



# Fundamentals of Deep Learning

Part 3: Convolutional Neural Networks



# Agenda

- Part 1: An Introduction to Deep Learning
- Part 2: How a Neural Network Trains
- Part 3: Convolutional Neural Networks
- Part 4: Data Augmentation and Deployment
- Part 5: Pre-Trained Models
- Part 6: Advanced Architectures

## Recap of the exercise

Trained a dense neural network model

Training accuracy was high

Validation accuracy was low

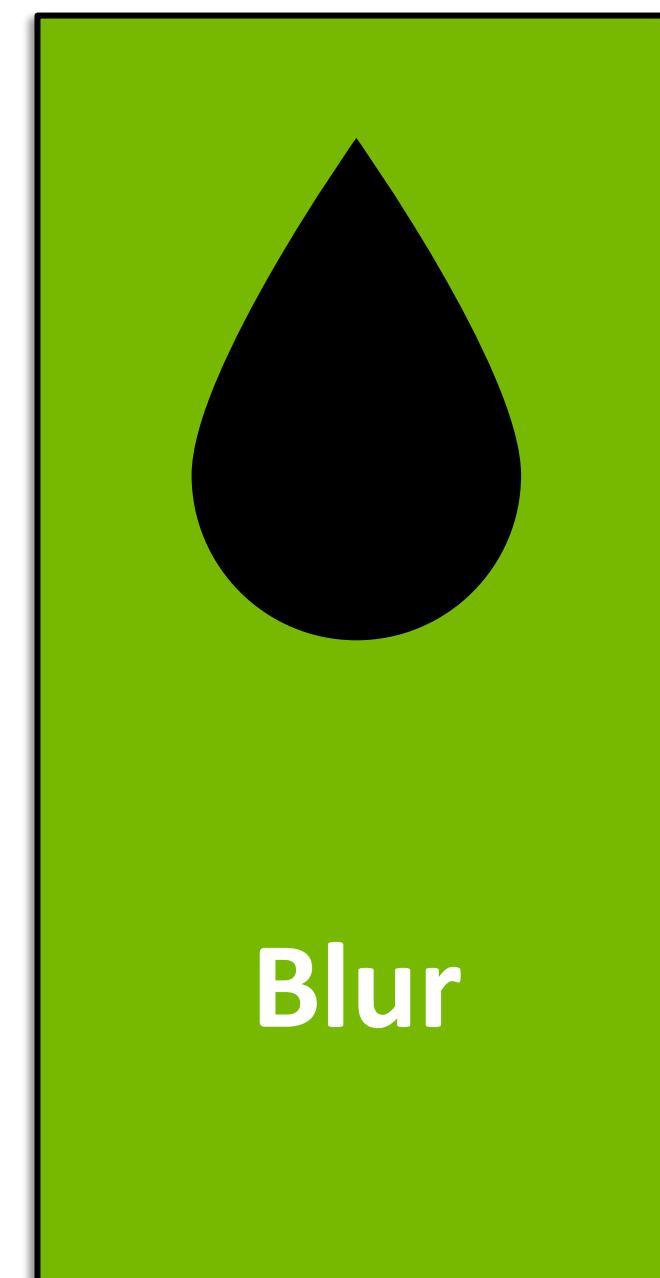
Evidence of overfitting

# Kernels and Convolution

# Kernels and Convolution



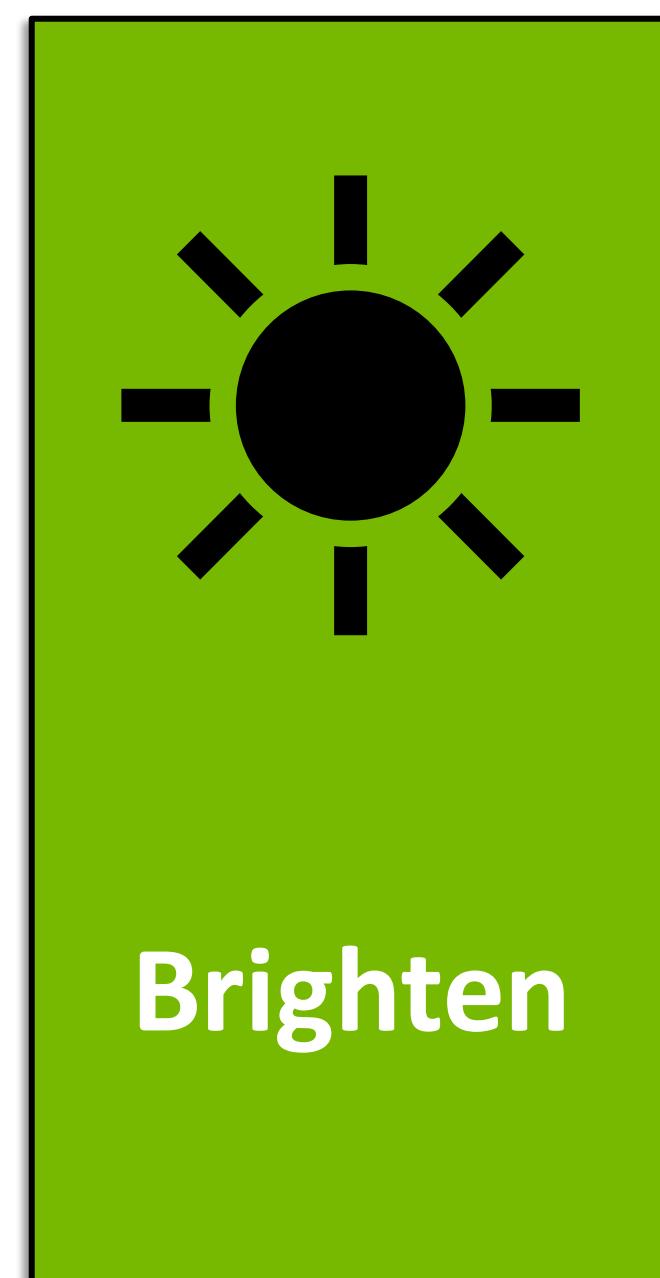
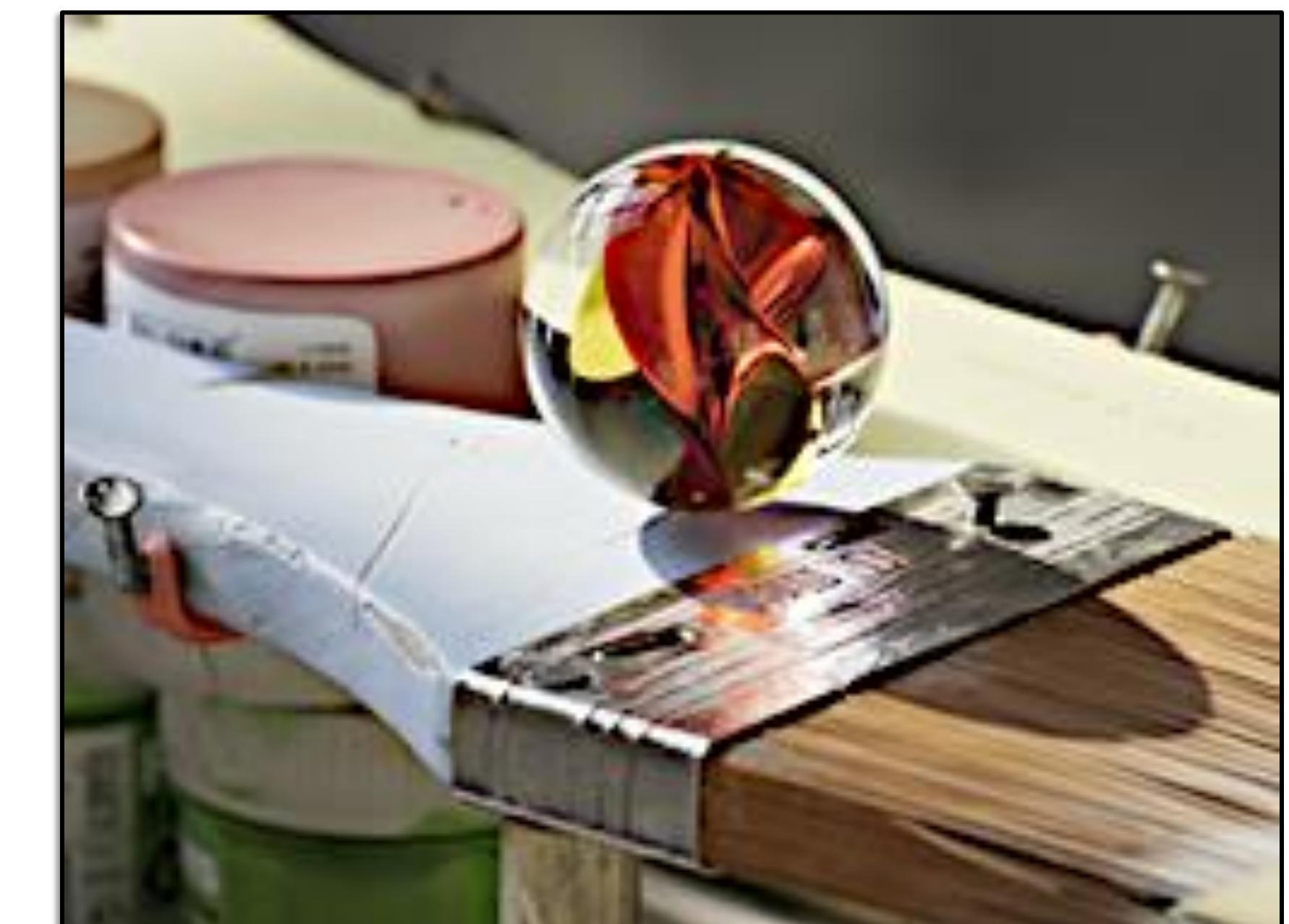
Original Image



