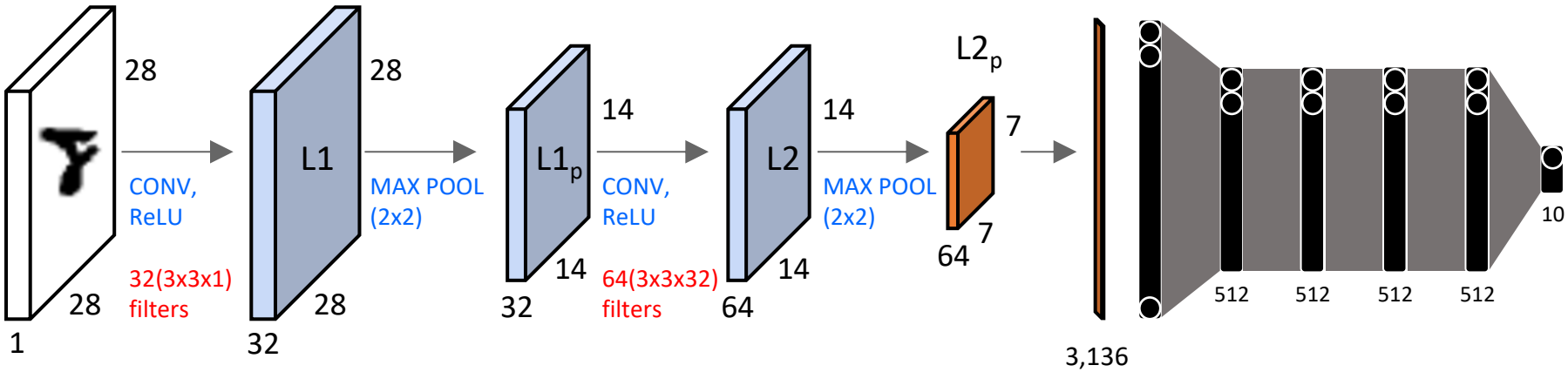
시냅스(연결)은 어디에?



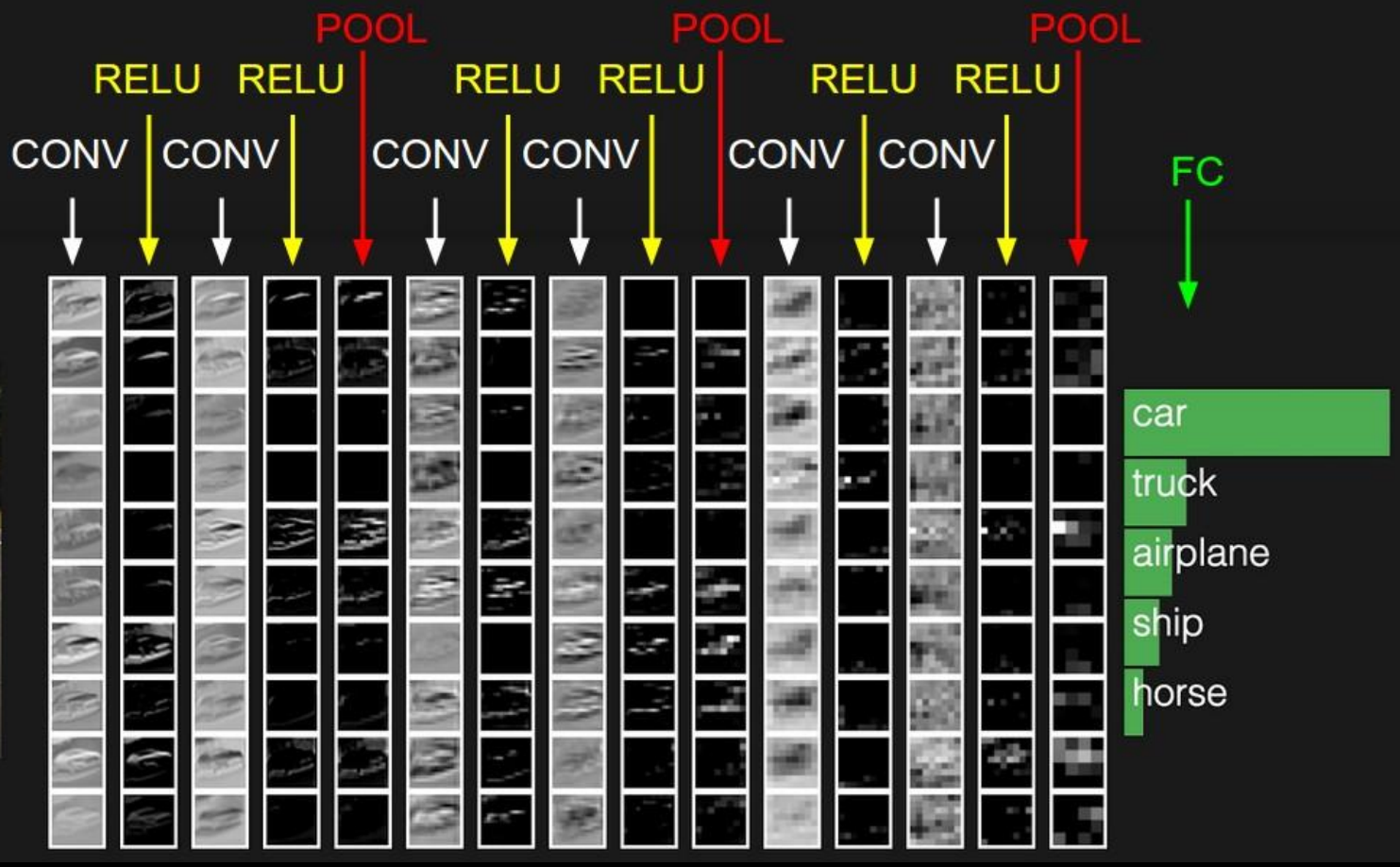
Accuracy: 99.38!!



L = tf.reshape(L2p, [-1, 7 * 7 * 64])


28
28
1
CONV,
ReLU
32(3x3x1)
filters
L1
28
28
32
MAX POOL
(2x2)
$L1_p$
14
14
32
CONV,
ReLU
64(3x3x32)
filters
L2
14
14
64
MAX POOL
(2x2)
$L2_p$
7
7
64
3,136
512
512
512
512
10

Two more layers to go: POOL/FC



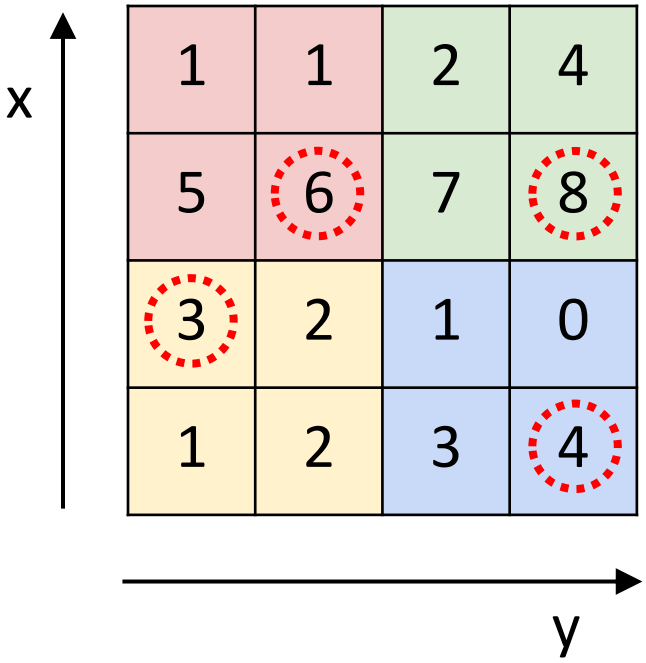
MAX POOLING

풀링은 차원감소를 의미함.

