Hochschule Offenburg
offenburg.university

AlexNet

Leon Friedrich, INFM

EMI Elektrotechnik, Medizintechnik und Informatik

Agenda

- Convolution
- AlexNet
  - Why AlexNet?
  - Architecture
- Practical Part
  - Visualization of learned Kernels
  - Visualization of Convolution

Convolution I

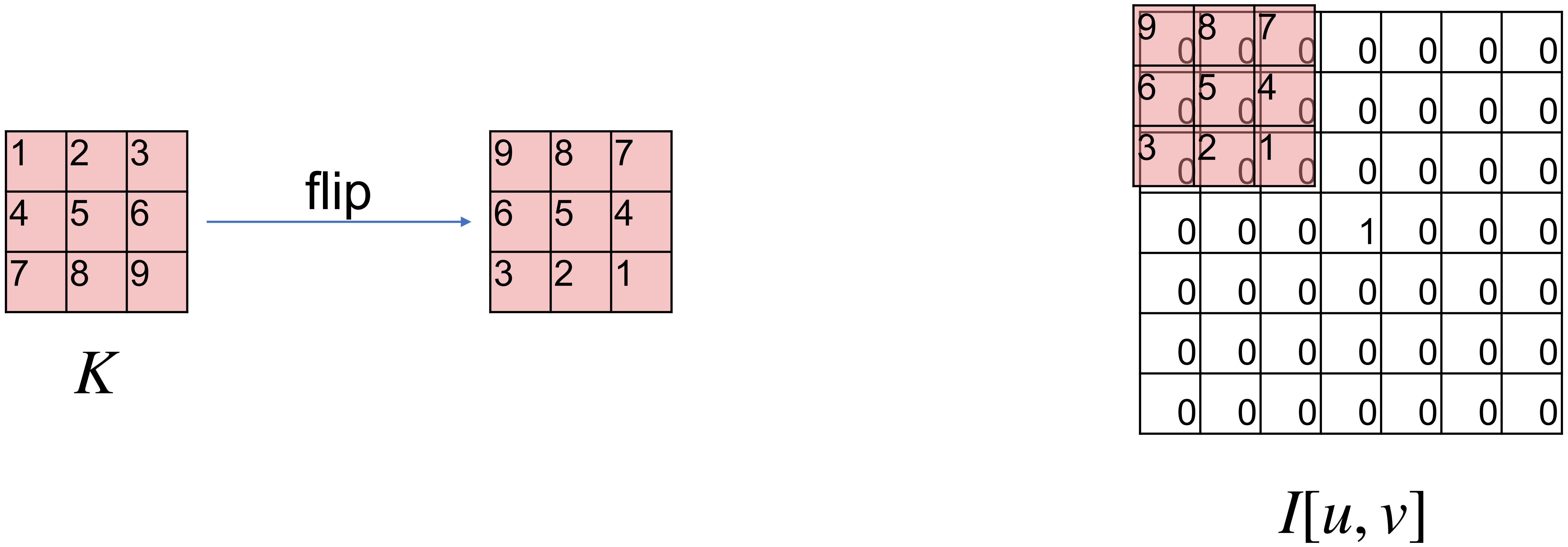
- Mathematical operation: $*$
- 2D convolution in image processing:
  - Image $I[u,v]$
  - Kernel K with size $[2a+1,\ 2b+1]$
  - Output $O[u,v]$

$$\begin{array}{c|ccc} & -1 & 0 & 1 \\ \hline -1 & 1 & 2 & 3 \\ 0 & 4 & 5 & 6 \\ 1 & 7 & 8 & 9 \end{array}$$

$$O[u,v] = I[u,v] * K = \sum_{s=-a}^{a} \sum_{t=-b}^{b} I[u-s, v-t]K[s,t]$$

Convolution II

$$O[u,v] = I[u,v] * K = \sum_{s=-a}^{a} \sum_{t=-b}^{b} I[u-s, v-t]K[s,t]$$

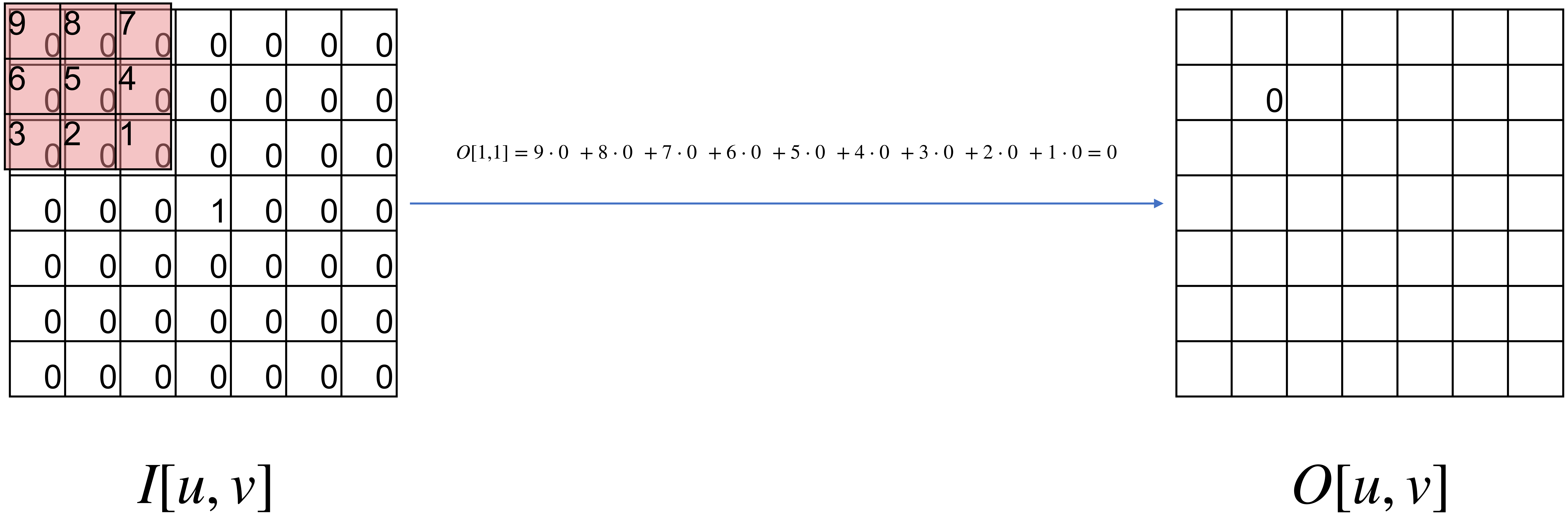


1	2	3
4	5	6
7	8	9

9	8	7
6	5	4
3	2	1

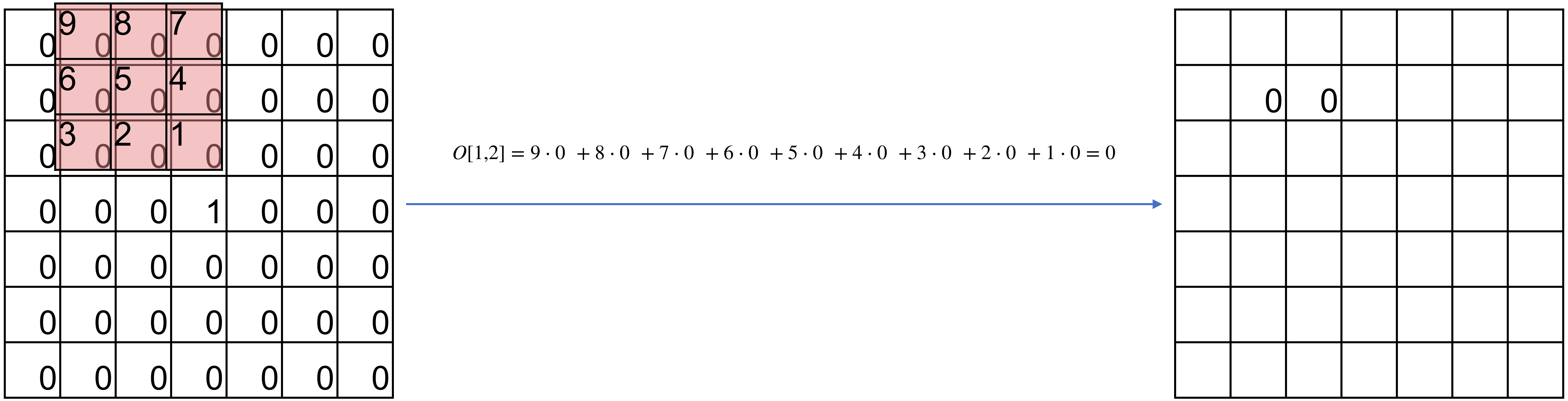
9 0	8 0	7 0	0	0	0	0
6 0	5 0	4 0	0	0	0	0
3 0	2 0	1 0	0	0	0	0
0	0	0	1	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

Convolution III



$$O[1,1] = 9\cdot 0\ + 8\cdot 0\ + 7\cdot 0\ + 6\cdot 0\ + 5\cdot 0\ + 4\cdot 0\ + 3\cdot 0\ + 2\cdot 0\ + 1\cdot 0 = 0$$

Convolution III



0	9 0	8 0	7 0	0	0	0
0	6 0	5 0	4 0	0	0	0
0	3 0	2 0	1 0	0	0	0
0	0	0	1	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