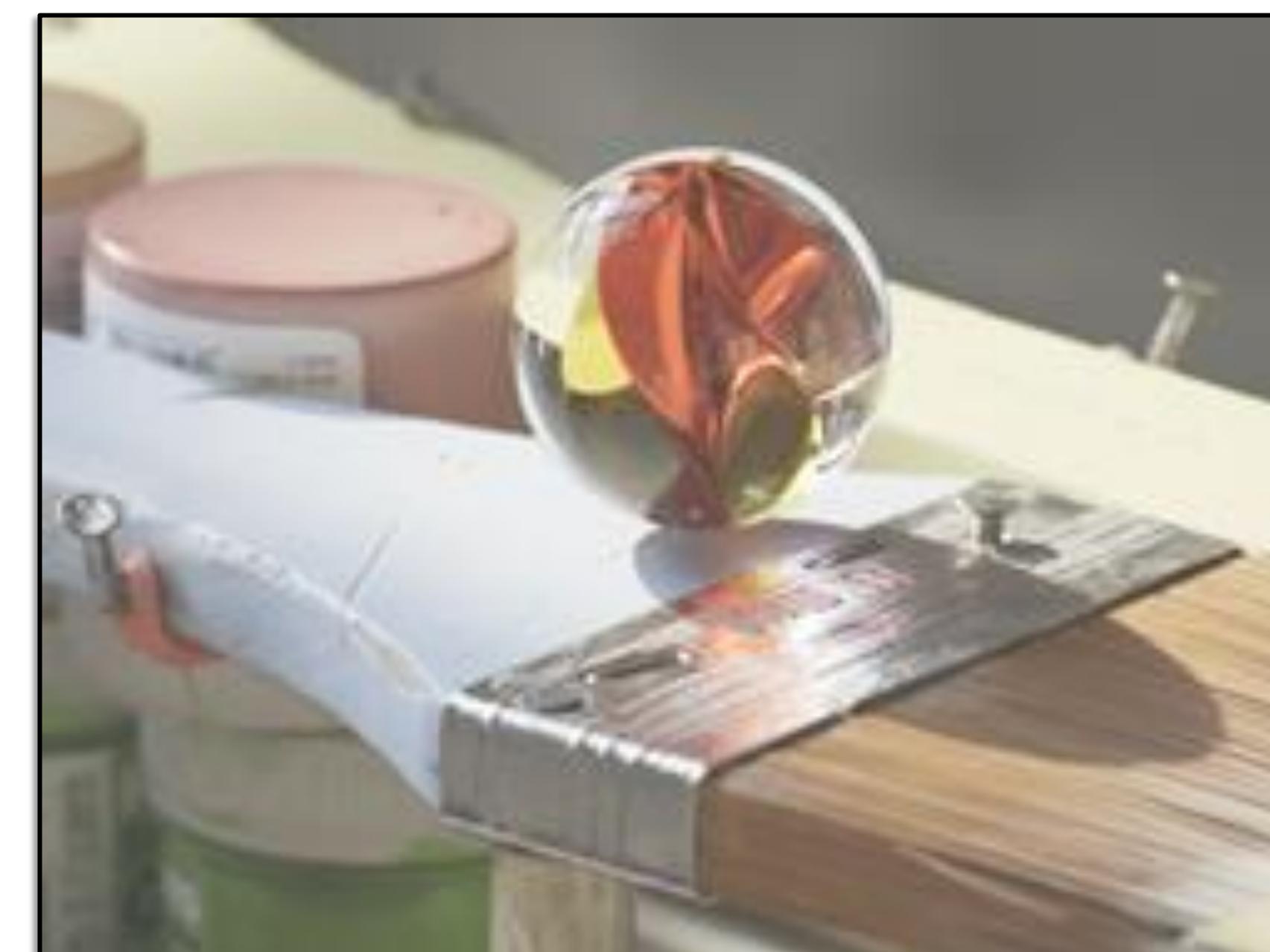
Blur



Sharpen



Brighten



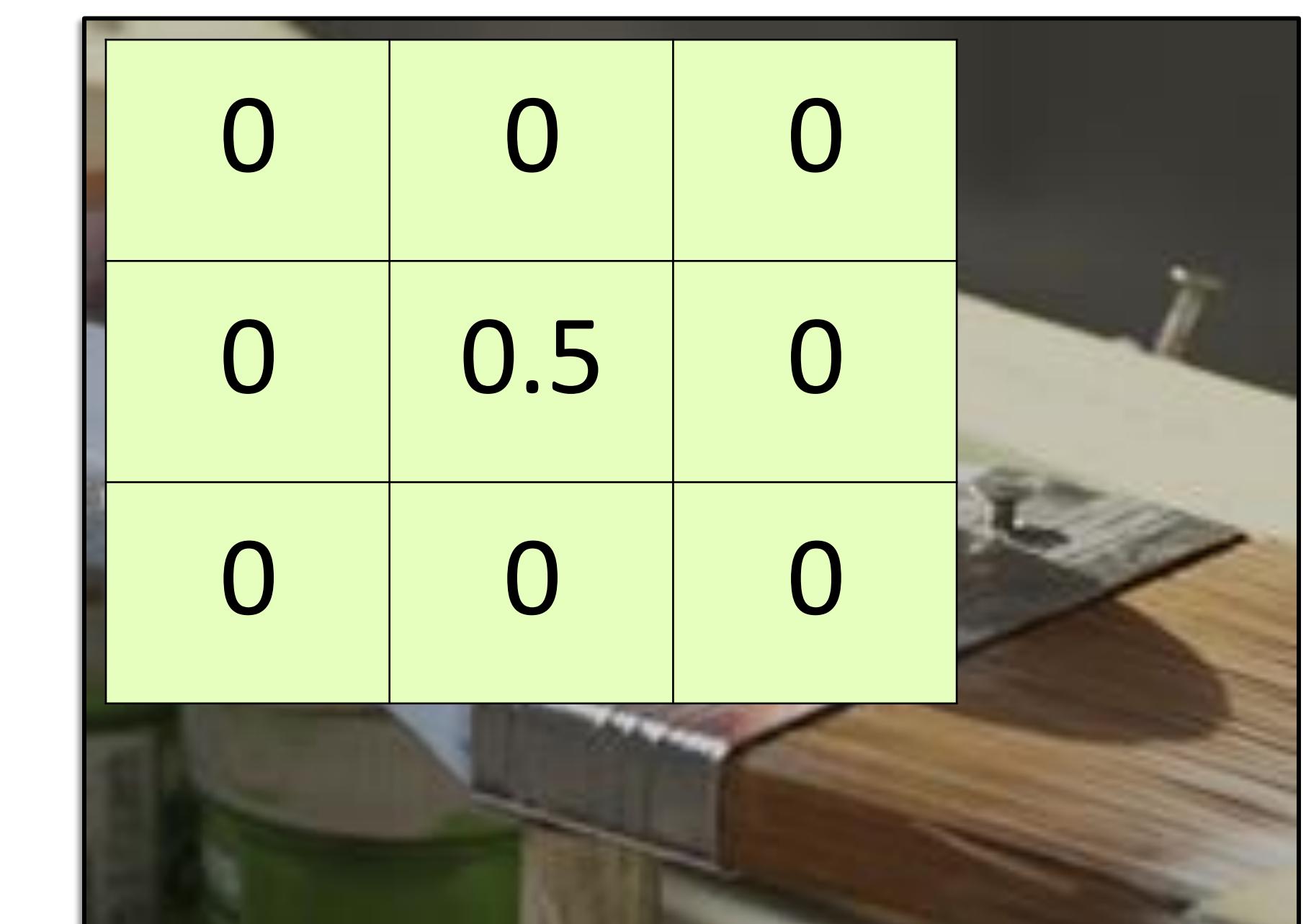