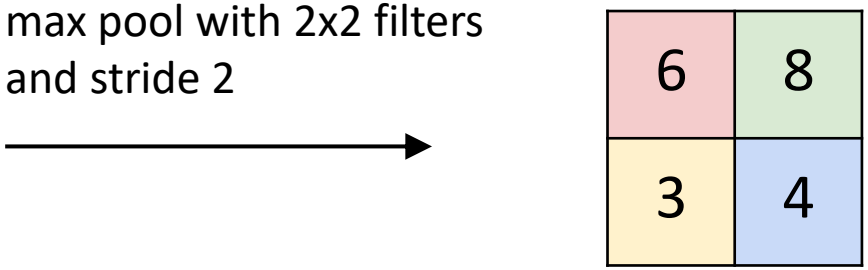
맥스 풀링은 큰값을 선택하여 차원감소하는 것.

CNN이 감지한 특징을 더욱 강조하기 위한 것.

Single depth slice

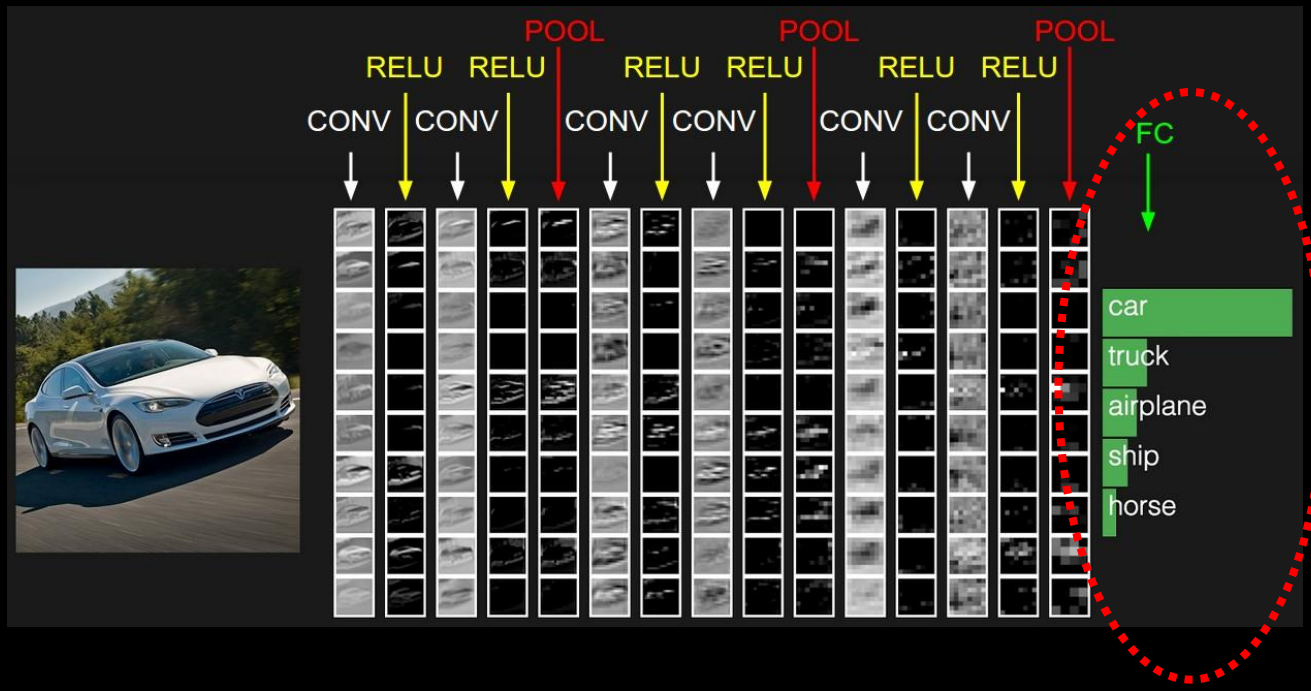


max pool with 2x2 filters
and stride 2



Fully Connected Layer (FC layer)