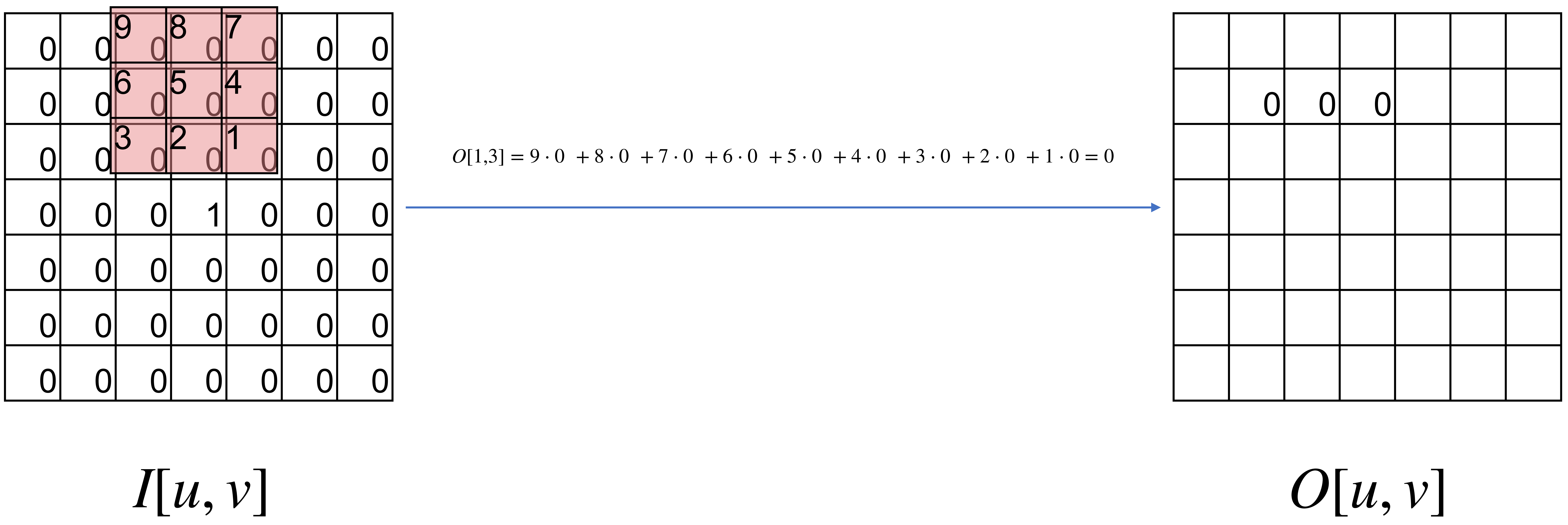
$$O[1,2] = 9 \cdot 0 \ + 8 \cdot 0 \ + 7 \cdot 0 \ + 6 \cdot 0 \ + 5 \cdot 0 \ + 4 \cdot 0 \ + 3 \cdot 0 \ + 2 \cdot 0 \ + 1 \cdot 0 = 0$$

	0	0				

$I[u,v]$

$O[u,v]$

Convolution III



0	0	9 0	8 0	7 0	0	0
0	0	6 0	5 0	4 0	0	0
0	0	3 0	2 0	1 0	0	0
0	0	0	1	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

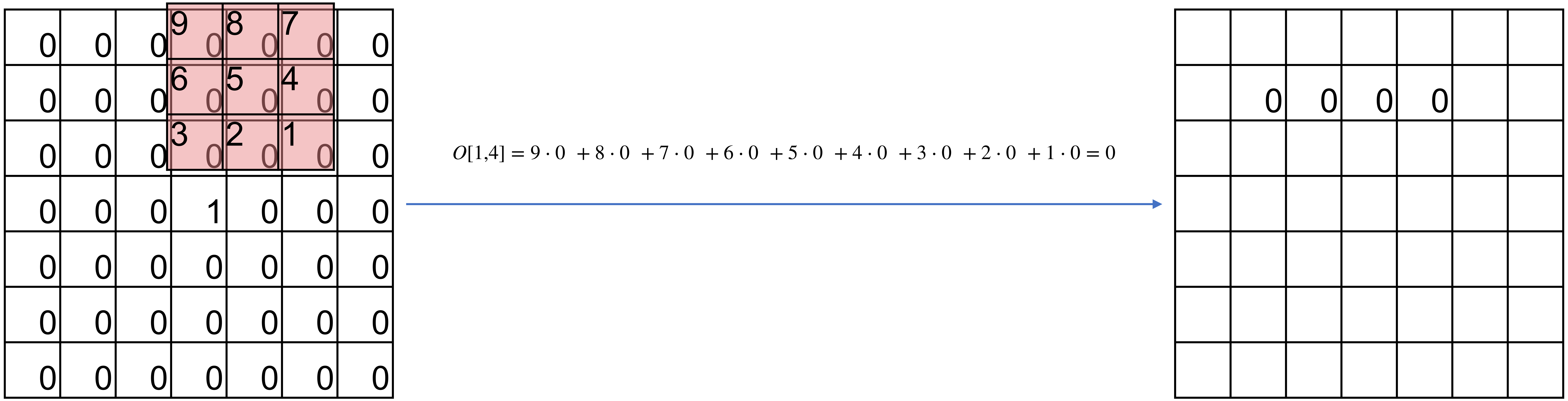
$$O[1,3] = 9 \cdot 0 \ + 8 \cdot 0 \ + 7 \cdot 0 \ + 6 \cdot 0 \ + 5 \cdot 0 \ + 4 \cdot 0 \ + 3 \cdot 0 \ + 2 \cdot 0 \ + 1 \cdot 0 = 0$$

	0	0	0			

$I[u,v]$

$O[u,v]$

Convolution III



0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	1	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

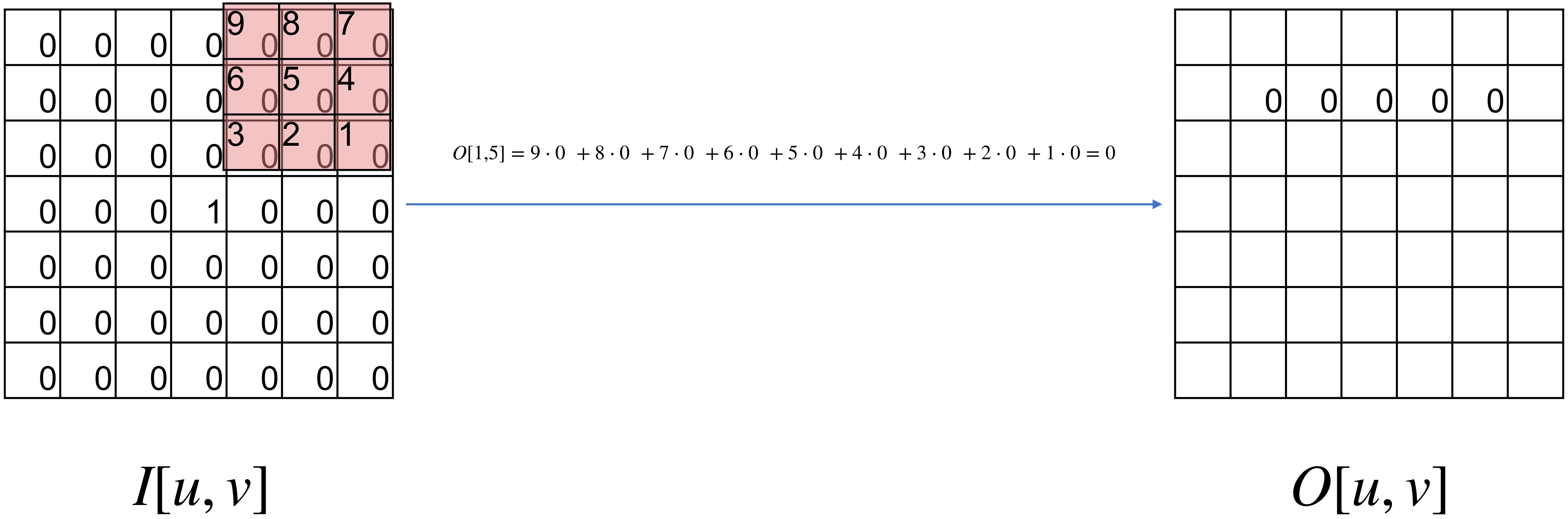
$I[u, v]$

$$O[1,4] = 9\cdot 0 + 8\cdot 0 + 7\cdot 0 + 6\cdot 0 + 5\cdot 0 + 4\cdot 0 + 3\cdot 0 + 2\cdot 0 + 1\cdot 0 = 0$$

	0	0	0	0		

$O[u, v]$

Convolution III



0	0	0	0	9 0	8 0	7 0
0	0	0	0	6 0	5 0	4 0
0	0	0	0	3 0	2 0	1 0
0	0	0	1	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

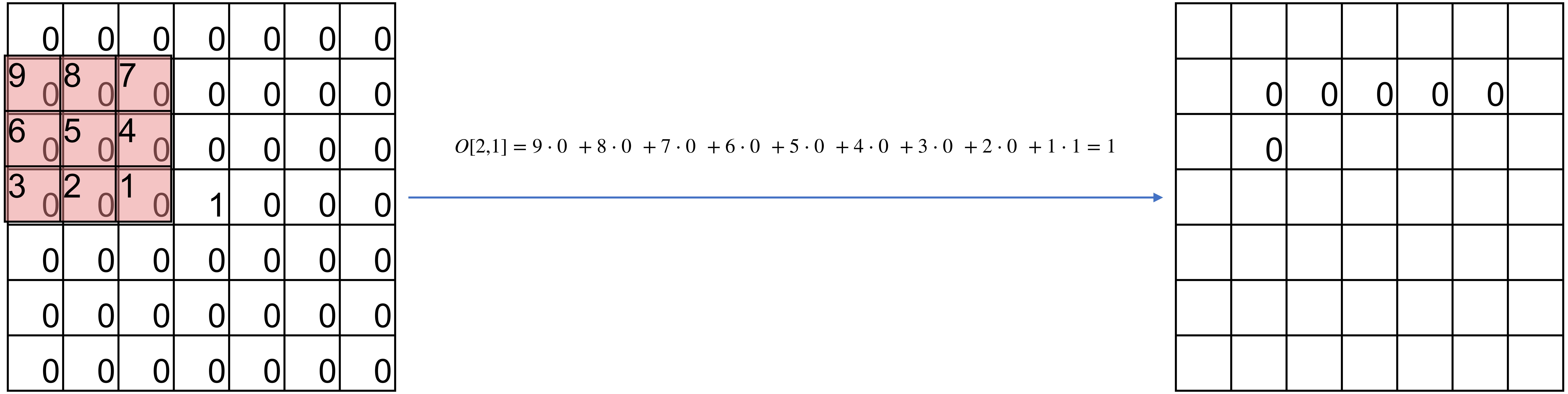
$I[u, v]$

$$O[1,5] = 9 \cdot 0 + 8 \cdot 0 + 7 \cdot 0 + 6 \cdot 0 + 5 \cdot 0 + 4 \cdot 0 + 3 \cdot 0 + 2 \cdot 0 + 1 \cdot 0 = 0$$

	0	0	0	0	0	

$O[u, v]$

Convolution III



0	0	0	0	0	0	0
9 0	8 0	7 0	0	0	0	0
6 0	5 0	4 0	0	0	0	0
3 0	2 0	1 0	1	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