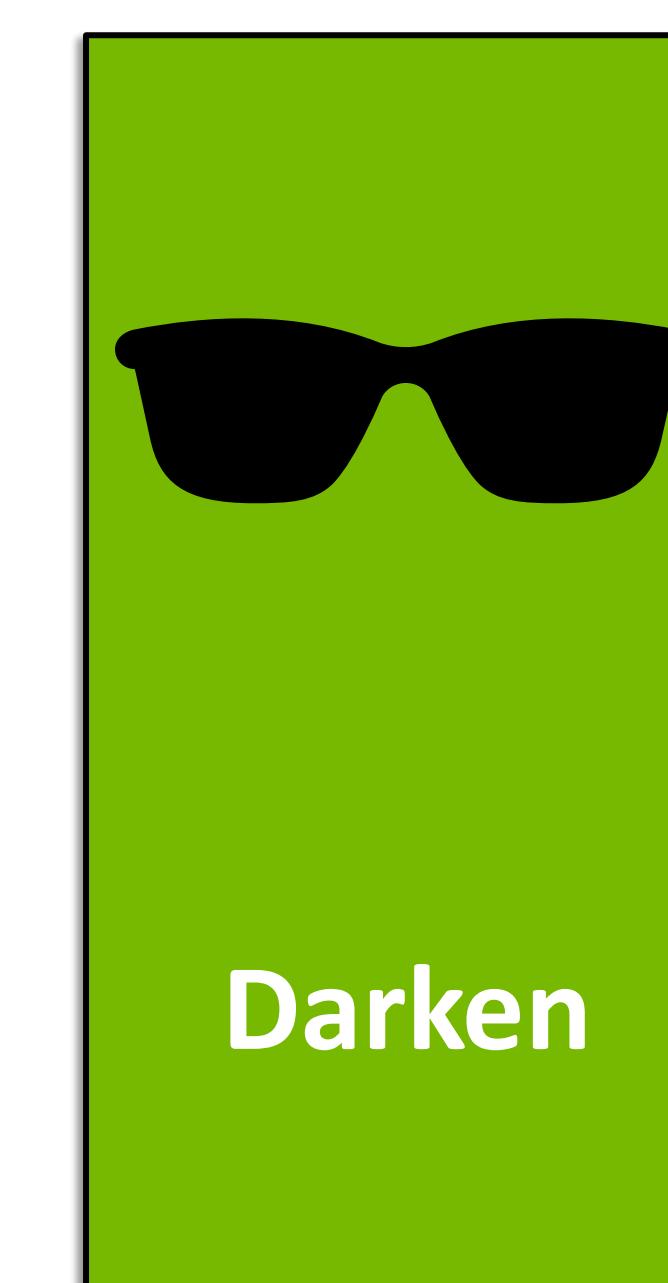
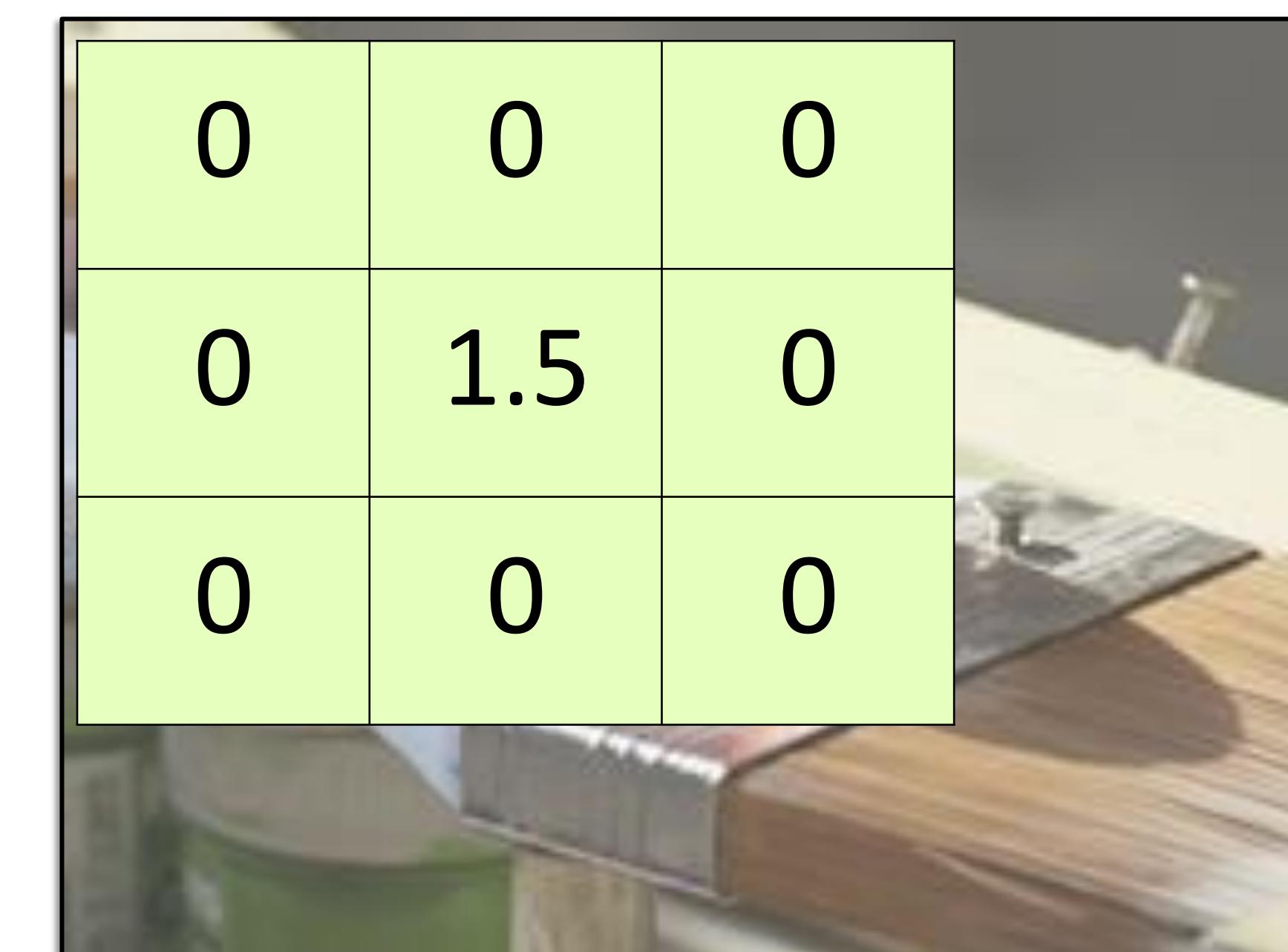
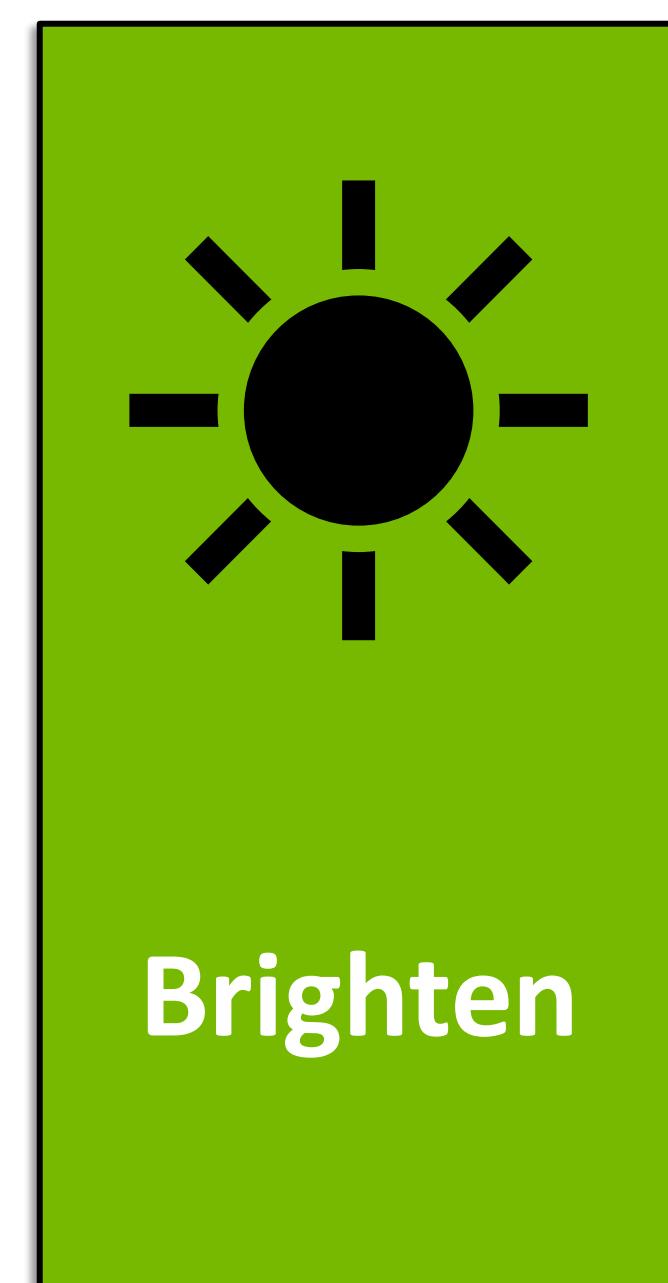