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



HOW A DEEP NEURAL NETWORK SEES

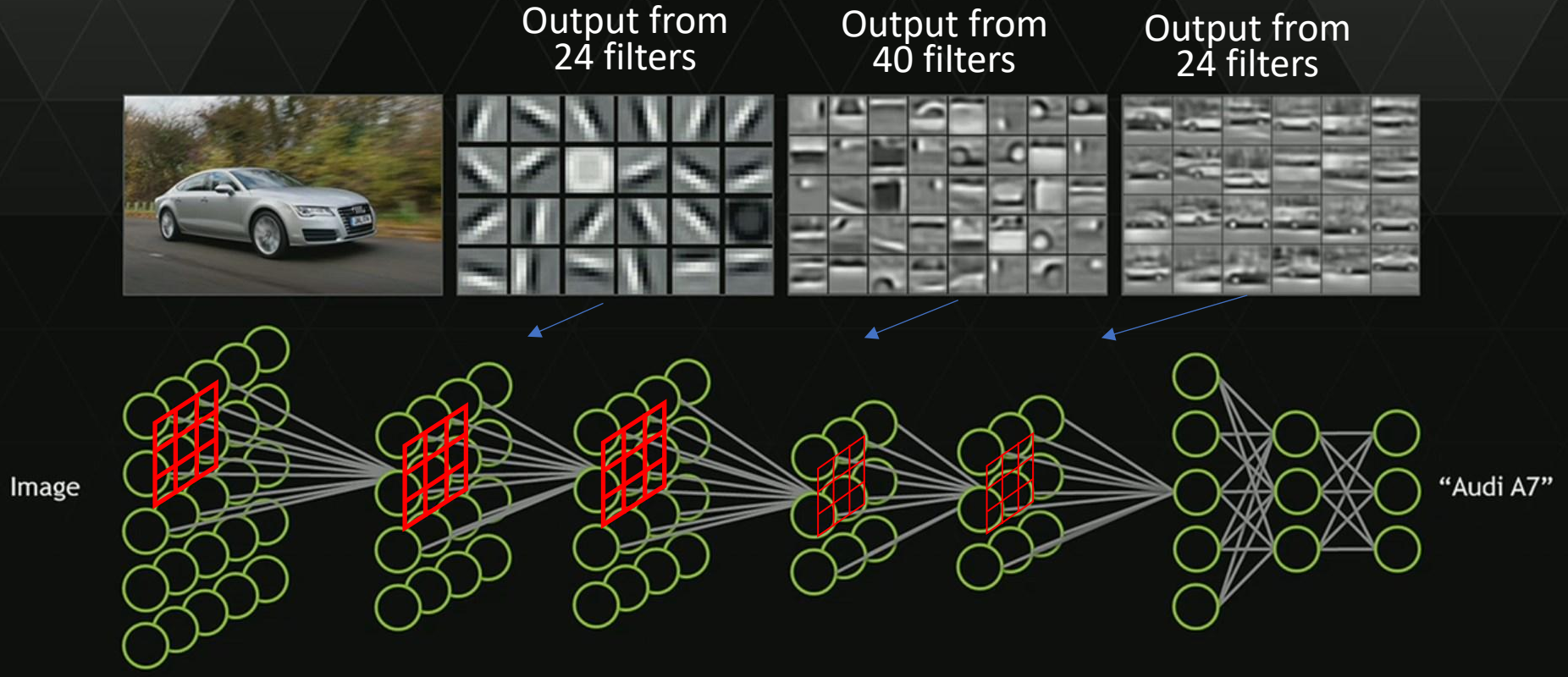
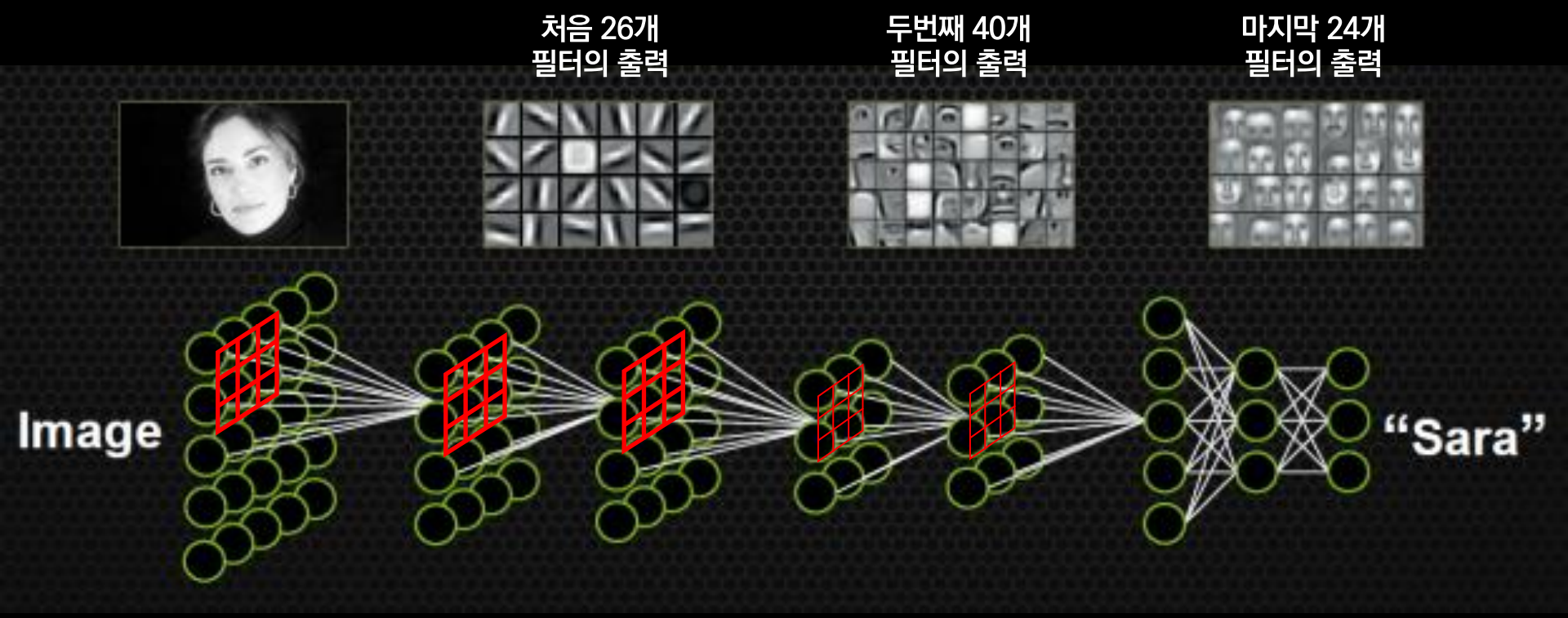


Image source: "Unsupervised Learning of Hierarchical Representations with Convolutional Deep Belief Networks" ICML 2009 & Comm. ACM 2011. Honglak Lee, Roger Grosse, Rajesh Ranganath, and Andrew Ng.


처음 26개
필터의 출력
두번째 40개
필터의 출력
마지막 24개
필터의 출력
Image
“Sara”

Learning in CNN

- Parameter tuning in filters
  → filter organizing
- Parameter tuning in fully connected layers

Theoretical backgrounds of CNN

A bit of history:

Hubel & Wiesel,

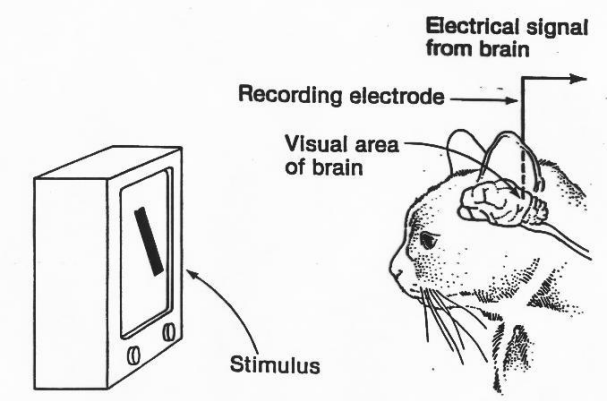
1959

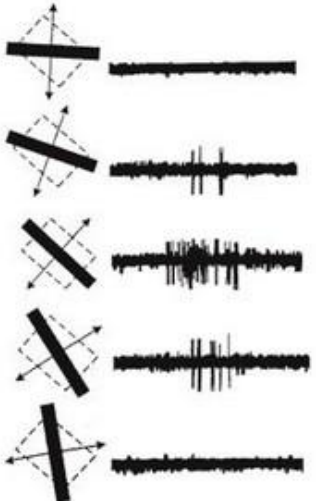
RECEPTIVE FIELDS OF SINGLE NEURONES IN
THE CAT'S STRIATE CORTEX

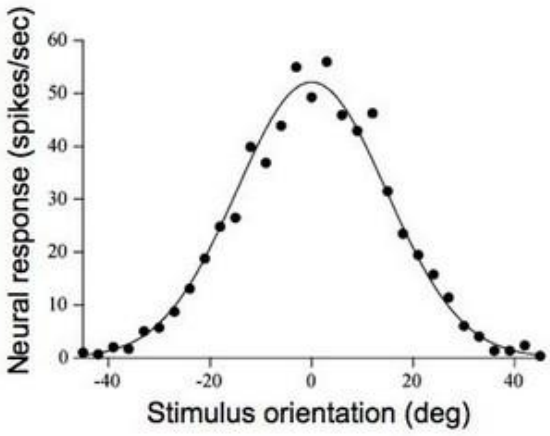
1962

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

1968...