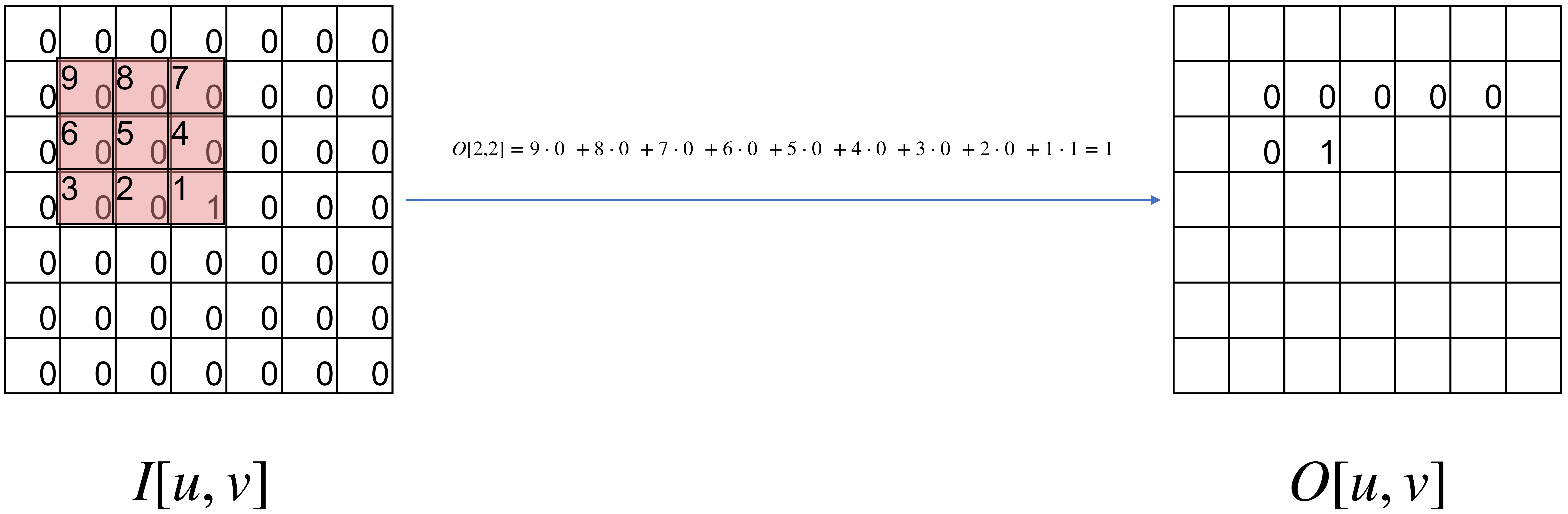
$$O[2,1] = 9\cdot 0 + 8\cdot 0 + 7\cdot 0 + 6\cdot 0 + 5\cdot 0 + 4\cdot 0 + 3\cdot 0 + 2\cdot 0 + 1\cdot 1 = 1$$

	0	0	0	0	0	
	0					

$$I[u,v]$$

$$O[u,v]$$

Convolution III



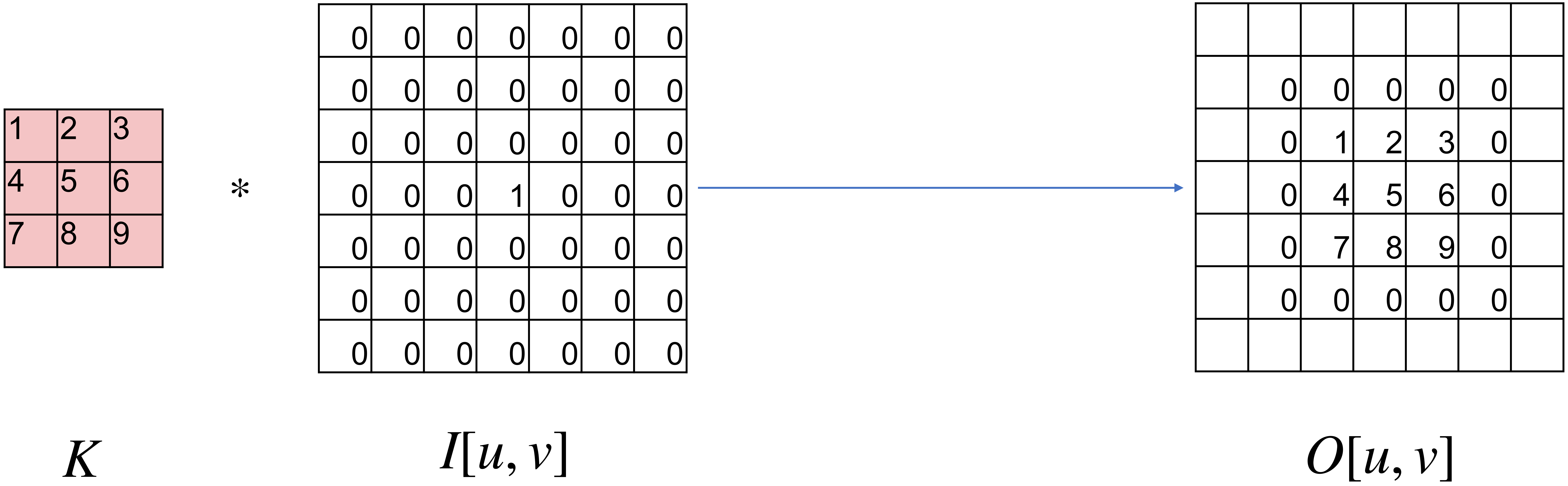
0	0	0	0	0	0	0
0	9 0	8 0	7 0	0	0	0
0	6 0	5 0	4 0	0	0	0
0	3 0	2 0	1 1	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0
0	0	0	0	0	0	0

$$O[2,2] = 9 \cdot 0 + 8 \cdot 0 + 7 \cdot 0 + 6 \cdot 0 + 5 \cdot 0 + 4 \cdot 0 + 3 \cdot 0 + 2 \cdot 0 + 1 \cdot 1 = 1$$

	0	0	0	0	0	
	0	1				

$I[u,v]$ $O[u,v]$

Convolution IV



$$\underset{K}{\begin{array}{|c|c|c|}\hline 1&2&3\\ \hline 4&5&6\\ \hline 7&8&9\\ \hline\end{array}} \quad * \quad \underset{I[u,v]}{\begin{array}{|c|c|c|c|c|c|c|}\hline 0&0&0&0&0&0&0\\ \hline 0&0&0&0&0&0&0\\ \hline 0&0&0&0&0&0&0\\ \hline 0&0&0&1&0&0&0\\ \hline 0&0&0&0&0&0&0\\ \hline 0&0&0&0&0&0&0\\ \hline 0&0&0&0&0&0&0\\ \hline\end{array}} \quad \longrightarrow \quad \underset{O[u,v]}{\begin{array}{|c|c|c|c|c|c|c|}\hline &&&&&&\\ \hline &0&0&0&0&0&\\ \hline &0&1&2&3&0&\\ \hline &0&4&5&6&0&\\ \hline &0&7&8&9&0&\\ \hline &0&0&0&0&0&\\ \hline &&&&&&\\ \hline\end{array}}$$