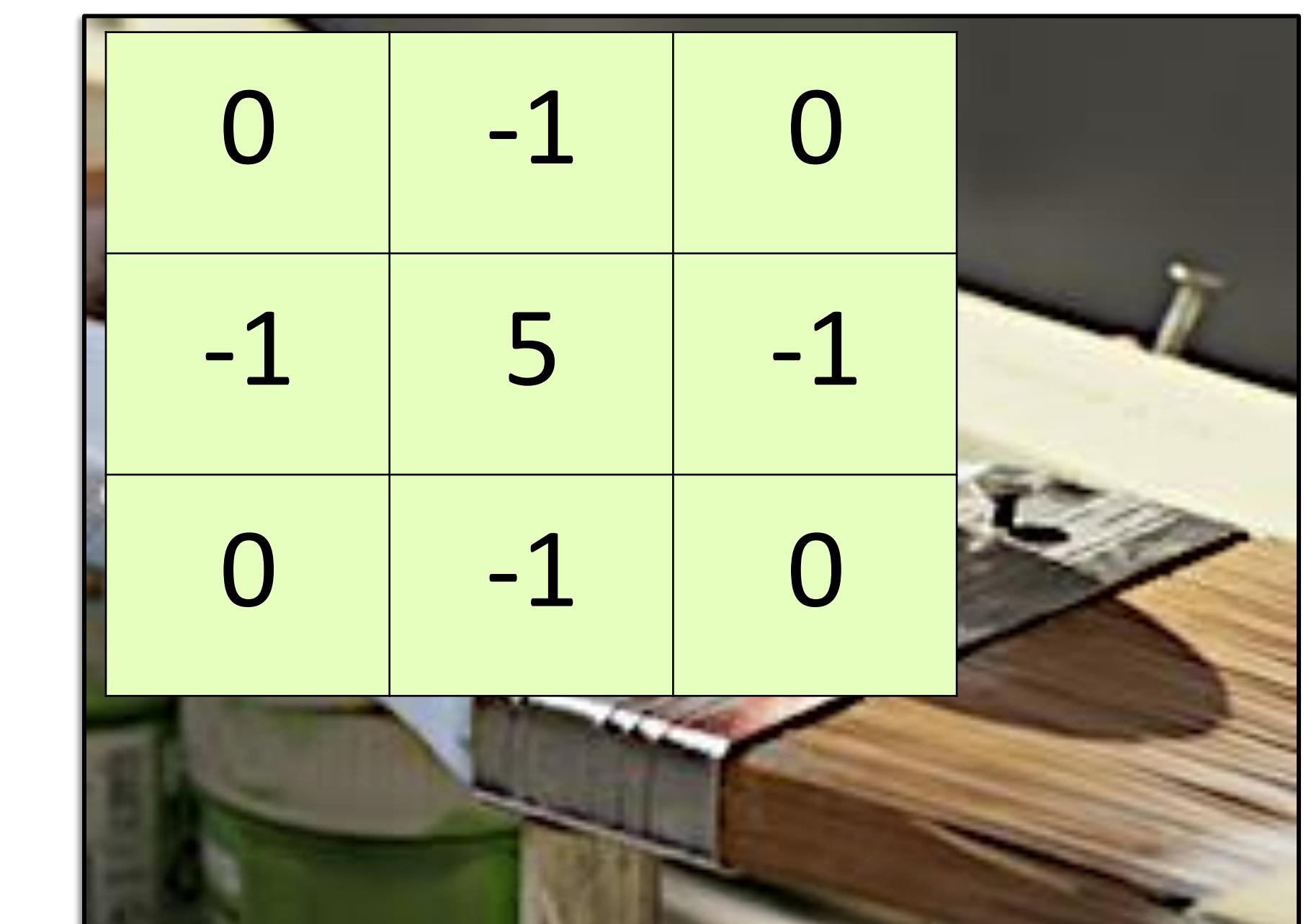
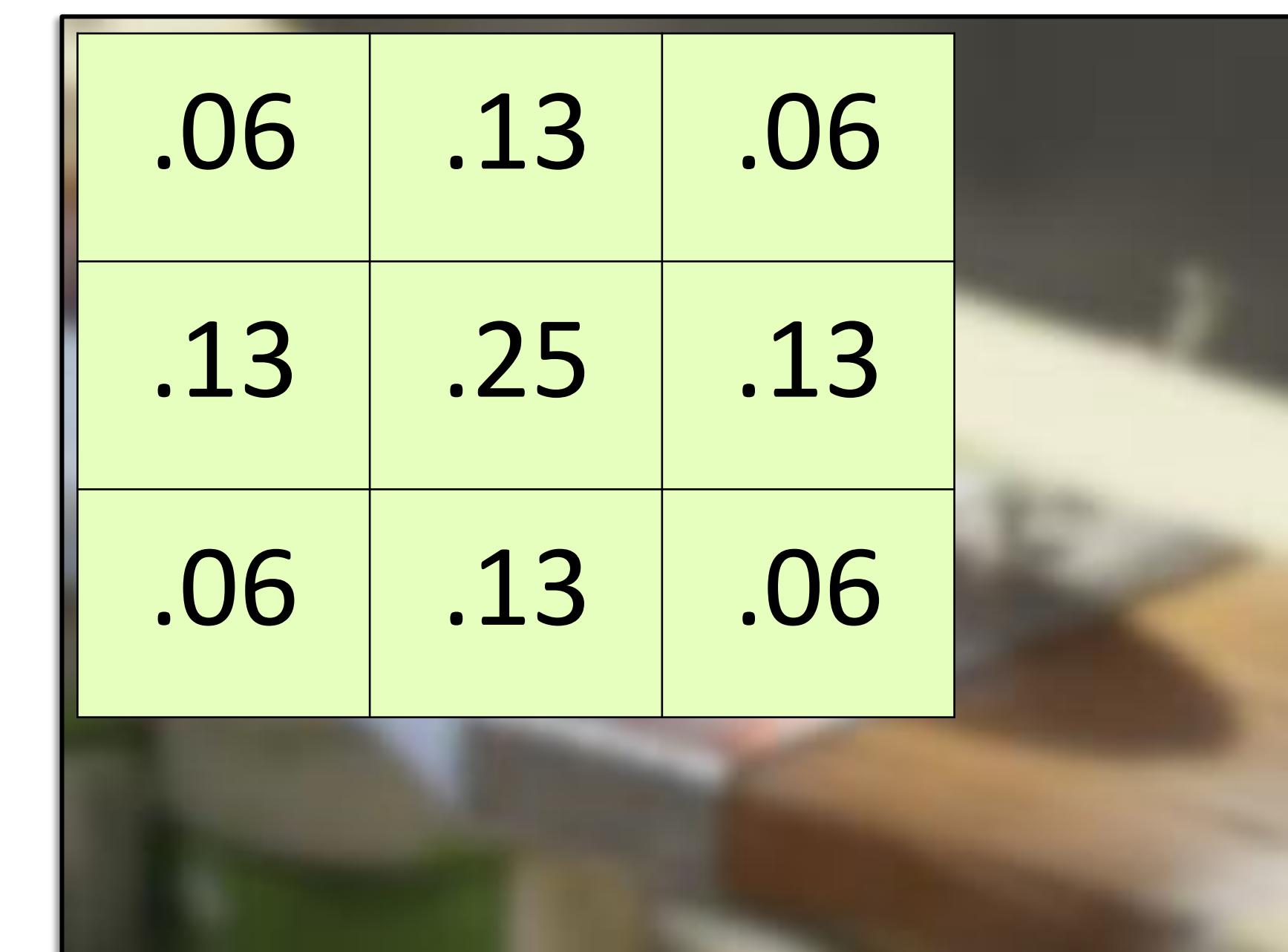
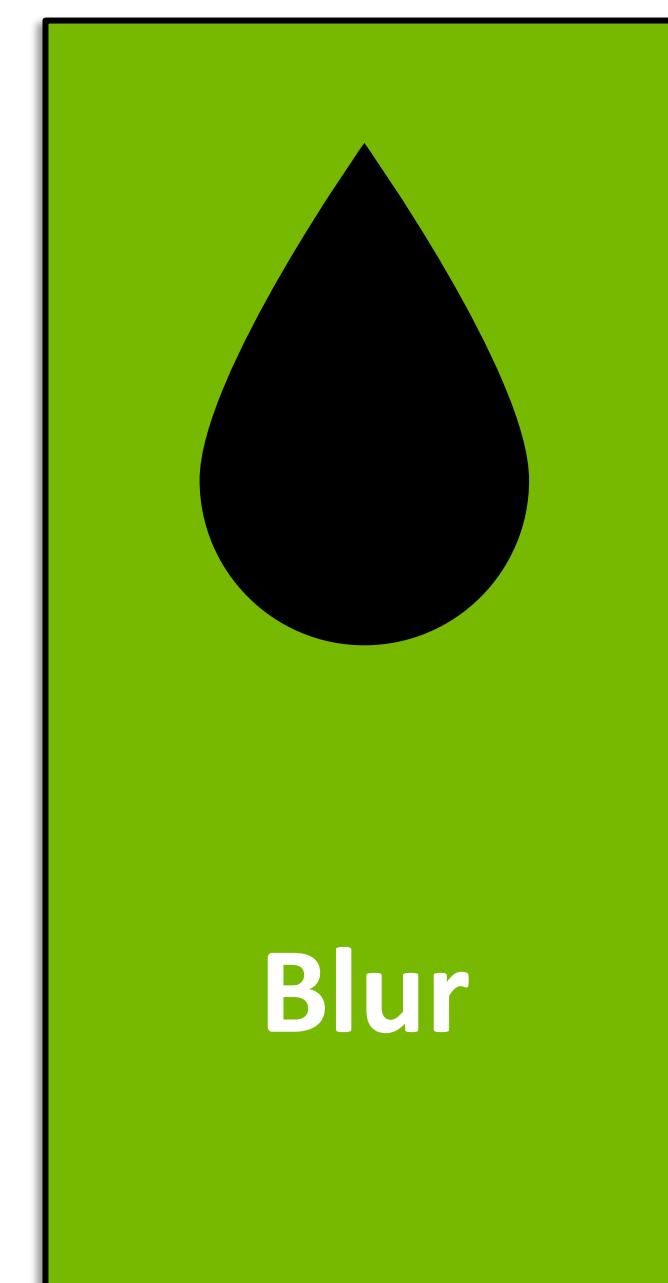
Darken