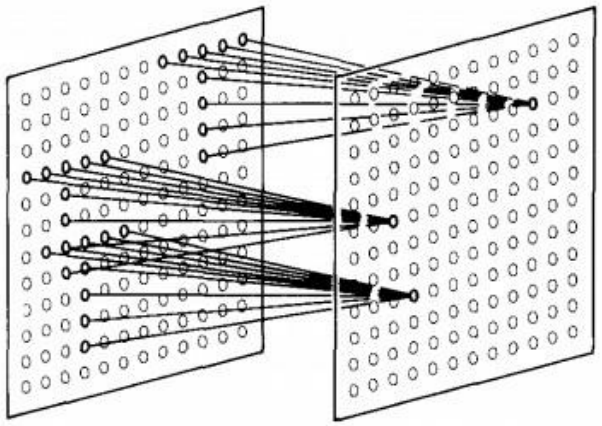




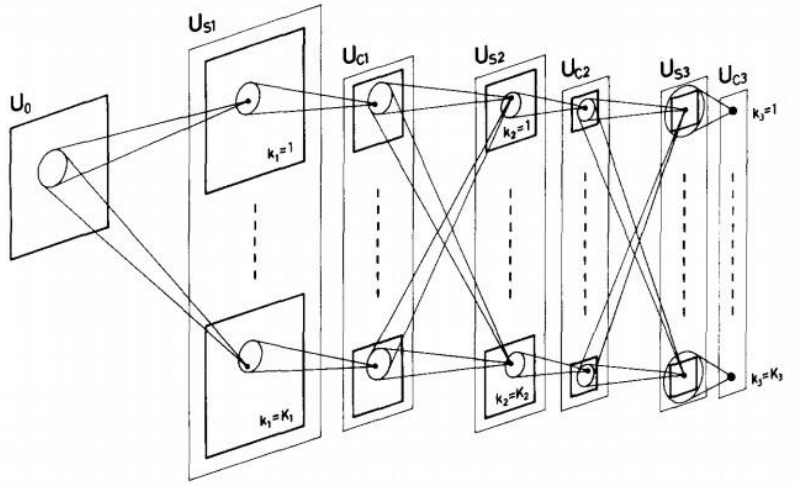
A bit of history:

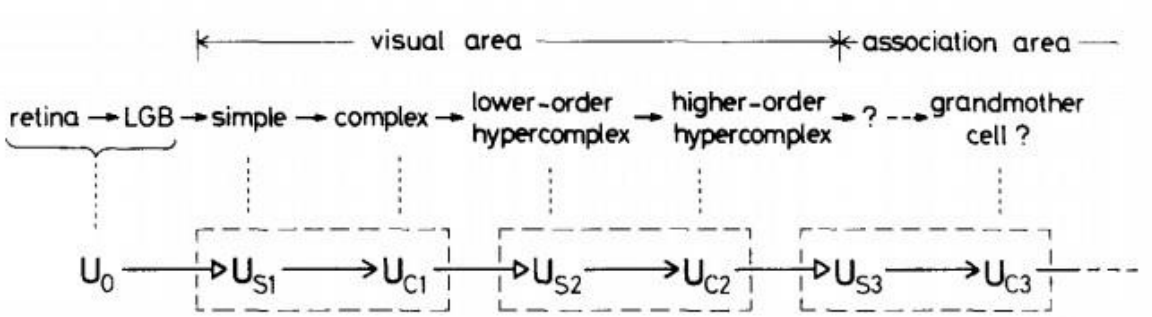
Neuro-cognitron

[Fukushima 1980]



"sandwich" architecture (SCSCSC…)
simple cells: modifiable parameters
complex cells: perform pooling