Convolution V

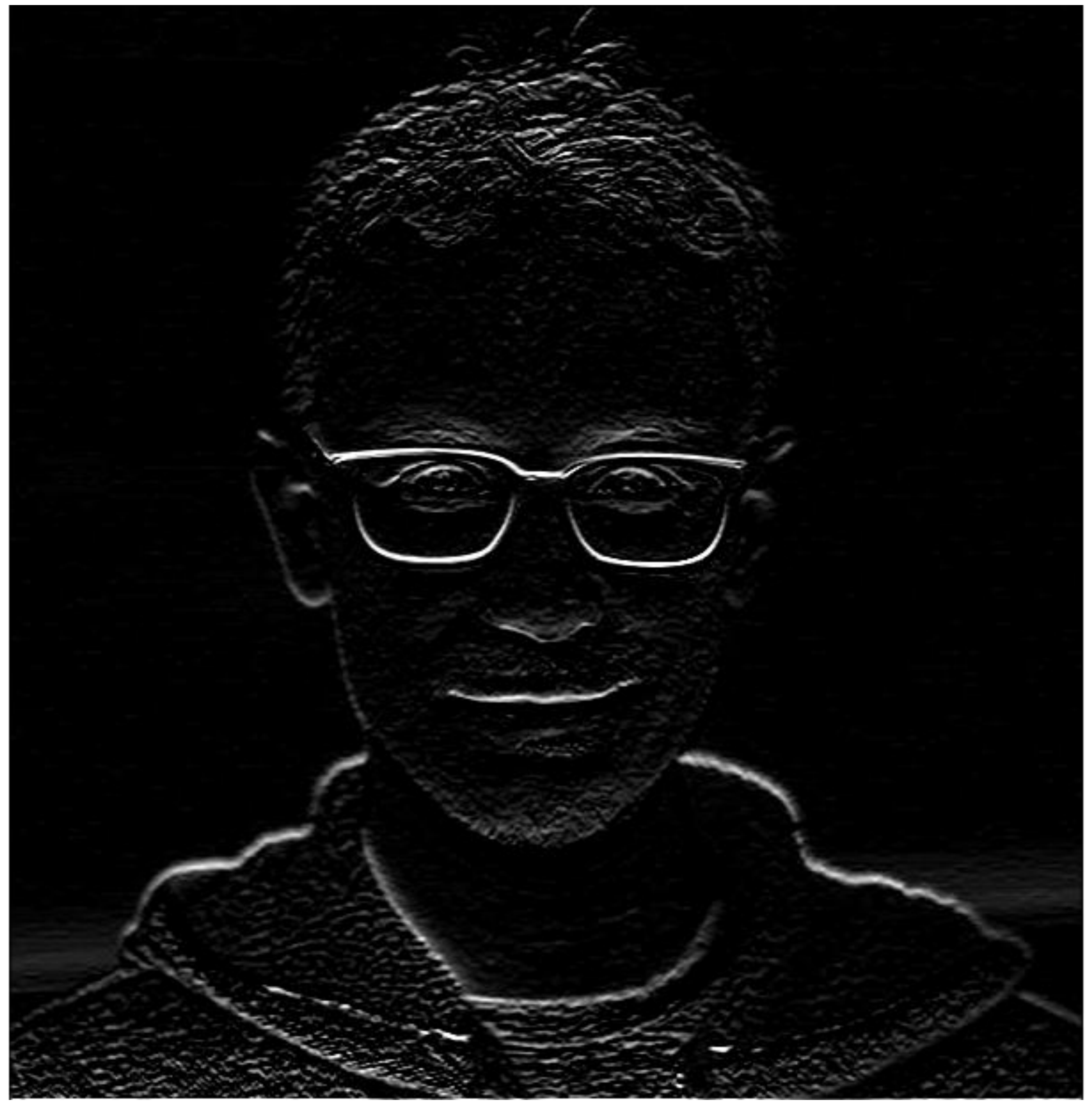
-1	-2	-1
0	0	0
1	2	1

K

$*$

$I[u,v]$

$\longrightarrow$

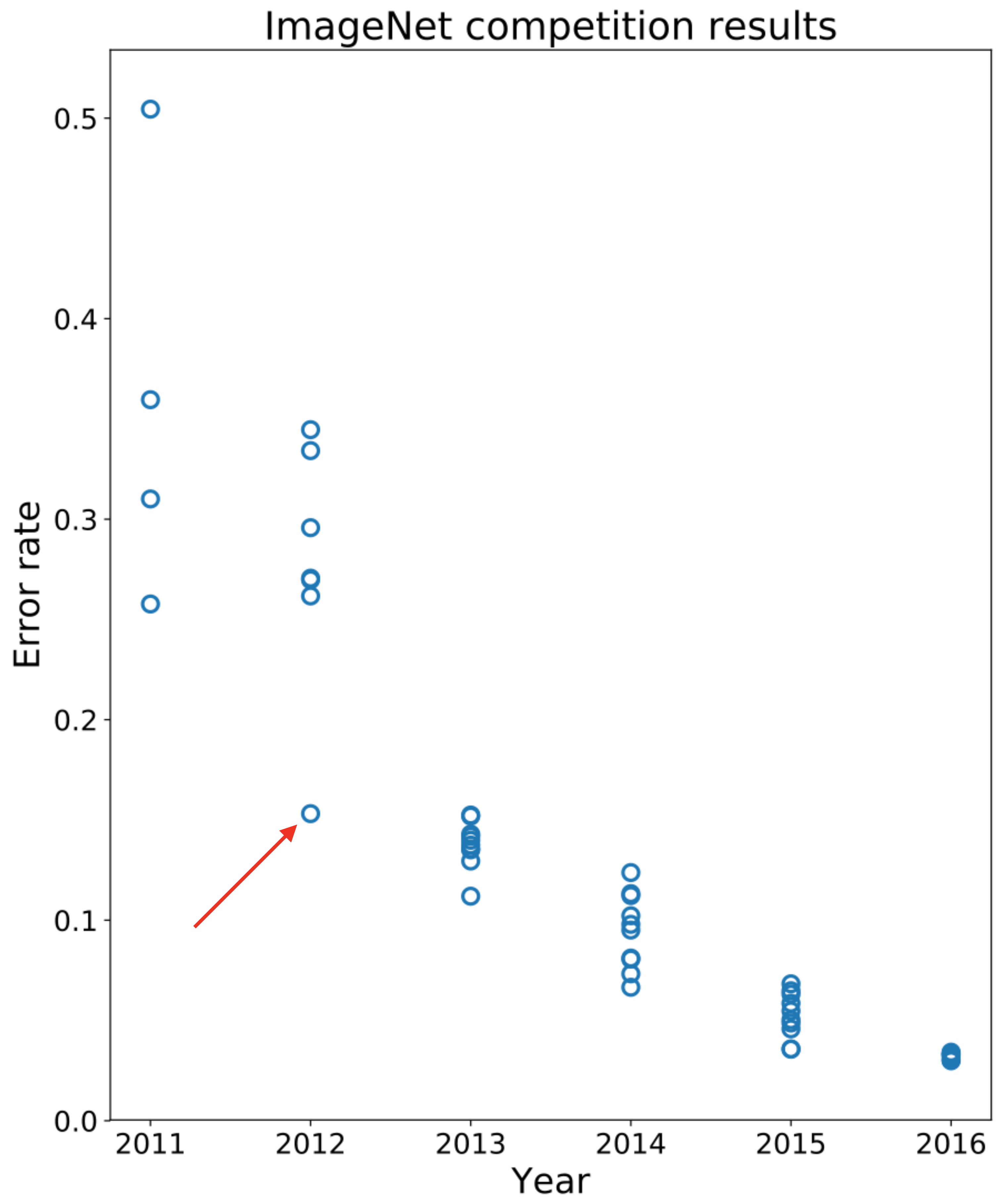


$O[u,v]$

Source: https://cms.qz.com/wp-content/uploads/2018/06/2018-05-11-Alex-Krizhevsky-8394-e1529095310611.jpg?quality=75&strip=all&w=1400

AlexNet - Why AlexNet?

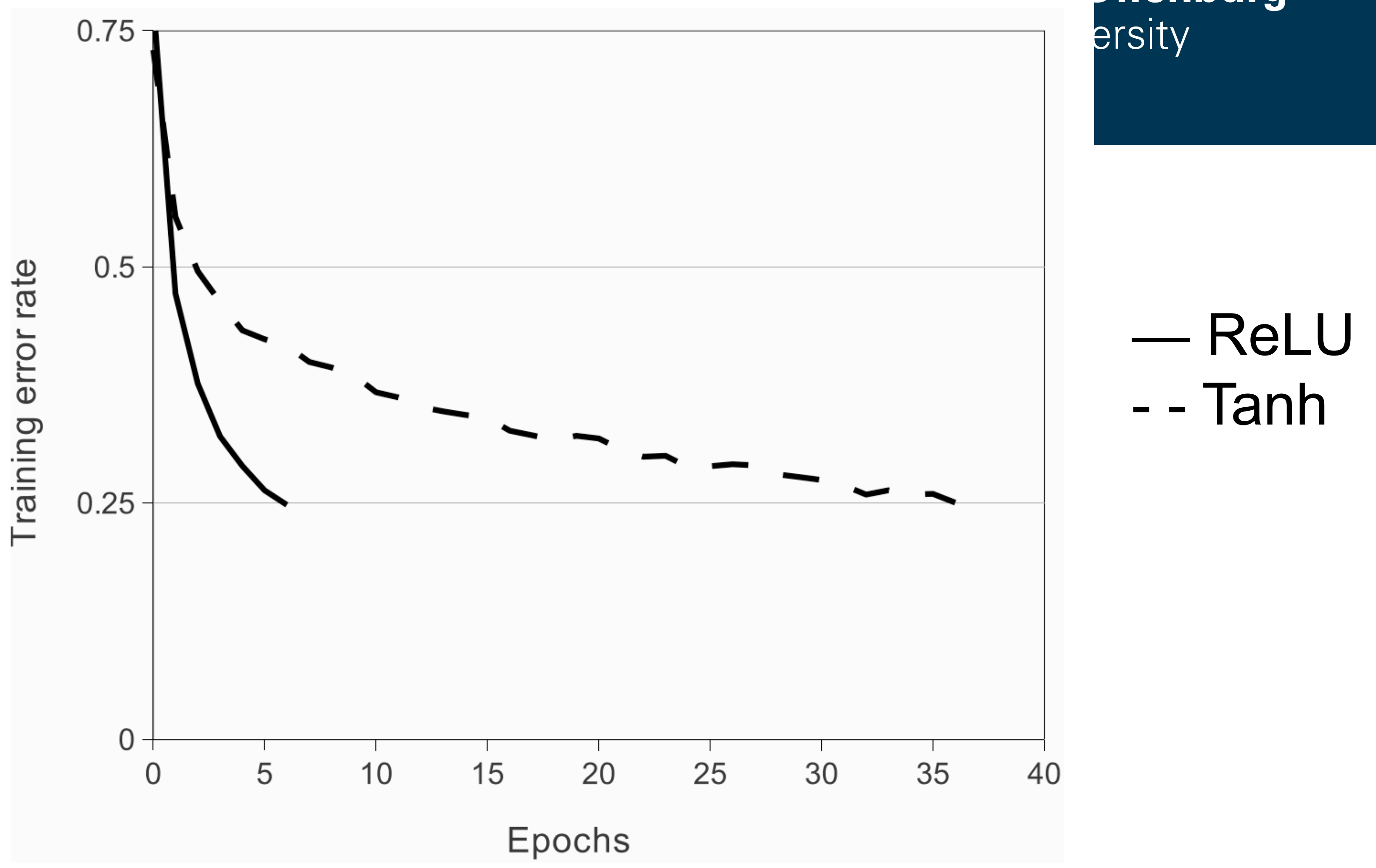
- Alex Krizhevsky et al. (2012)
- Winner ILSVRC-2012
  - Top-5 test error rate: 15.3%
- Key to success: Faster training

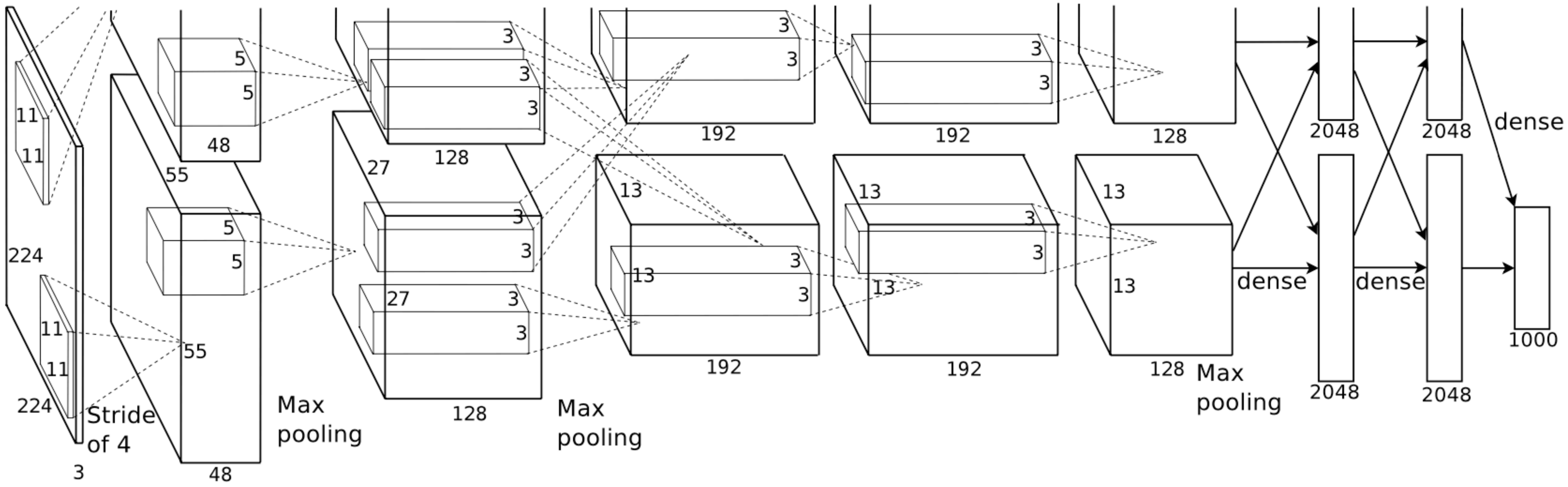


By Gkrusze - Own work, CC BY-SA 4.0,
https://commons.wikimedia.org/w/index.php?curid=69750373