# Kernels and Convolution



Original Image



# Kernels and Convolution

Blur Kernel

.06	.13	.06
.13	.25	.13
.06	.13	.06

Original Image

$$\begin{matrix} 1 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \end{matrix} * \begin{matrix} .06 & .13 & .06 \\ .13 & .25 & .13 \\ .06 & .13 & .06 \end{matrix} = \begin{matrix} \text{[Result Matrix]} \end{matrix}$$

Convolved Image

# Kernels and Convolution

Blur Kernel

.06	.13	.06
.13	.25	.13
.06	.13	.06

Original Image

$$\begin{matrix} 1 & 0 & 1 & 1 & 0 & 1 \\ 0 & 1 & 0 & 0 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \end{matrix} * \begin{matrix} .06 & .13 & .06 \\ .13 & .25 & .13 \\ .06 & .13 & .06 \end{matrix} = \begin{matrix} \text{[Redacted]} \end{matrix}$$

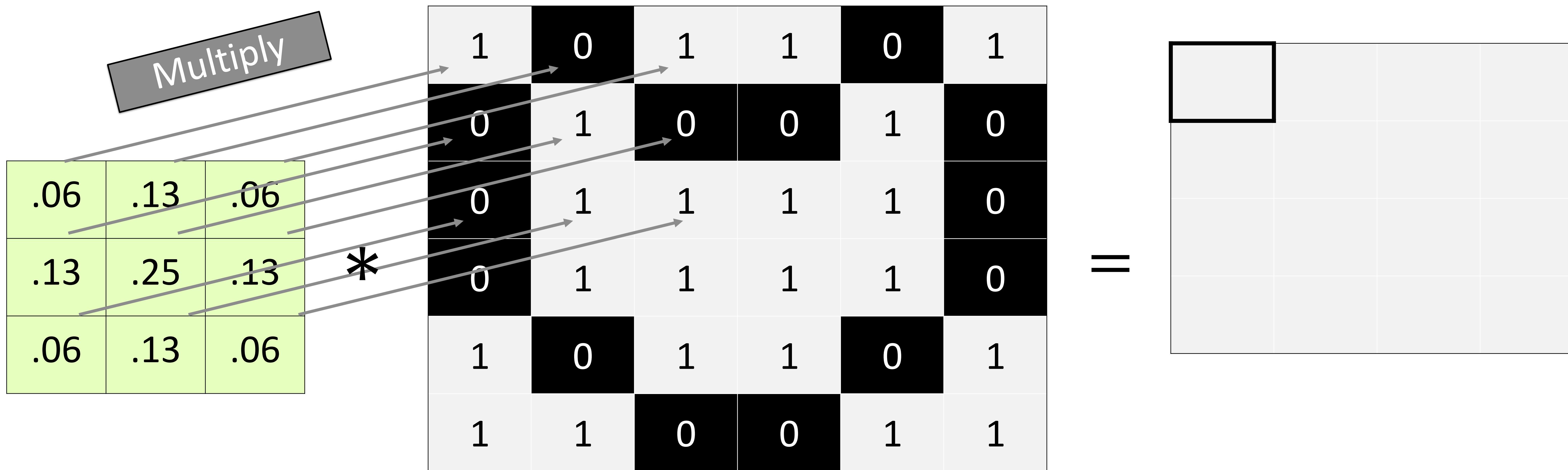
Convolved Image

# Kernels and Convolution

Blur Kernel

Original Image

Convolved Image



# Kernels and Convolution

Blur Kernel

.06	.13	.06
.13	.25	.13
.06	.13	.06

Original Image

$$\begin{matrix} .06 & 0 & .06 & 1 & 0 & 1 \\ 0 & .25 & 0 & \text{Total} & 0 \\ 0 & .13 & .06 & 1 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \end{matrix} = .56$$

The diagram illustrates the convolution process. A 3x3 kernel (Blur Kernel) is applied to a 6x6 original image. The result is a 3x3 convolved image with a value of .56. The 'Total' cell in the kernel matrix indicates the sum of the kernel values, which is 1.0.