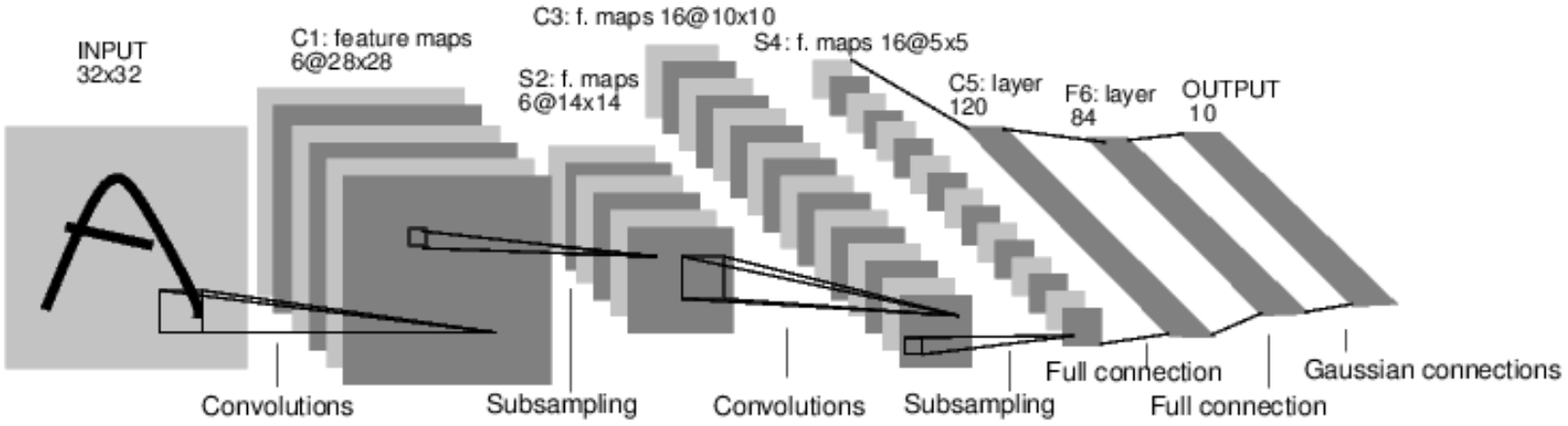




LeNet-5

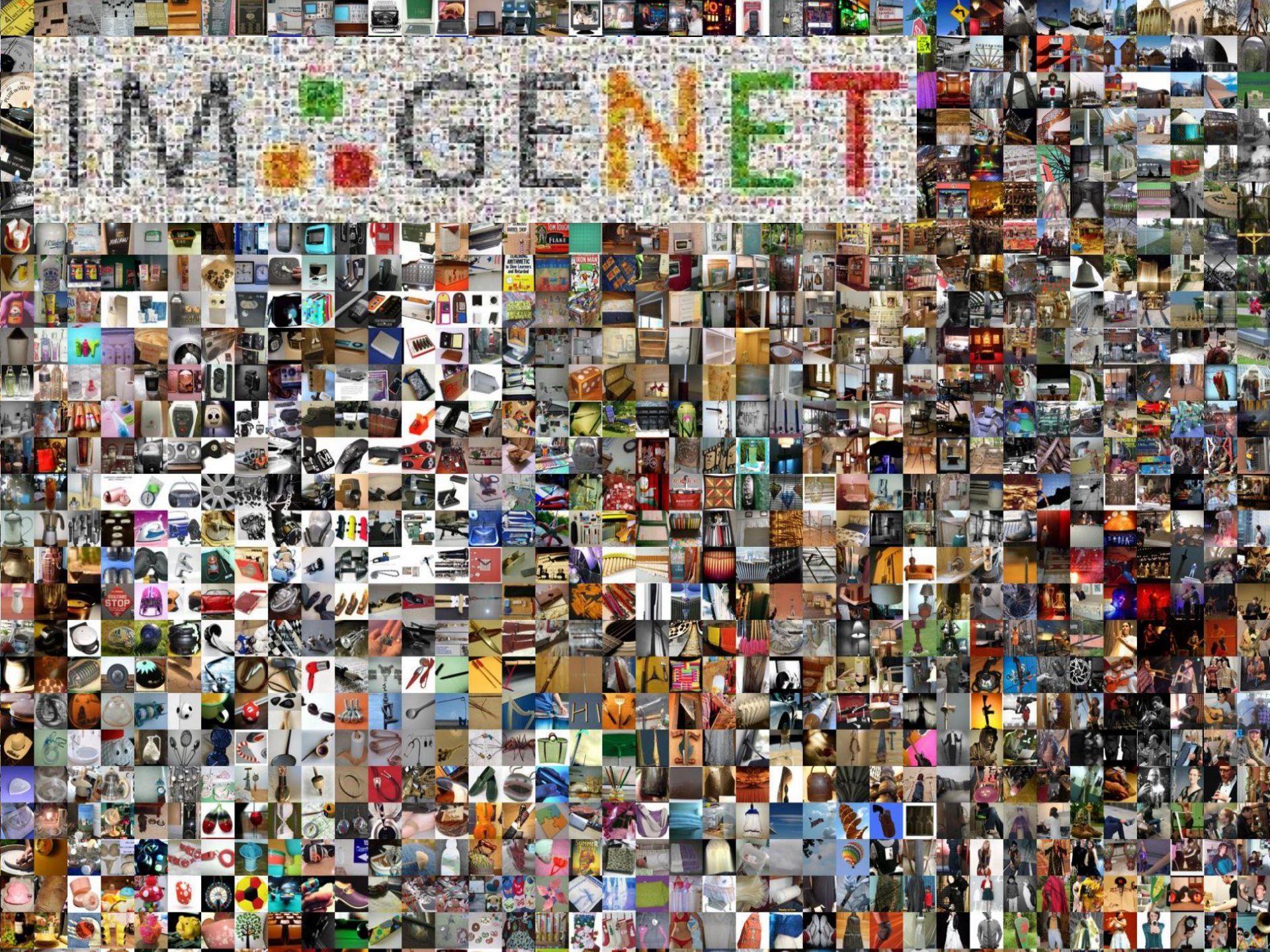
Gradient-based learning applied to document recognition

[LeCun, Bottou, Bengio, Haffner 1998]



Convolution-Pooling-Convolution-Pooling-FC

Case Studies

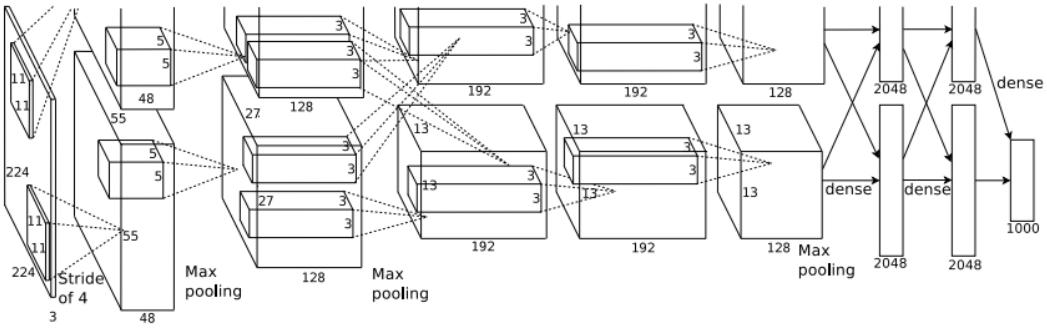

IMAGENET

ImageNet and Competition

- ImageNet: categorization of huge amount of images according to WordNet schema
- database for ILSVRC (ImageNet Large Scale Visual Recognition Competition)
- Largest Computer Vision Challenge showing state-of-the-art performance on the dataset every year
- firstly collected by Deng et al. in 2009
- And it has been organized by Stanford University Vision Lab (prof. Fei-Fei Li) since 2010.

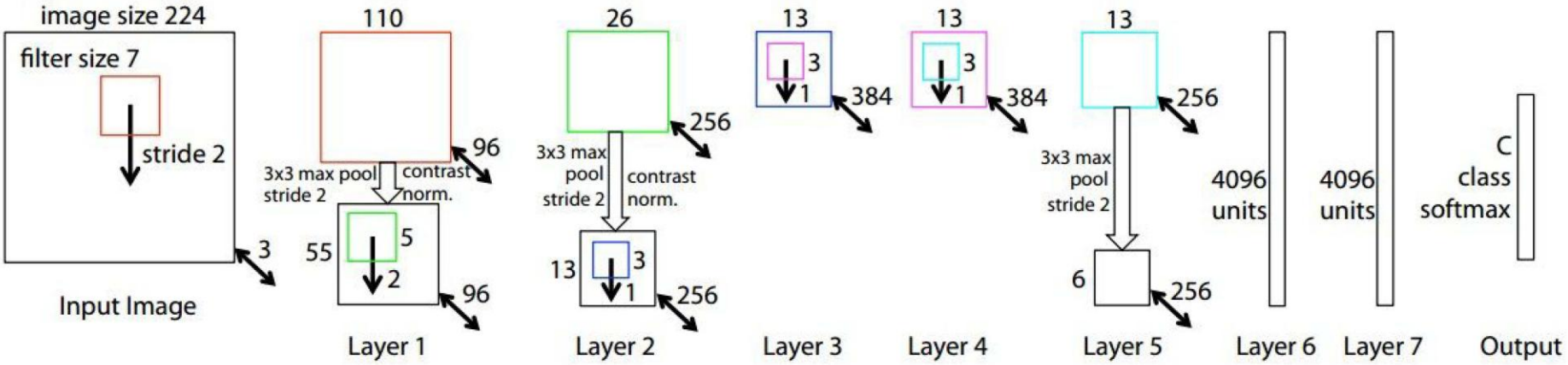
Case Study: AlexNet

[Krizhevsky et al. 2012]



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)

Case Study: ZFNet *[Zeiler and Fergus, 2013]*



AlexNet but:
CONV1: change from (11x11 stride 4) to (7x7 stride 2)
CONV3,4,5: instead of 384, 384, 256 filters use 512, 1024, 512

ImageNet top 5 error: 15.4% -> 14.8%

Case Study: VGGNet

[Simonyan and Zisserman, 2014]