AlexNet - Architecture I

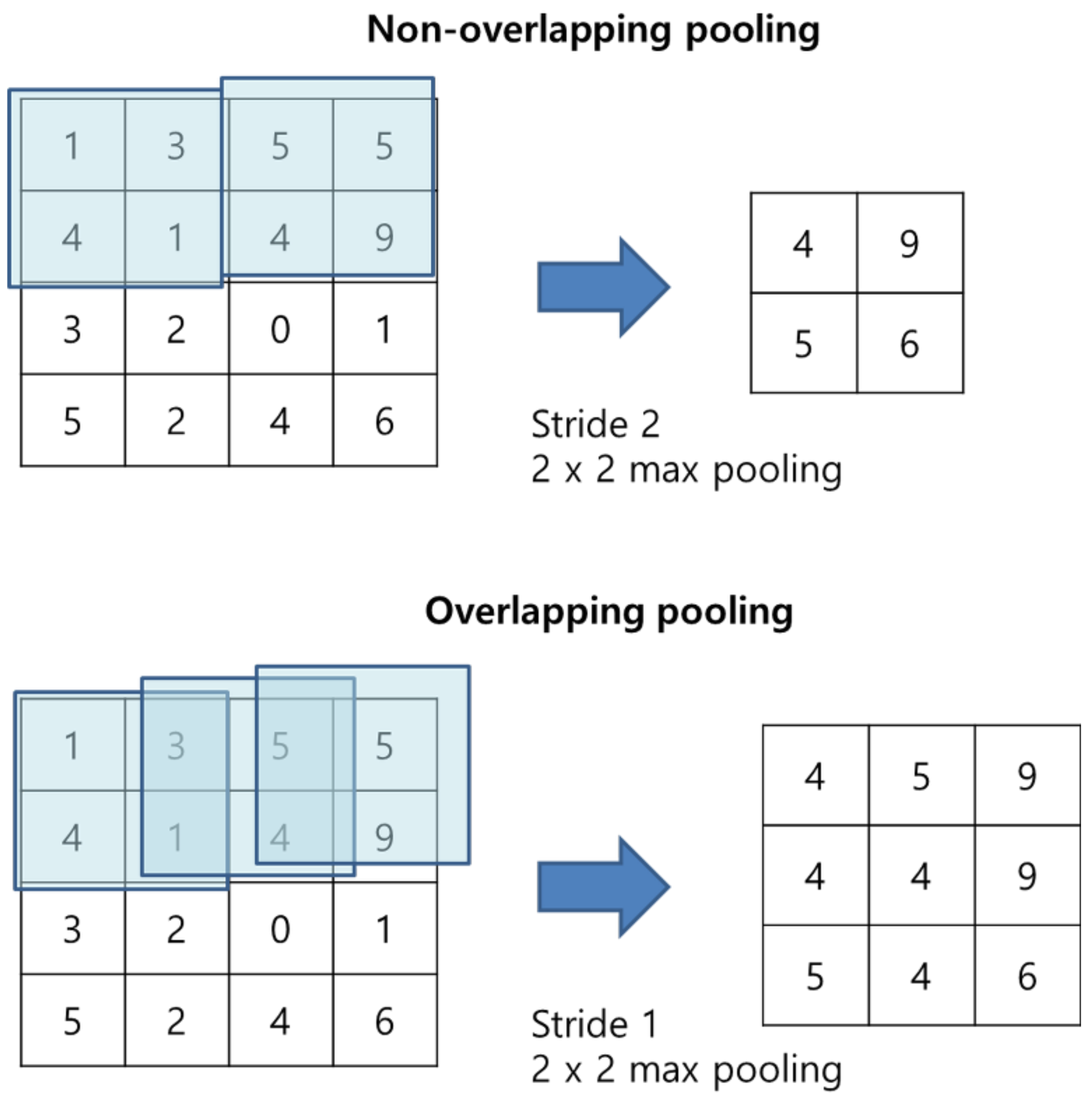
- 5 convolutional, 3 fully-connected
- Multiple GPUs
- ReLU: $f(x) = max(0, x)$