# Kernels and Convolution

Blur Kernel

.06	.13	.06
.13	.25	.13
.06	.13	.06

Original Image

$$\begin{matrix} & \begin{matrix} 1 & 0 & .13 & .06 & 0 & 1 \\ 0 & .13 & 0 & 0 & 1 & 0 \\ 0 & .06 & .13 & .06 & 1 & 0 \\ 0 & 1 & 1 & 1 & 1 & 0 \\ 1 & 0 & 1 & 1 & 0 & 1 \\ 1 & 1 & 0 & 0 & 1 & 1 \end{matrix} & = \end{matrix}$$

The diagram illustrates the convolution process. A 3x3 blur kernel is applied to a 6x6 original image. The result is a 3x3 convolved image. The highlighted section of the original image shows the receptive field of the central output unit, which is calculated by summing the products of the kernel values and the corresponding input values from the original image.

Convolved Image

.56	.57

# Kernels and Convolution

Blur Kernel

.06	.13	.06
.13	.25	.13
.06	.13	.06

Original Image

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

\*

Convolved Image

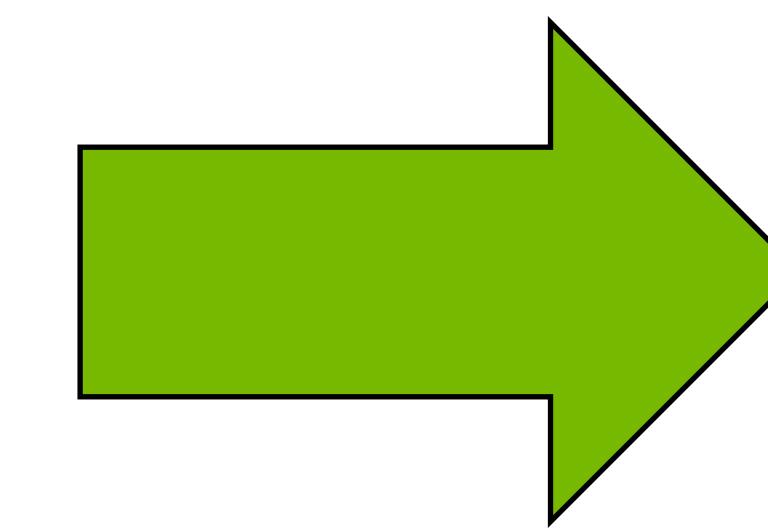
.56	.57	.57	.56
.7	.82	.82	.7
.69	.95	.95	.69
.64	.69	.69	.64

=

# Stride

Stride 1

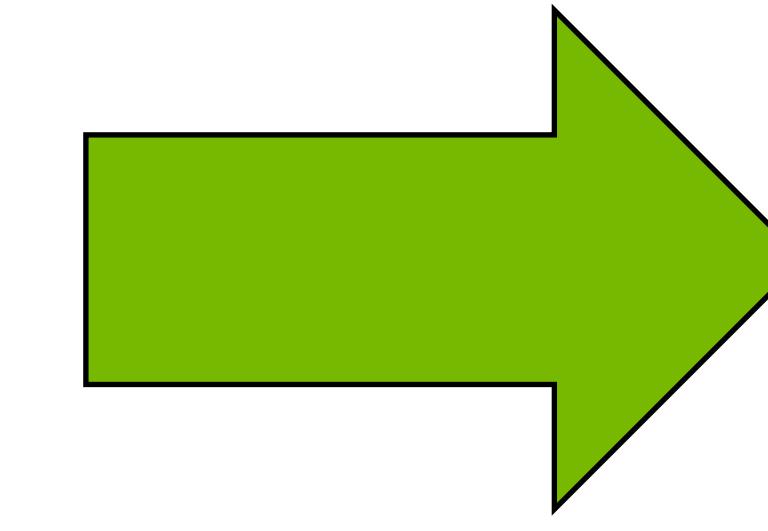
1	0	1	1	0	1
0	1	0	0	1	0
0	1	1	1	1	0



.56	.57	.57	.56
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Stride 2

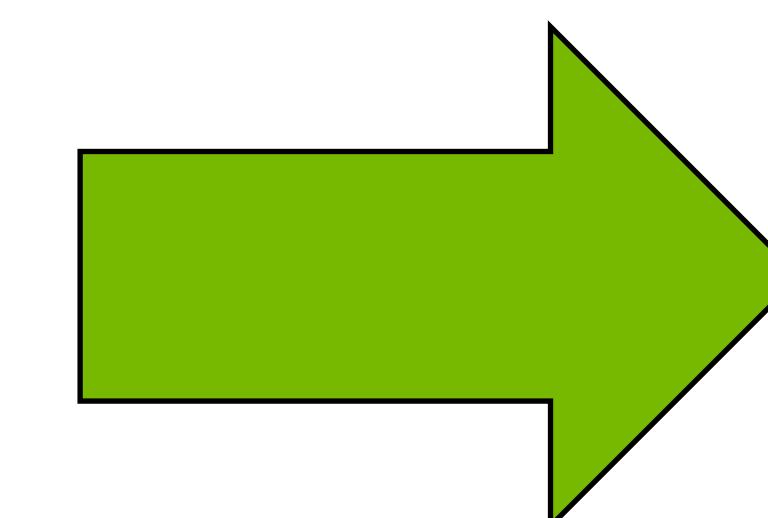
1	0	1	1	0	1
0	1	0	0	1	0
0	1	1	1	1	0



.56	.57
-----	-----

Stride 3

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



.56	.56
-----	-----

# Padding

Original Image

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

Zero Padding

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

# Padding

Original Image

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

Mirror Padding

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

# Kernels and Neural Networks

# Kernels and Neural Networks

Kernel

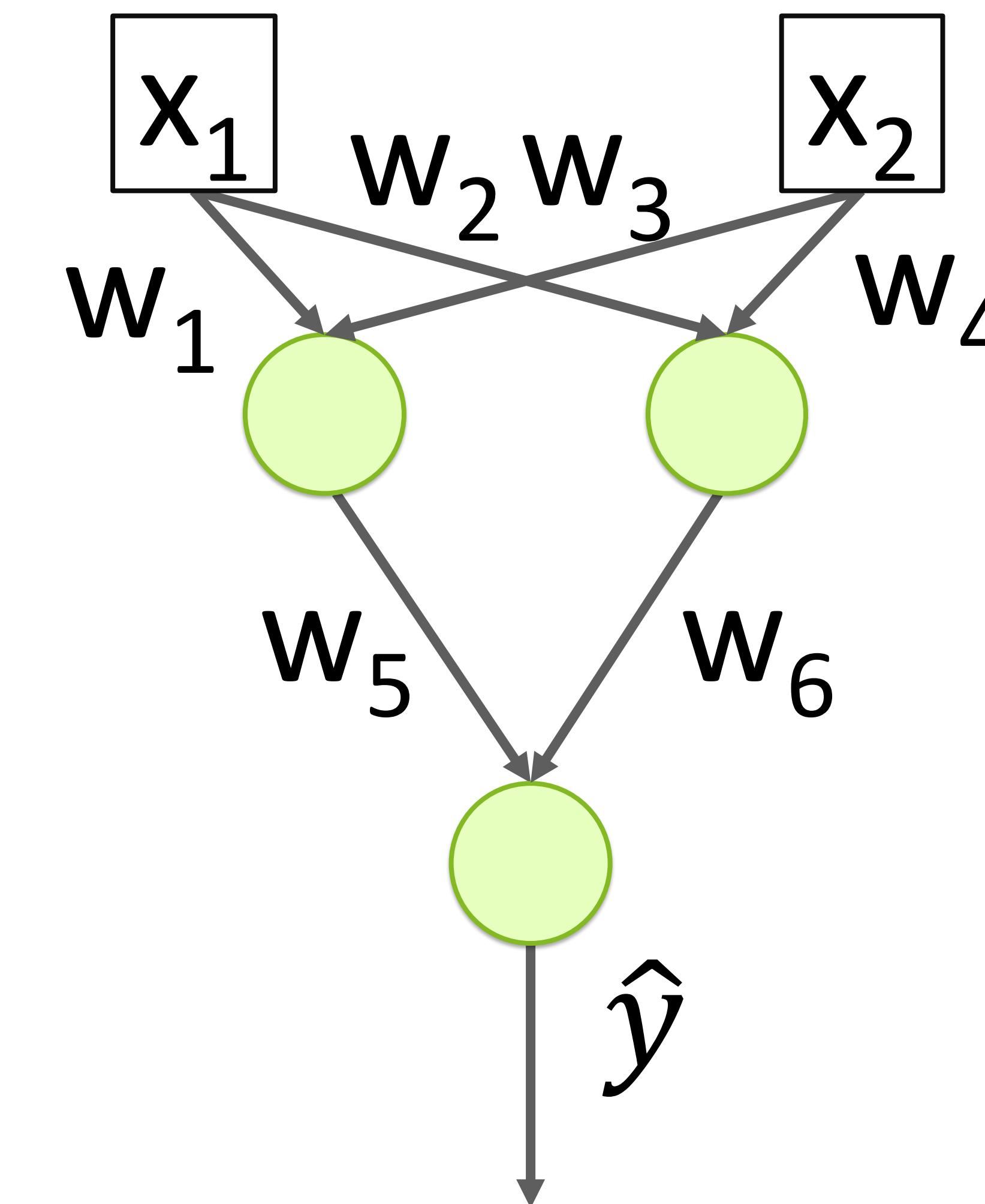
$w_1$	$w_2$	$w_3$
$w_4$	$w_5$	$w_6$
$w_7$	$w_8$	$w_9$