Only 3x3 CONV stride 1, pad 1
and 2x2 MAX POOL stride 2

best model

11.2% top 5 error in ILSVRC 2013
->
7.3% top 5 error

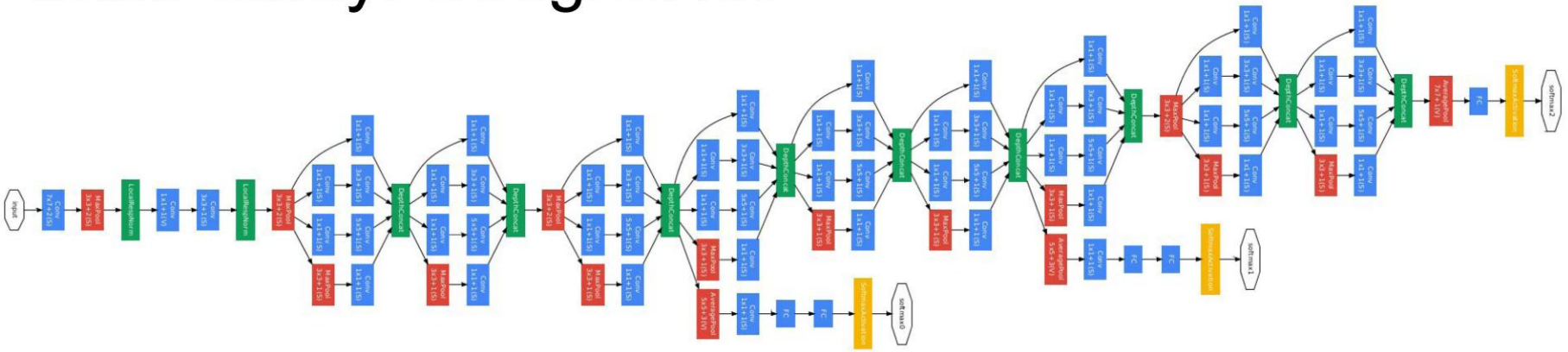
ConvNet Configuration					
A	A-LRN	B	C	D	E
11 weight layers	11 weight layers	13 weight layers	16 weight layers	16 weight layers	19 weight layers
input (224 × 224 RGB image)					
conv3-64	conv3-64 **LRN**	conv3-64 **conv3-64**	conv3-64 conv3-64	conv3-64 conv3-64	conv3-64 conv3-64
maxpool					
conv3-128	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 **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					

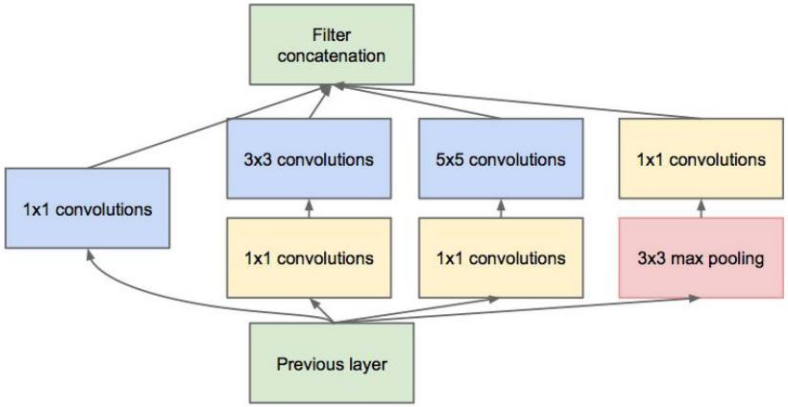
Table 2: **Number of parameters** (in millions).

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

Case Study: GoogLeNet

[Szegedy et al., 2014]