AlexNet - Reduce Overfitting

- 60 Mio. parameters
- Data Augmentation
- Dropout
- Overlapping Pooling



Non-overlapping pooling

1	3	5	5
4	1	4	9
3	2	0	1
5	2	4	6

4	9
5	6

Stride 2
2 x 2 max pooling

Overlapping pooling

1	3	5	5
4	1	4	9
3	2	0	1
5	2	4	6

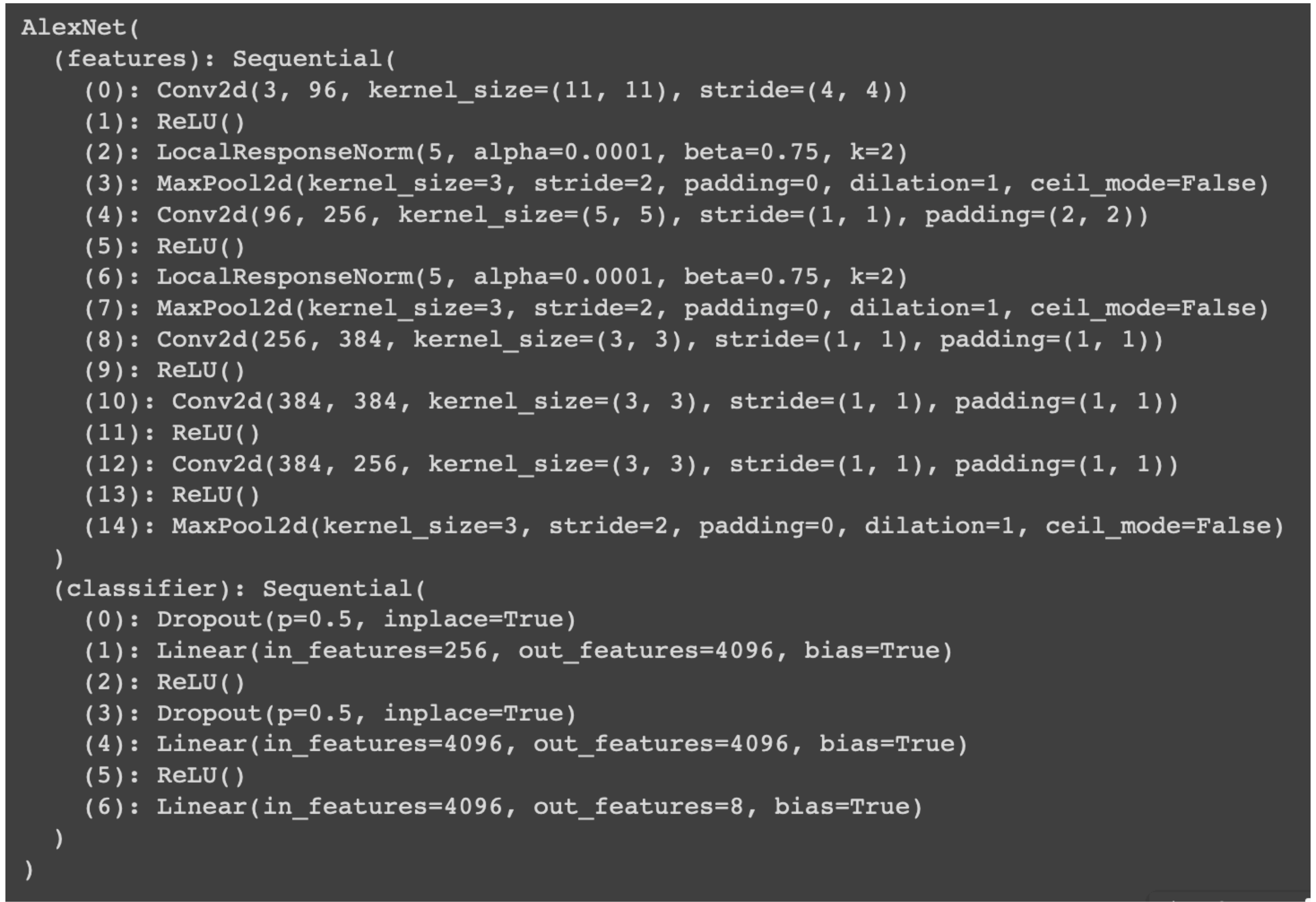
4	5	9
4	4	9
5	4	6

Stride 1
2 x 2 max pooling

Source: https://bskyvision.com/421

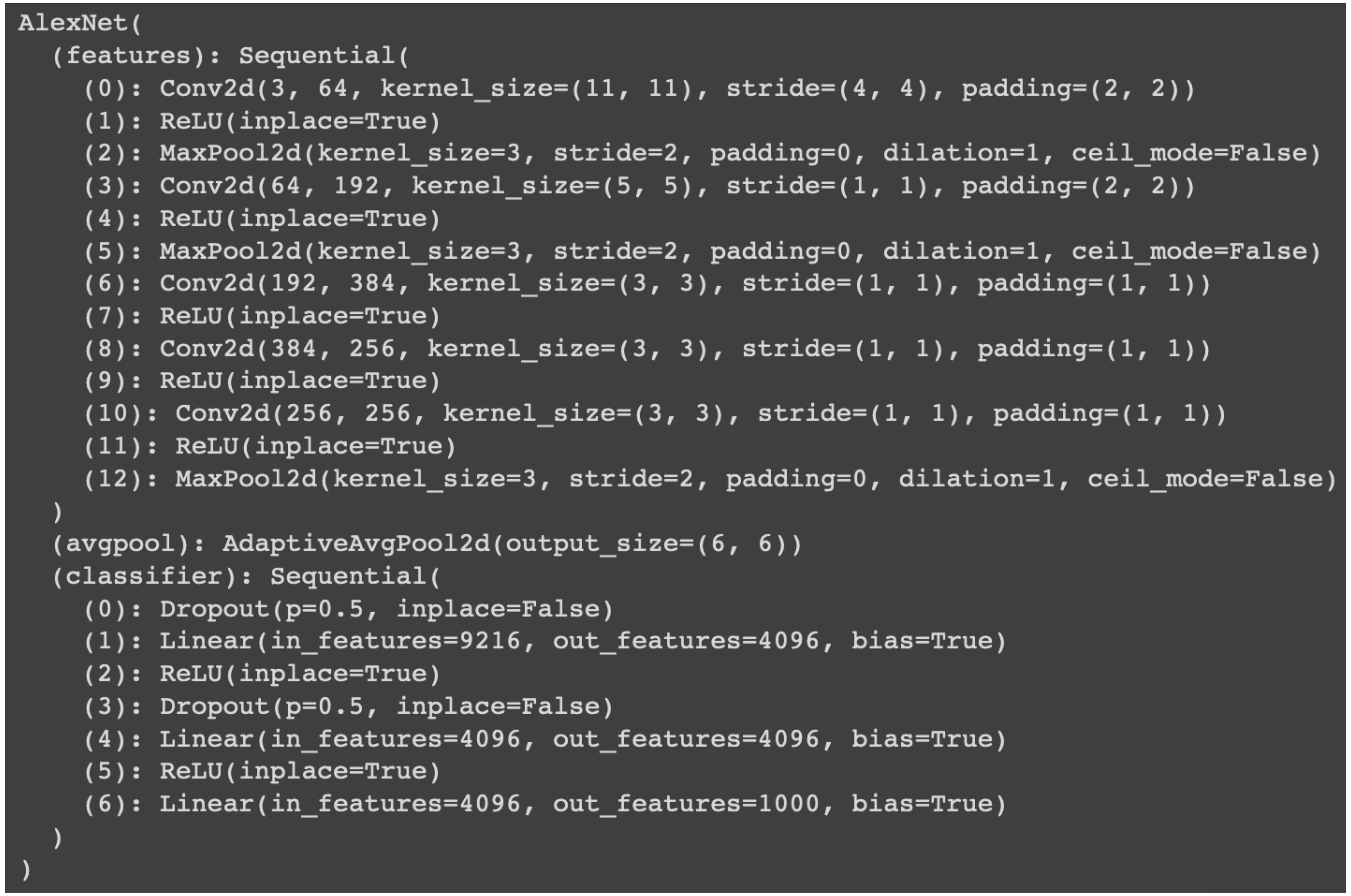
Practical Part - AlexNet

Manually implemented:



```
AlexNet(
  (features): Sequential(
    (0): Conv2d(3, 96, kernel_size=(11, 11), stride=(4, 4))
    (1): ReLU()
    (2): LocalResponseNorm(5, alpha=0.0001, beta=0.75, k=2)
    (3): MaxPool2d(kernel_size=3, stride=2, padding=0, dilation=1, ceil_mode=False)
    (4): Conv2d(96, 256, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
    (5): ReLU()
    (6): LocalResponseNorm(5, alpha=0.0001, beta=0.75, k=2)
    (7): MaxPool2d(kernel_size=3, stride=2, padding=0, dilation=1, ceil_mode=False)
    (8): Conv2d(256, 384, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (9): ReLU()
    (10): Conv2d(384, 384, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (11): ReLU()
    (12): Conv2d(384, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (13): ReLU()
    (14): MaxPool2d(kernel_size=3, stride=2, padding=0, dilation=1, ceil_mode=False)
  )
  (classifier): Sequential(
    (0): Dropout(p=0.5, inplace=True)
    (1): Linear(in_features=256, out_features=4096, bias=True)
    (2): ReLU()
    (3): Dropout(p=0.5, inplace=True)
    (4): Linear(in_features=4096, out_features=4096, bias=True)
    (5): ReLU()
    (6): Linear(in_features=4096, out_features=8, bias=True)
  )
)
```

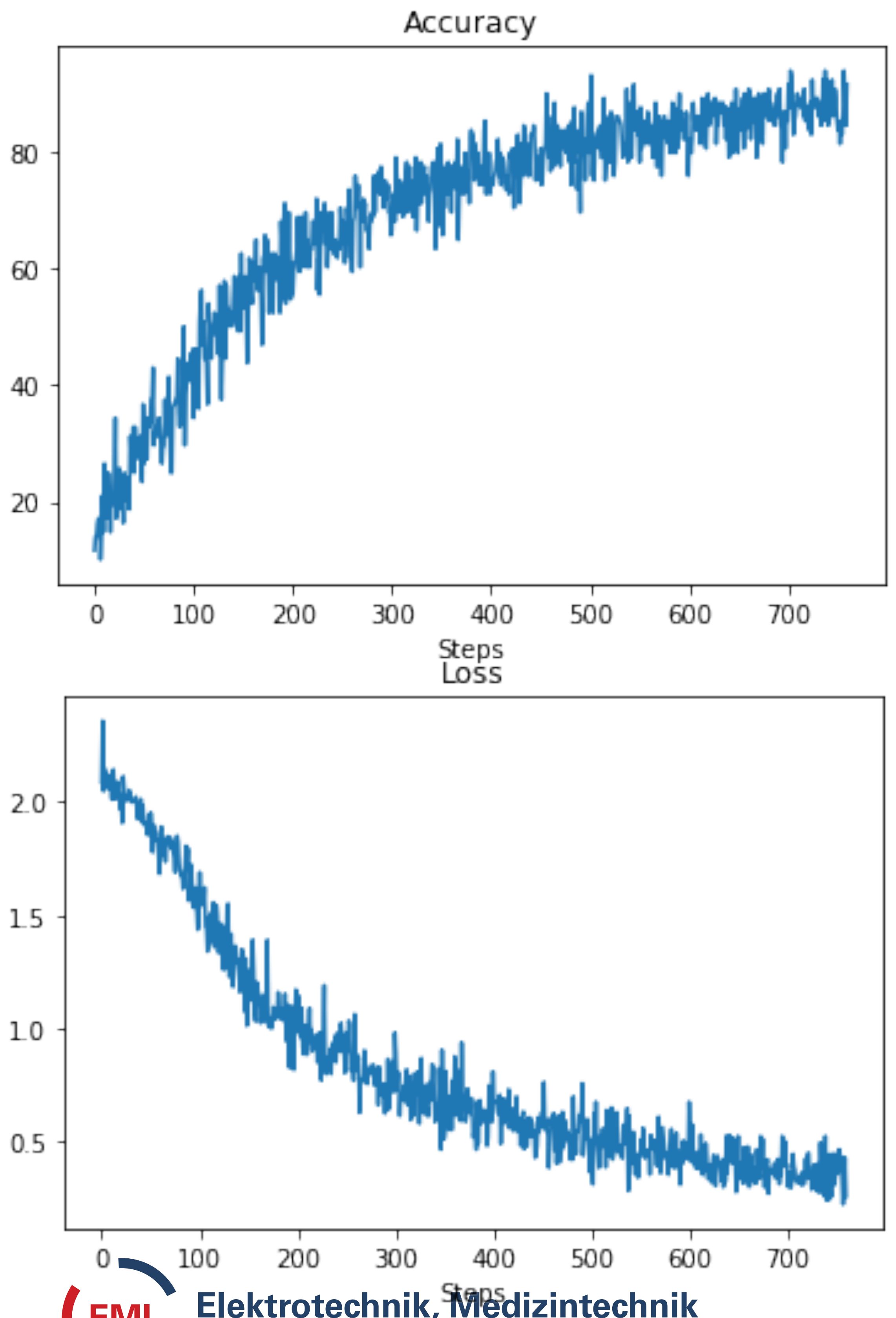
Pytorch version:



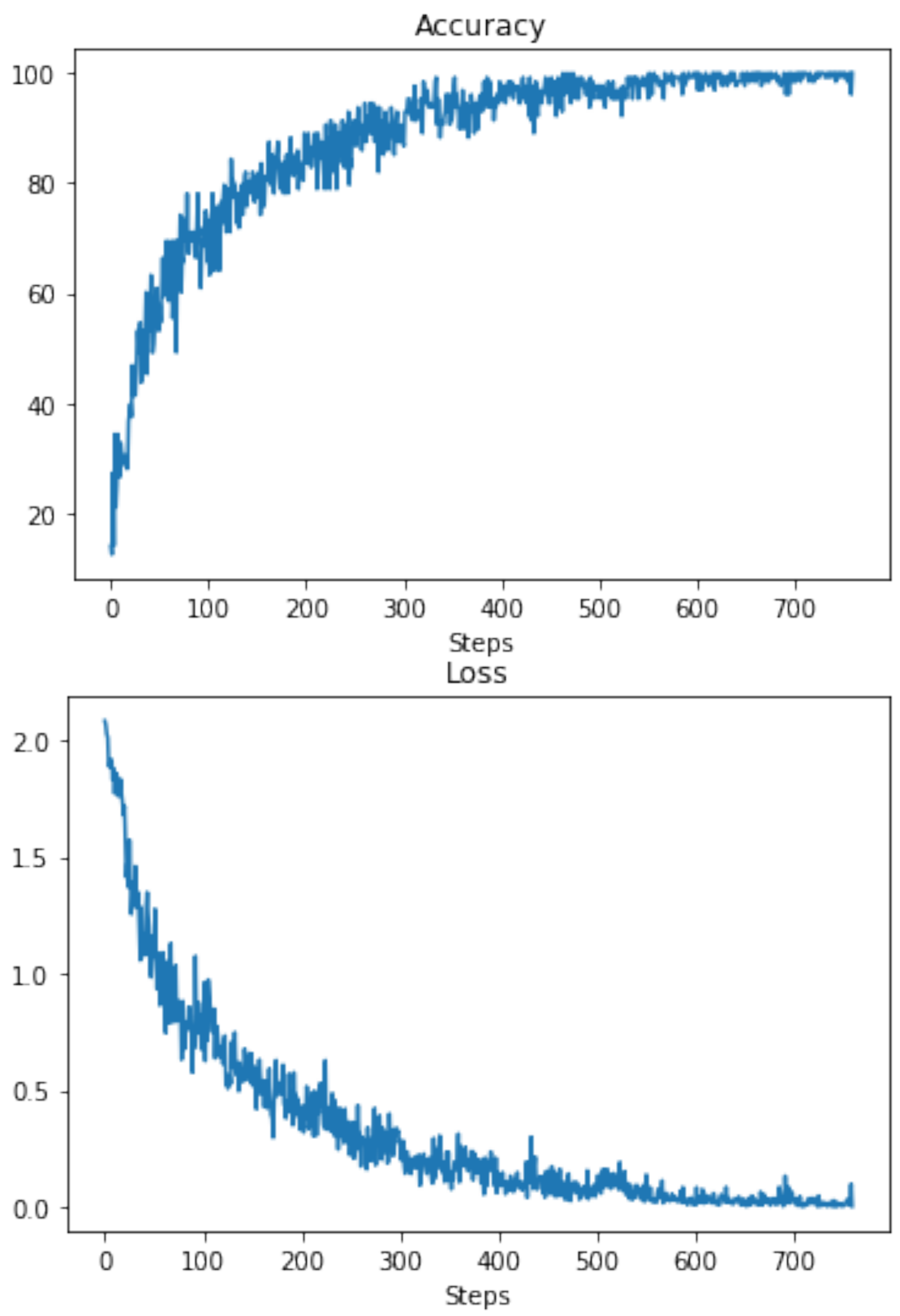
```
AlexNet(
  (features): Sequential(
    (0): Conv2d(3, 64, kernel_size=(11, 11), stride=(4, 4), padding=(2, 2))
    (1): ReLU(inplace=True)
    (2): MaxPool2d(kernel_size=3, stride=2, padding=0, dilation=1, ceil_mode=False)
    (3): Conv2d(64, 192, kernel_size=(5, 5), stride=(1, 1), padding=(2, 2))
    (4): ReLU(inplace=True)
    (5): MaxPool2d(kernel_size=3, stride=2, padding=0, dilation=1, ceil_mode=False)
    (6): Conv2d(192, 384, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (7): ReLU(inplace=True)
    (8): Conv2d(384, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (9): ReLU(inplace=True)
    (10): Conv2d(256, 256, kernel_size=(3, 3), stride=(1, 1), padding=(1, 1))
    (11): ReLU(inplace=True)
    (12): MaxPool2d(kernel_size=3, stride=2, padding=0, dilation=1, ceil_mode=False)
  )
  (avgpool): AdaptiveAvgPool2d(output_size=(6, 6))
  (classifier): Sequential(
    (0): Dropout(p=0.5, inplace=False)
    (1): Linear(in_features=9216, out_features=4096, bias=True)
    (2): ReLU(inplace=True)
    (3): Dropout(p=0.5, inplace=False)
    (4): Linear(in_features=4096, out_features=4096, bias=True)
    (5): ReLU(inplace=True)
    (6): Linear(in_features=4096, out_features=1000, bias=True)
  )
)
```