# Kernels and Neural Networks

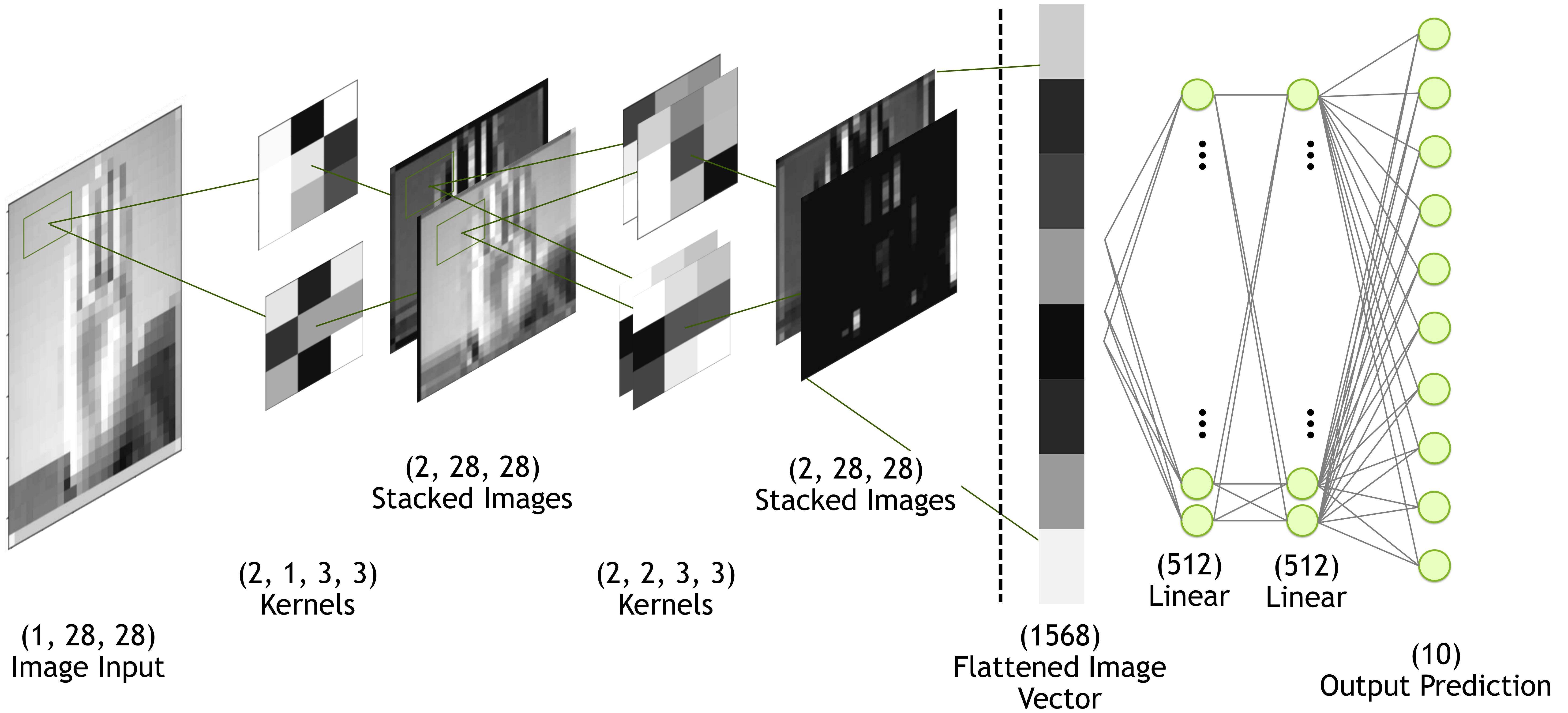
Kernel

$w_1$	$w_2$	$w_3$
$w_4$	$w_5$	$w_6$
$w_7$	$w_8$	$w_9$

Neuron

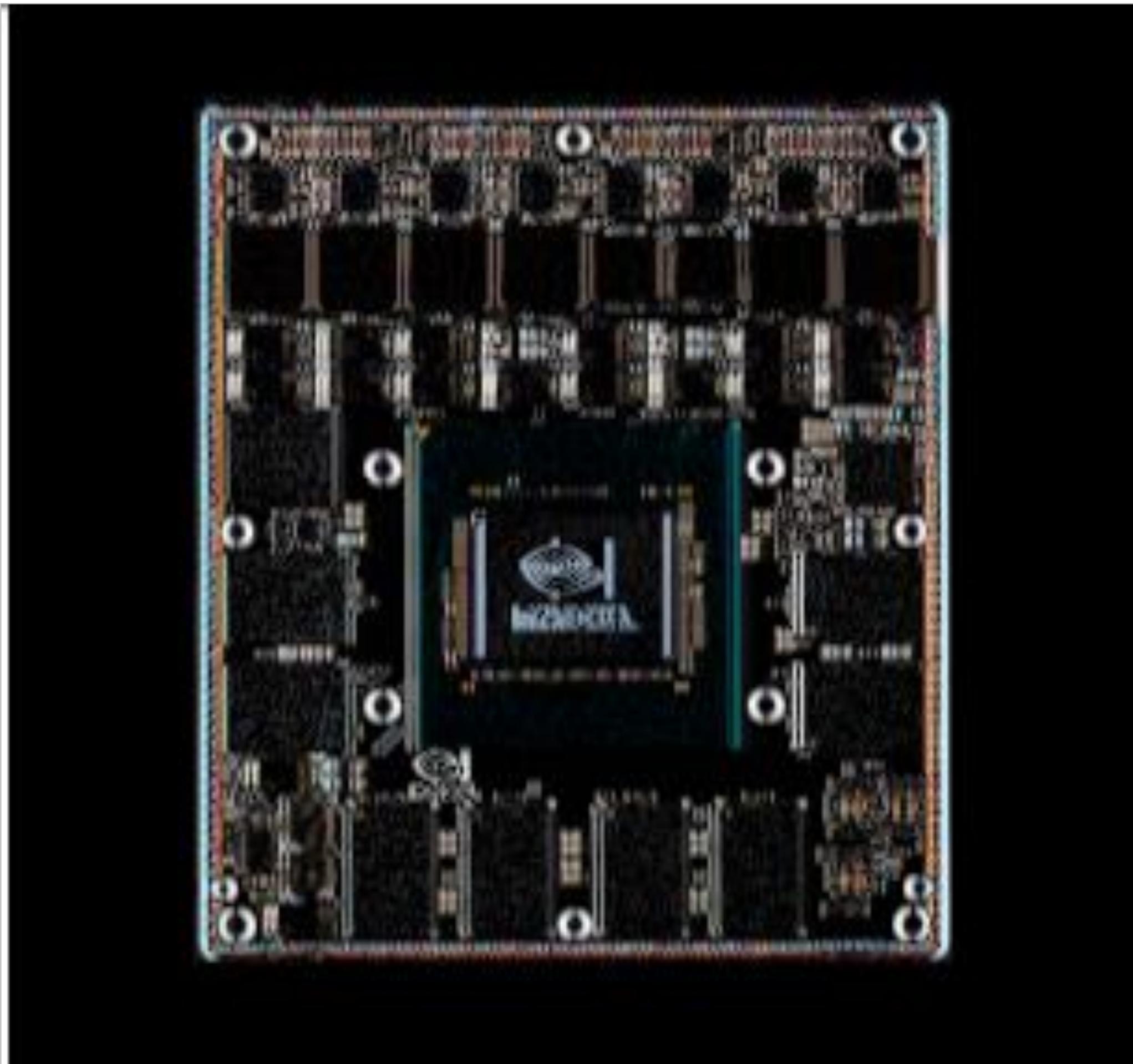


# Kernels and Neural Networks



# Finding Edges

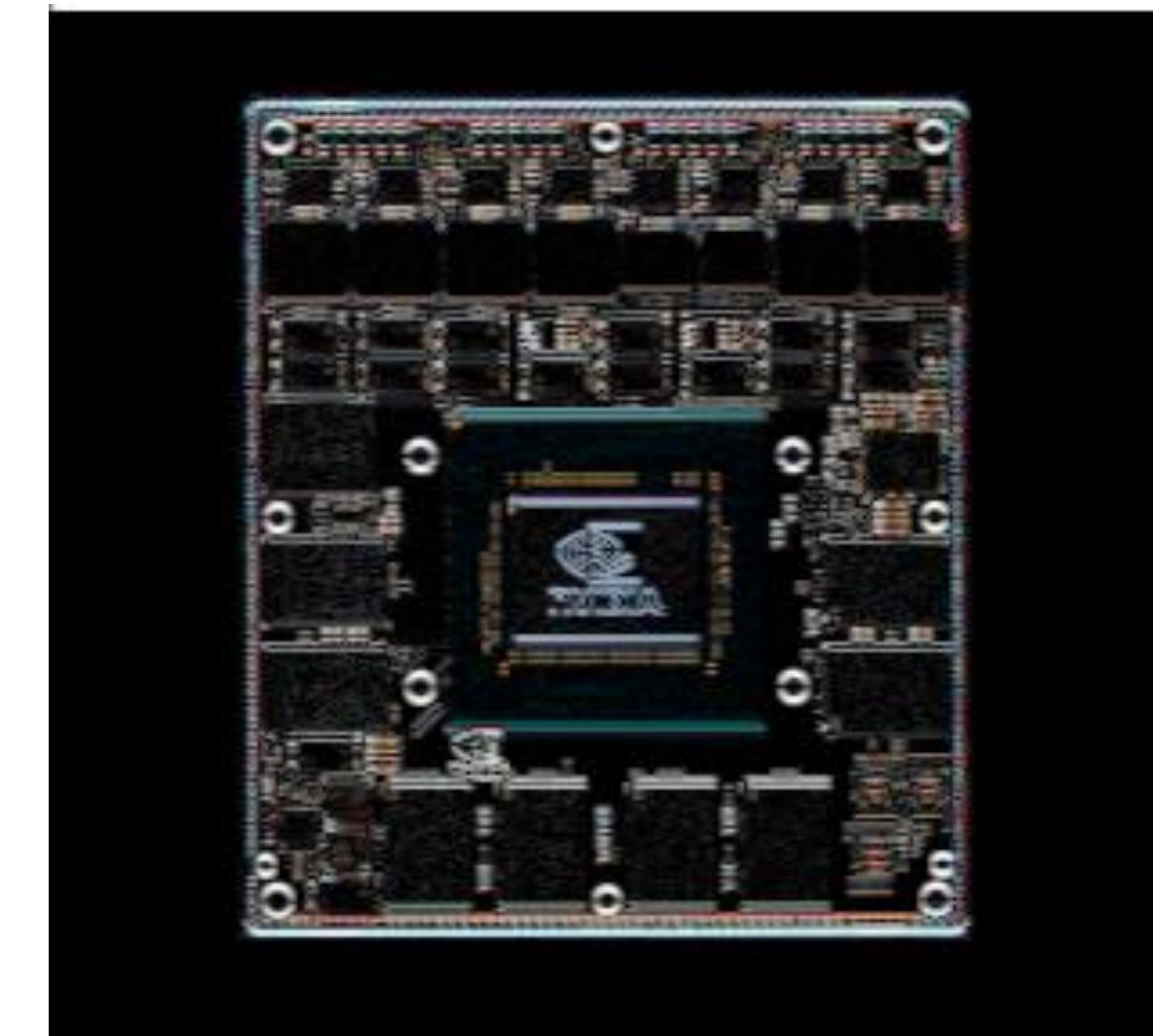