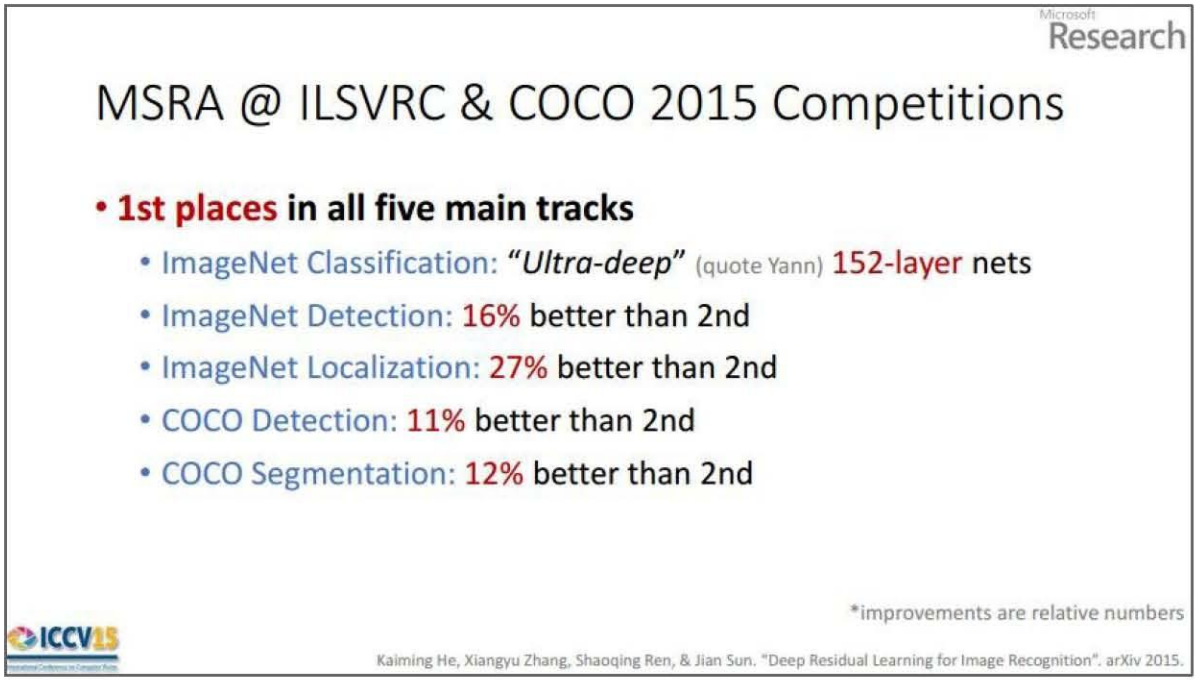


Inception module

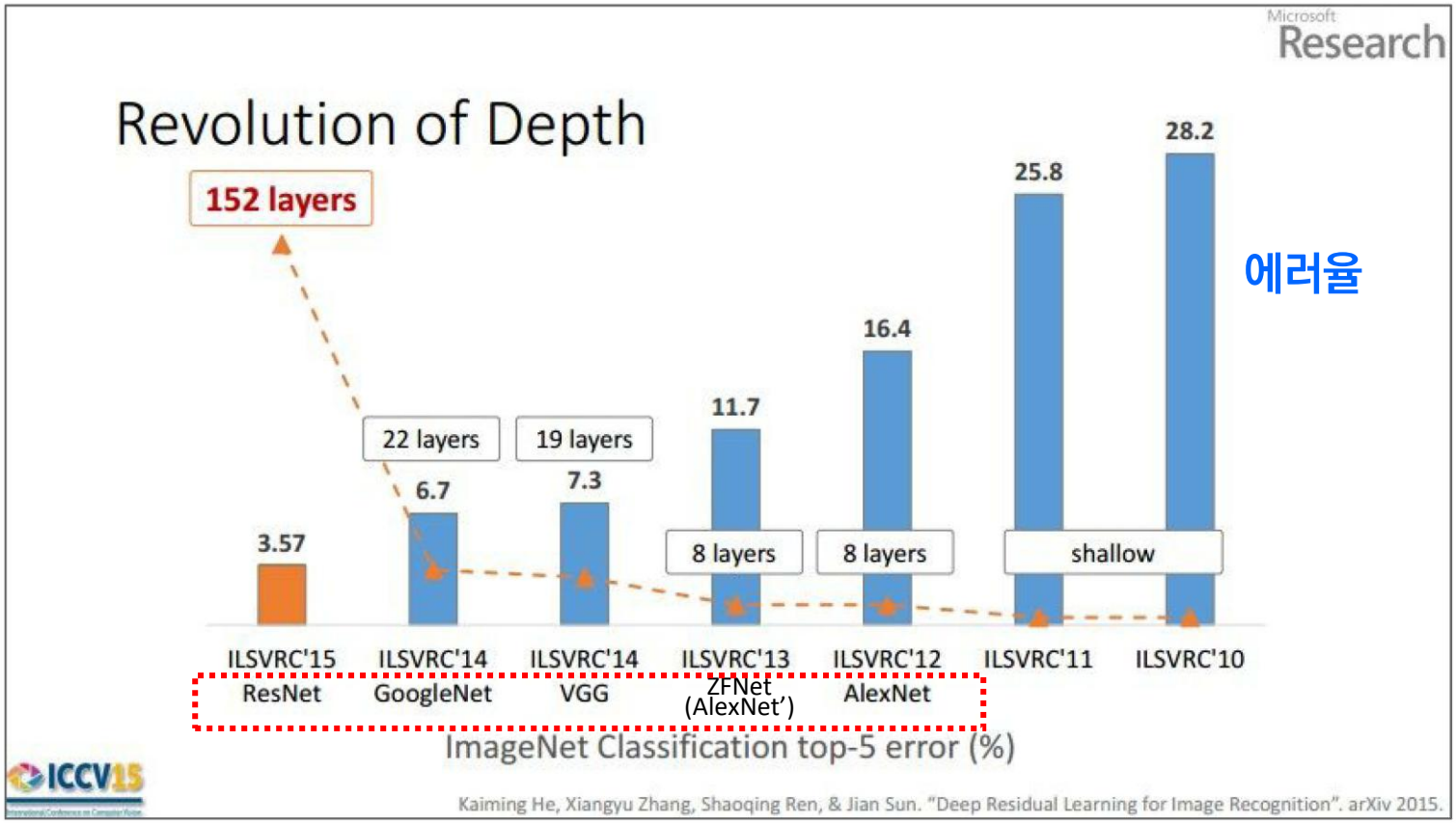
ILSVRC 2014 winner (6.7% top 5 error)

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

ILSVRC 2015 winner (3.6% top 5 error)



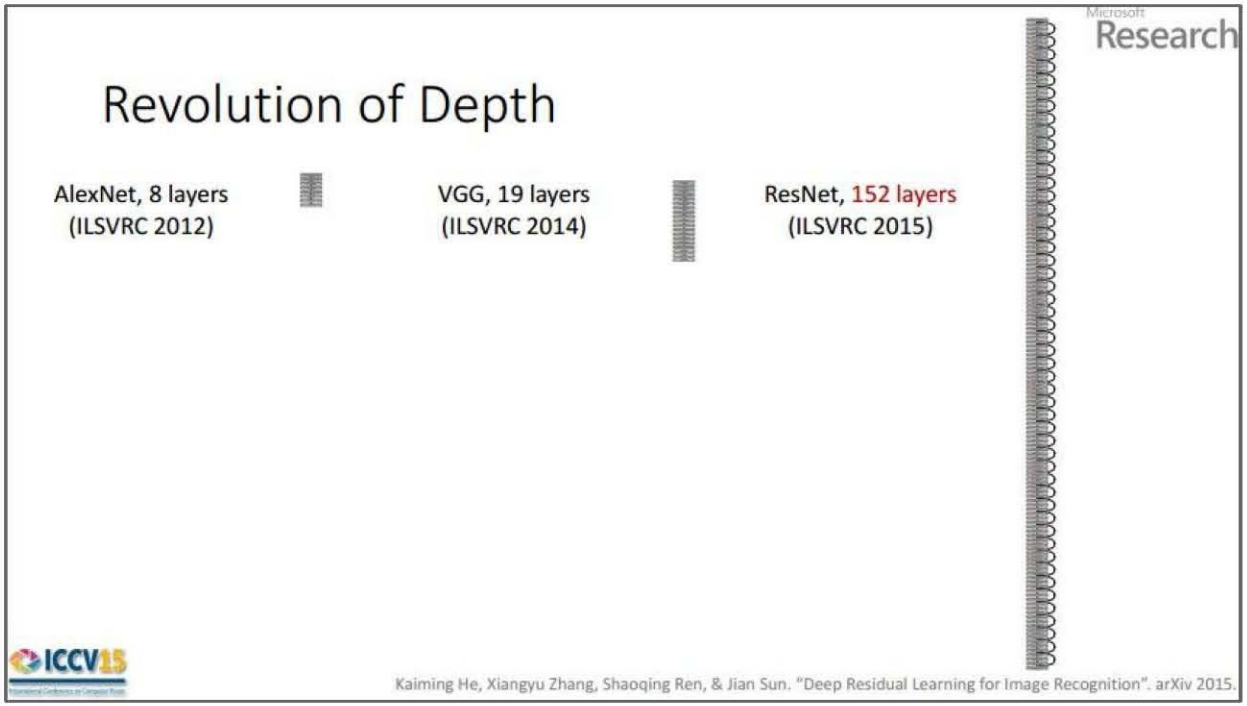
Slide from Kaiming He's recent presentation https://www.youtube.com/watch?v=1PGLj-uKT1w



(slide from Kaiming He's recent presentation)

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

ILSVRC 2015 winner (3.6% top 5 error)



2-3 weeks of training on 8 GPU machine

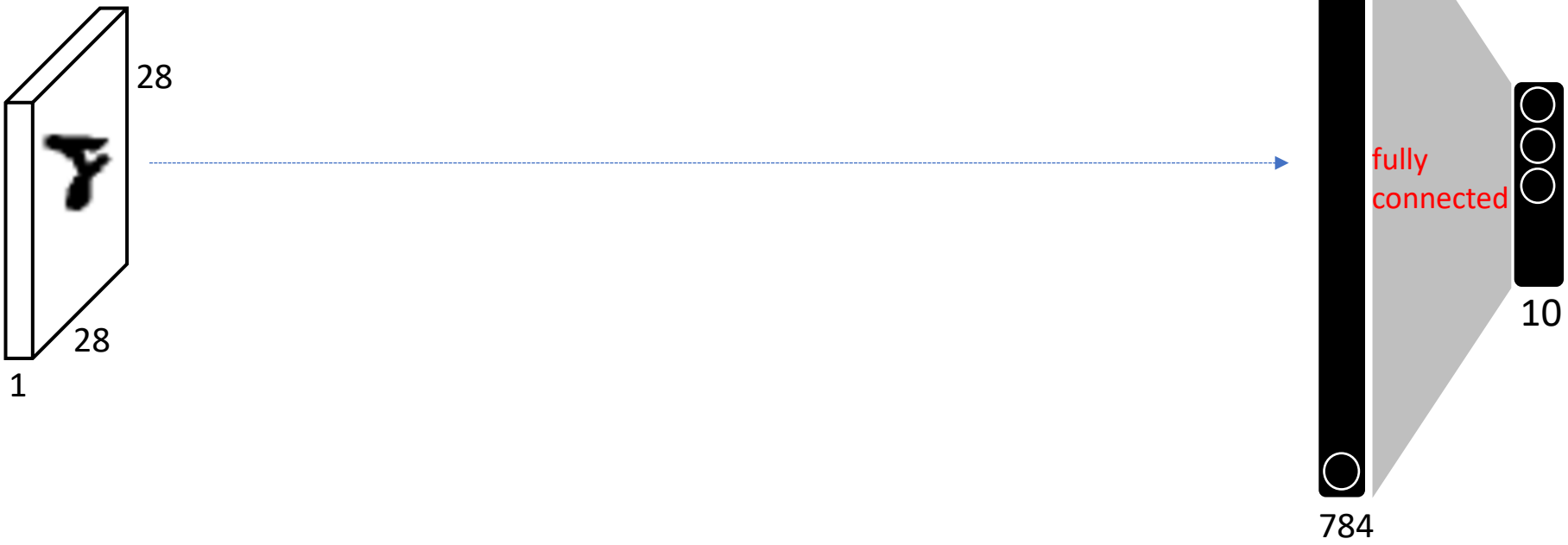
at runtime: faster than a VGGNet! (even though it has 8x more layers)