Accuracy and Loss

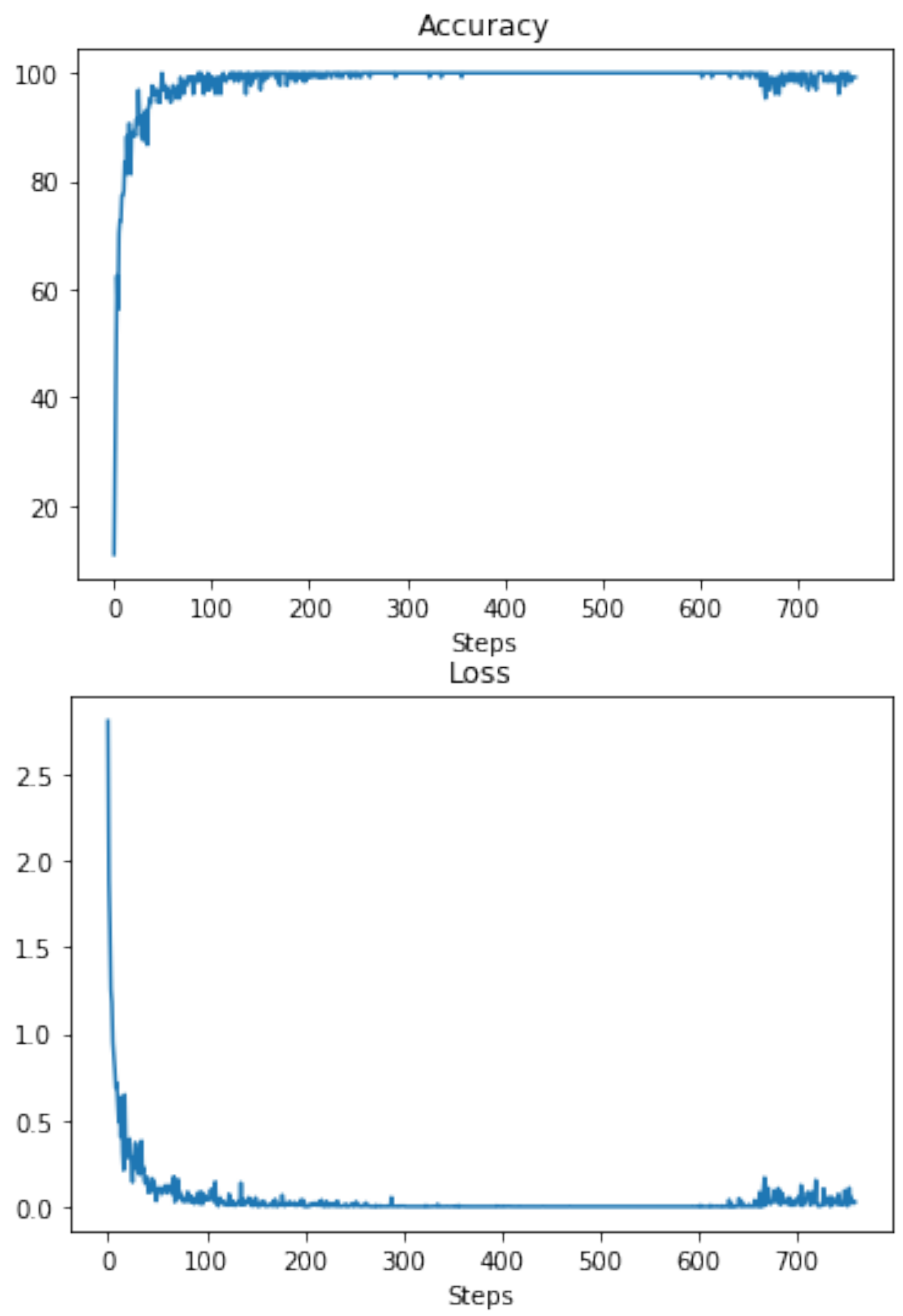
Manual Implementation



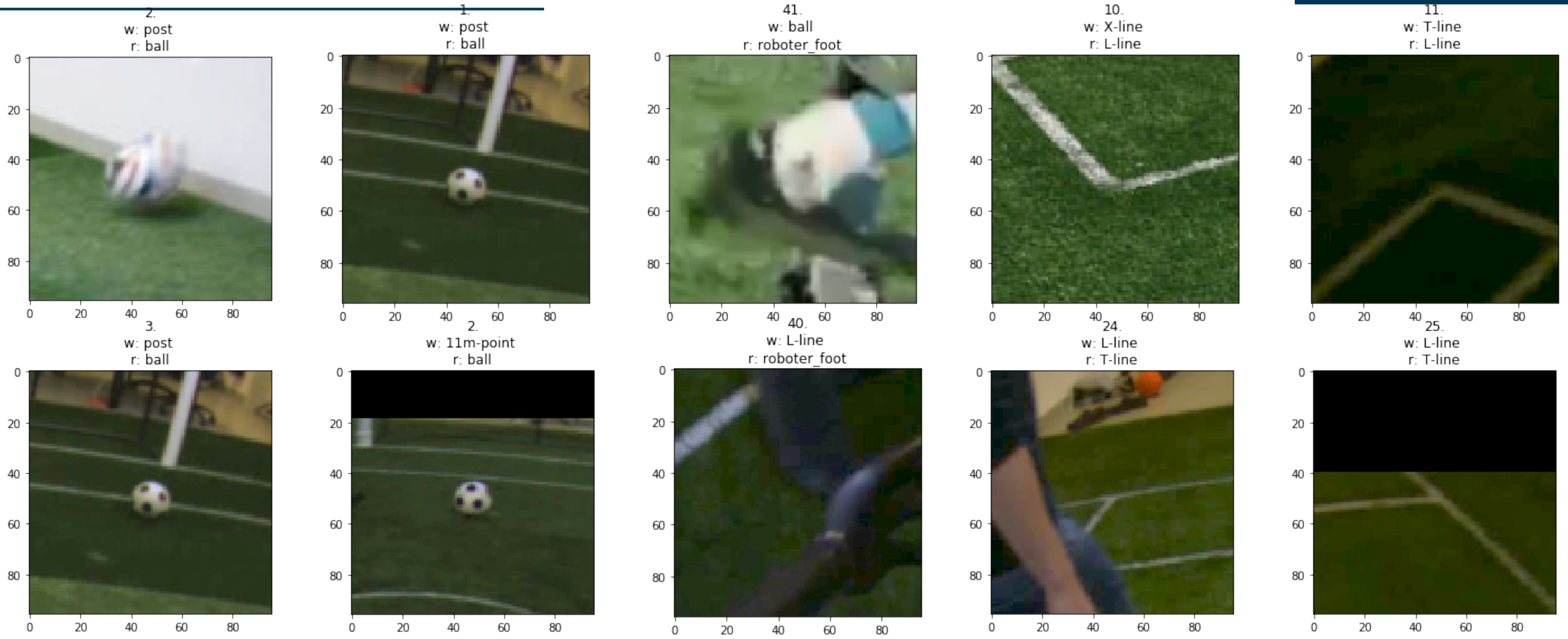
Pytorch not pretrained



Pytorch pretrained



Wrongly Classified Images



2.
w: post
r: ball

1.
w: post
r: ball

41.
w: ball
r: roboter_foot

10.
w: X-line
r: L-line

11.
w: T-line
r: L-line

3.
w: post
r: ball

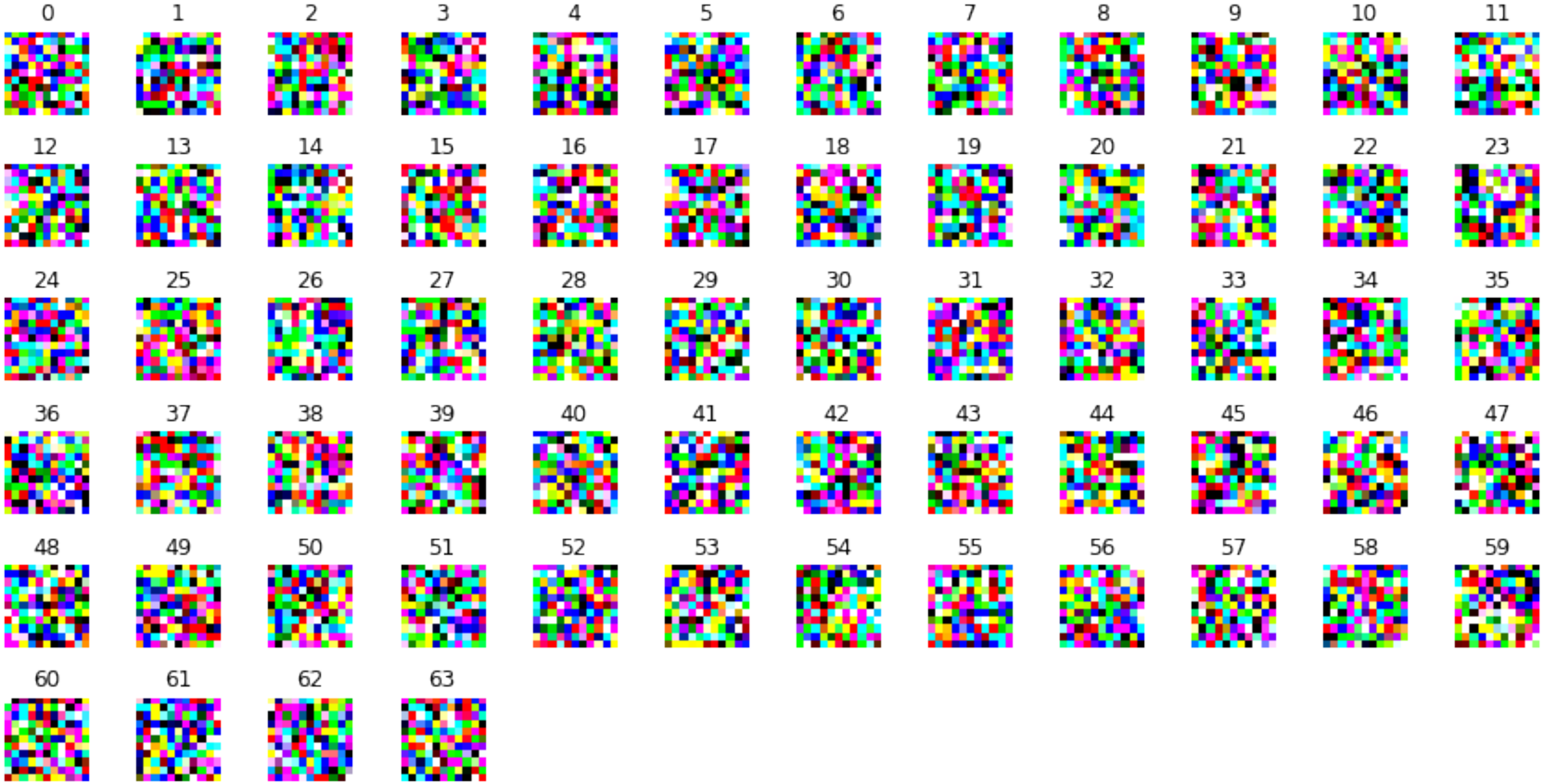
2.
w: 11m-point
r: ball

40.
w: L-line
r: roboter_foot

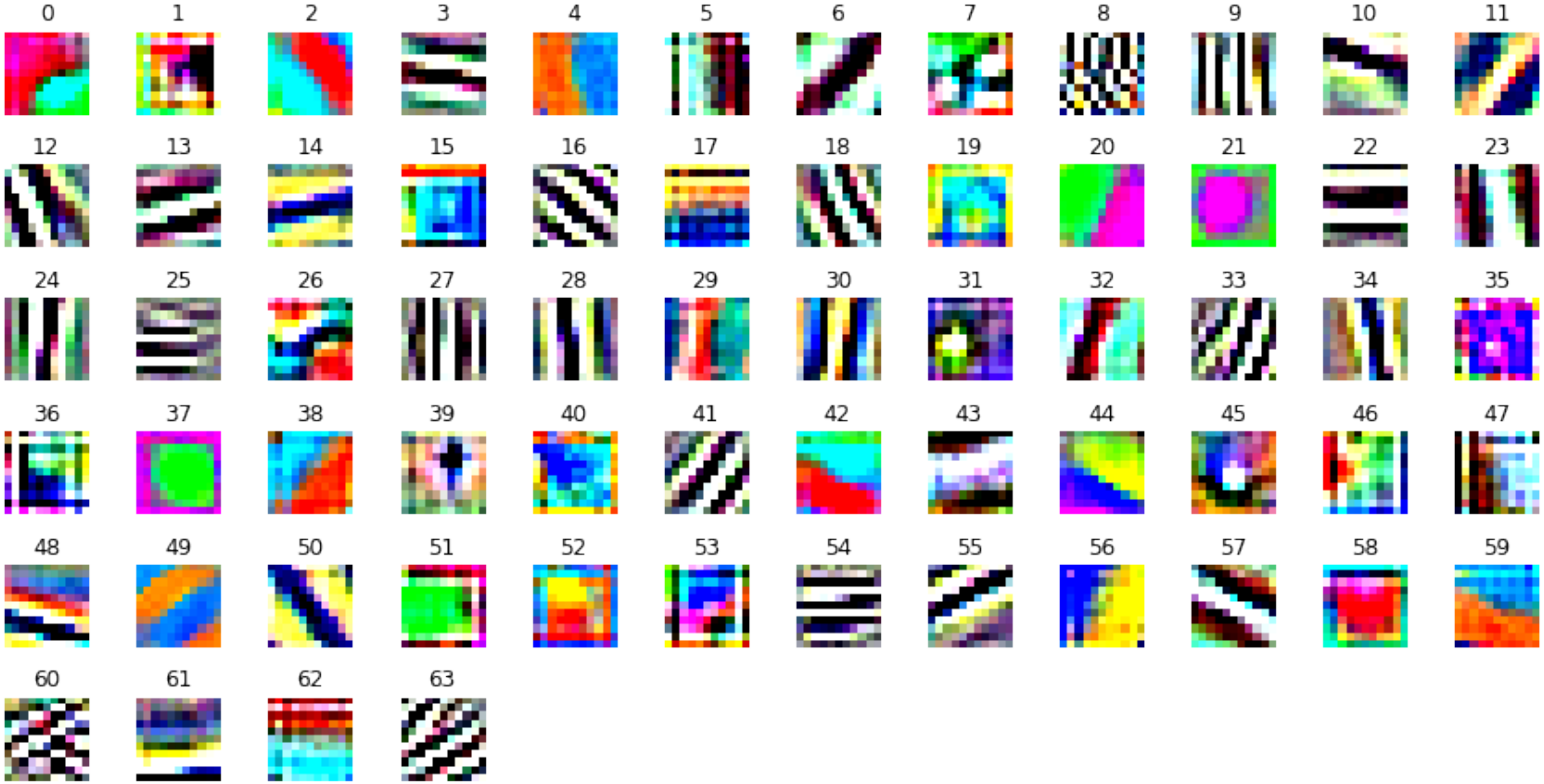
24.
w: L-line
r: T-line

25.
w: L-line
r: T-line

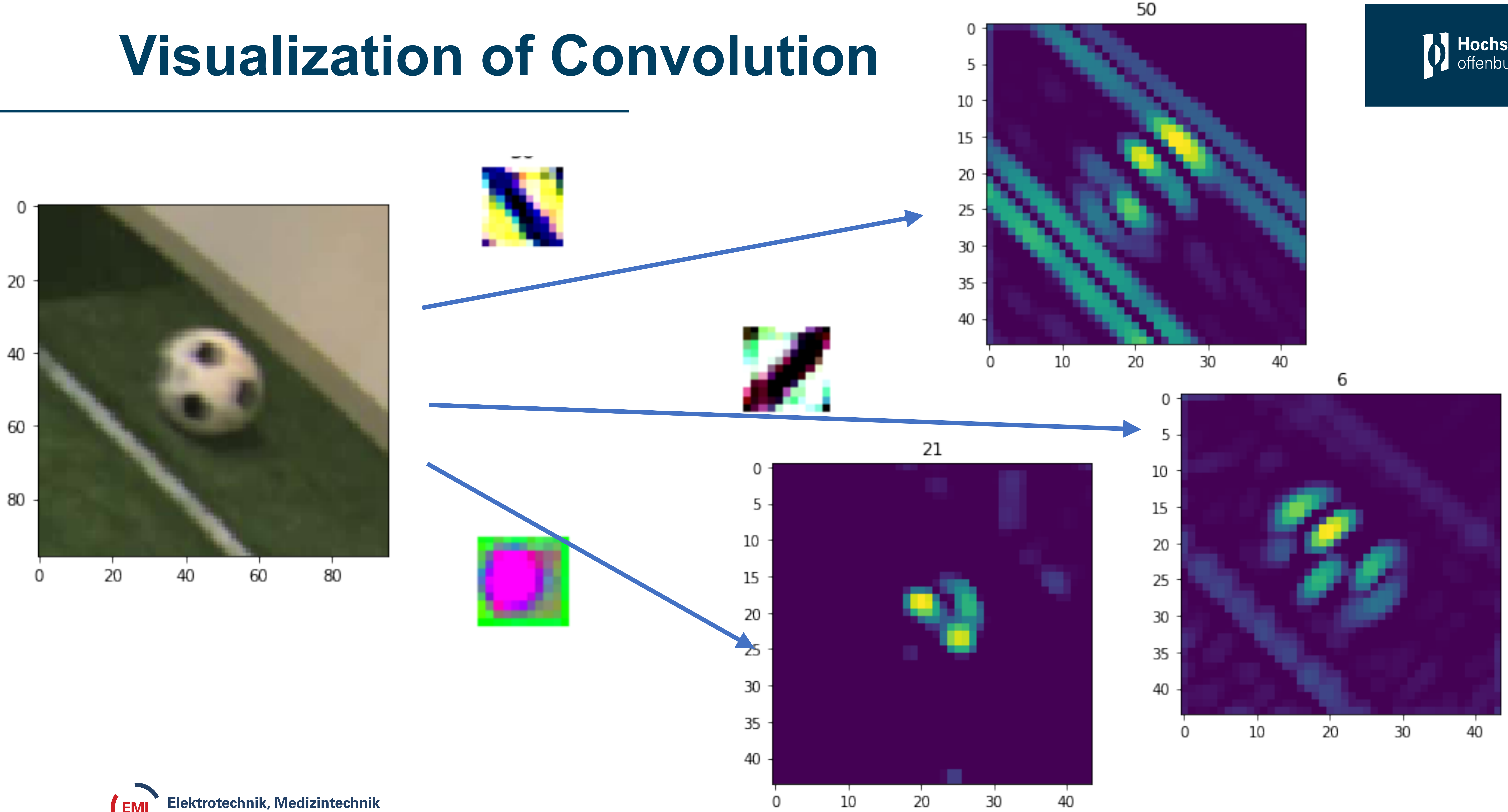
Learned Kernels - Not Pretrained



Learned Kernels - Pretrained



Visualization of Convolution



Thank you!

Sources

Paper:

https://papers.nips.cc/paper/4824-imagenet-classification-with-deep-convolutional-neural-networks.pdf

Gitlab Repo with slides, notebook and paper:

https://gitlab.iz.hs-offenburg.de/lfriedri/deep-learning-alexnet.git

Further sources:

https://en.wikipedia.org/wiki/AlexNet

https://ujjwalkarn.me/2016/08/11/intuitive-explanation-convnets/

https://machinelearninguru.com/computer_vision/basics/convolution/image_convolution_1.html

https://en.wikipedia.org/wiki/Kernel_(image_processing)