(slide from Kaiming He's recent presentation)

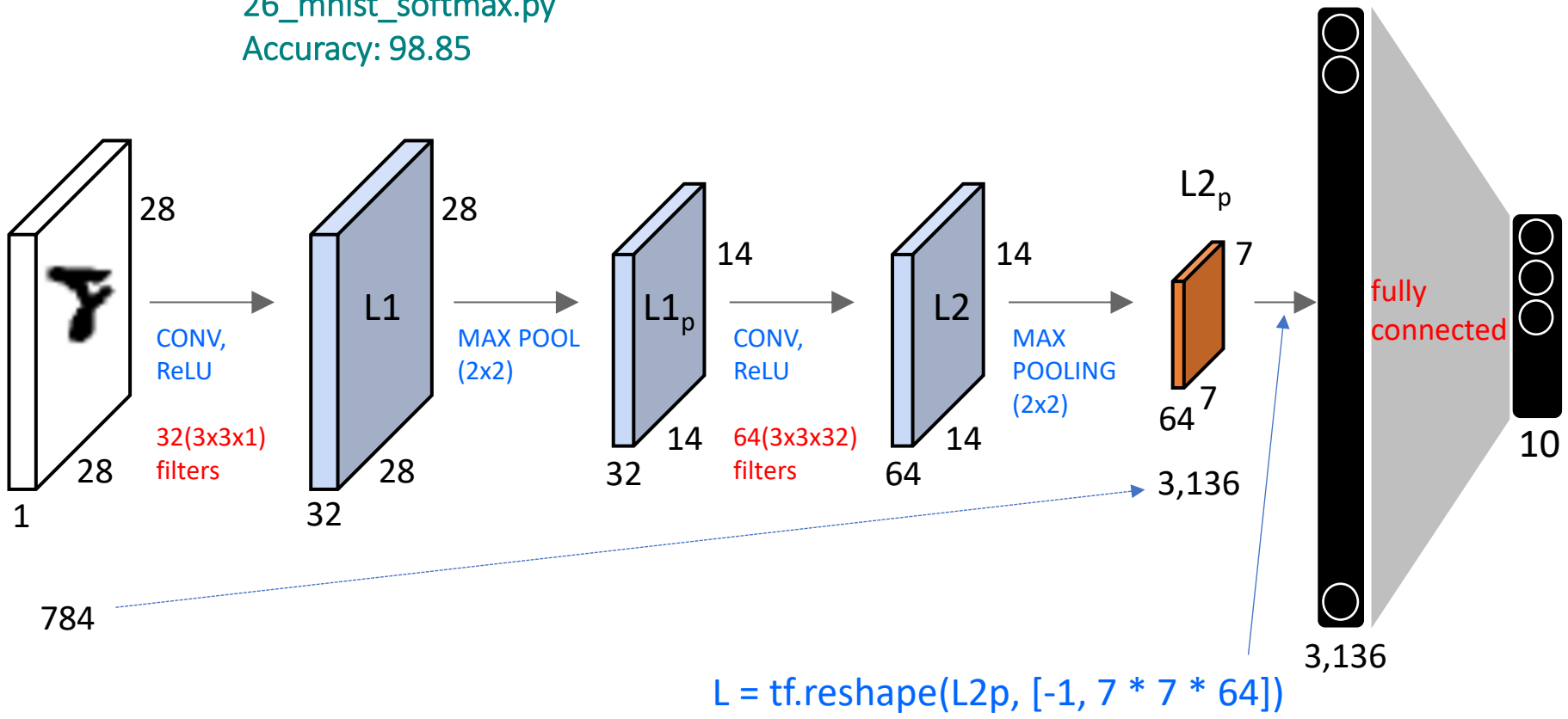
Dot product & shift for feature extraction

CNN, Convolutional Neural Network

20_mnist_softmax.py
Accuracy: 90.23

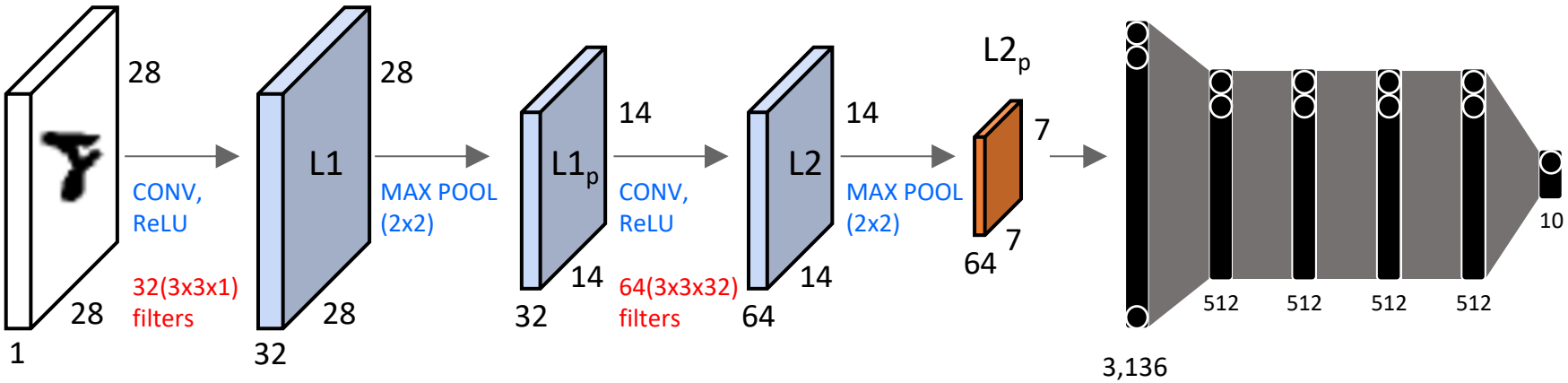


26_mnist_softmax.py
Accuracy: 98.85



L = tf.reshape(L2p, [-1, 7 * 7 * 64])

Accuracy: ?????


28
28
1
CONV,
ReLU
32(3x3x1)
filters
L1
28
28
32
MAX POOL
(2x2)
L1p
14
14
32
CONV,
ReLU
64(3x3x32)
filters
L2
14
14
64
MAX POOL
(2x2)
L2p
7
7
64
3,136
512
512
512
512
10