Vertical Edges



Original Image



Horizontal Edges

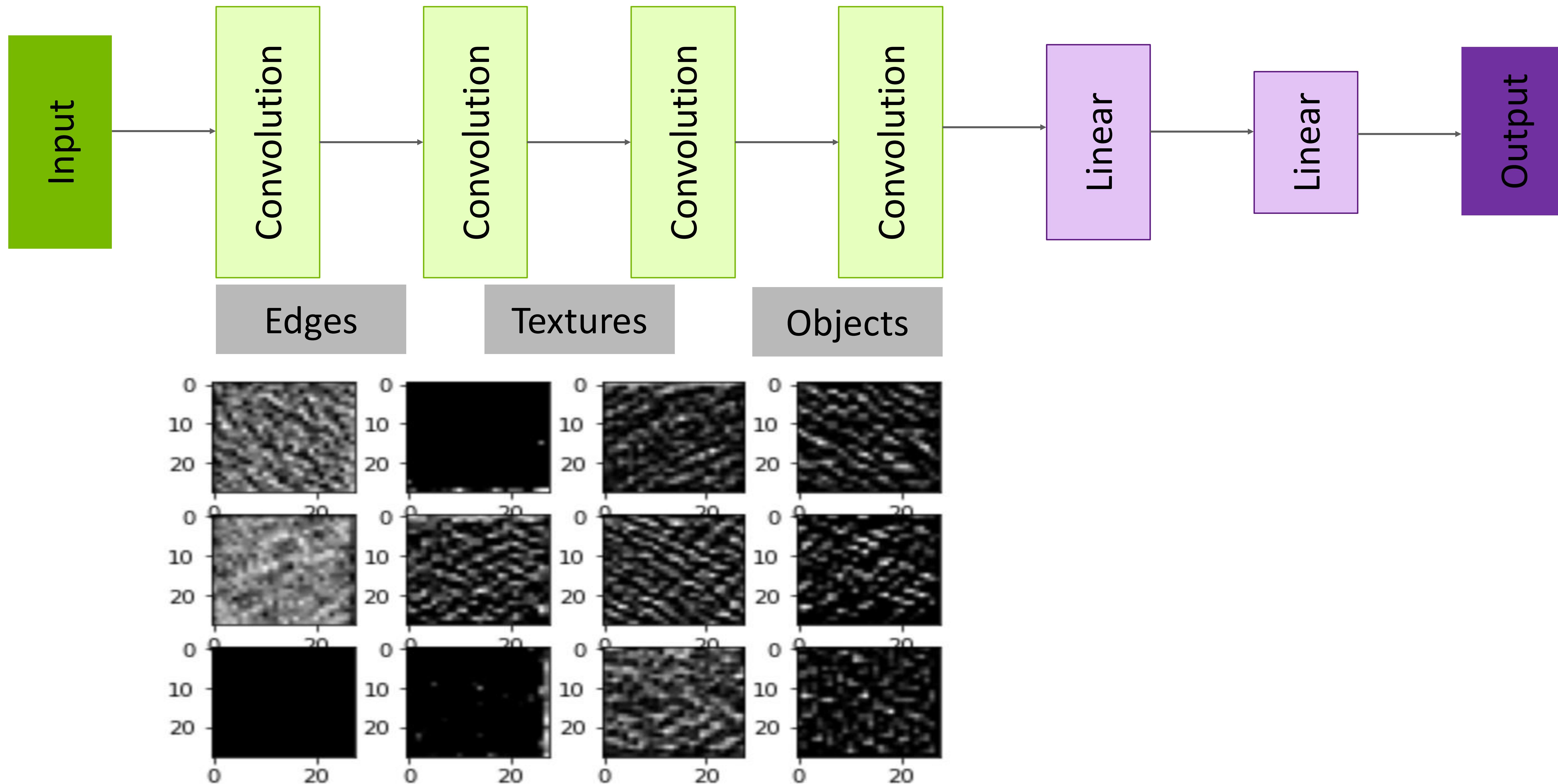


1	0	-1
2	0	-2
1	0	-1

0	0	0
0	1	0
0	0	0

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

# Neural Network Perception

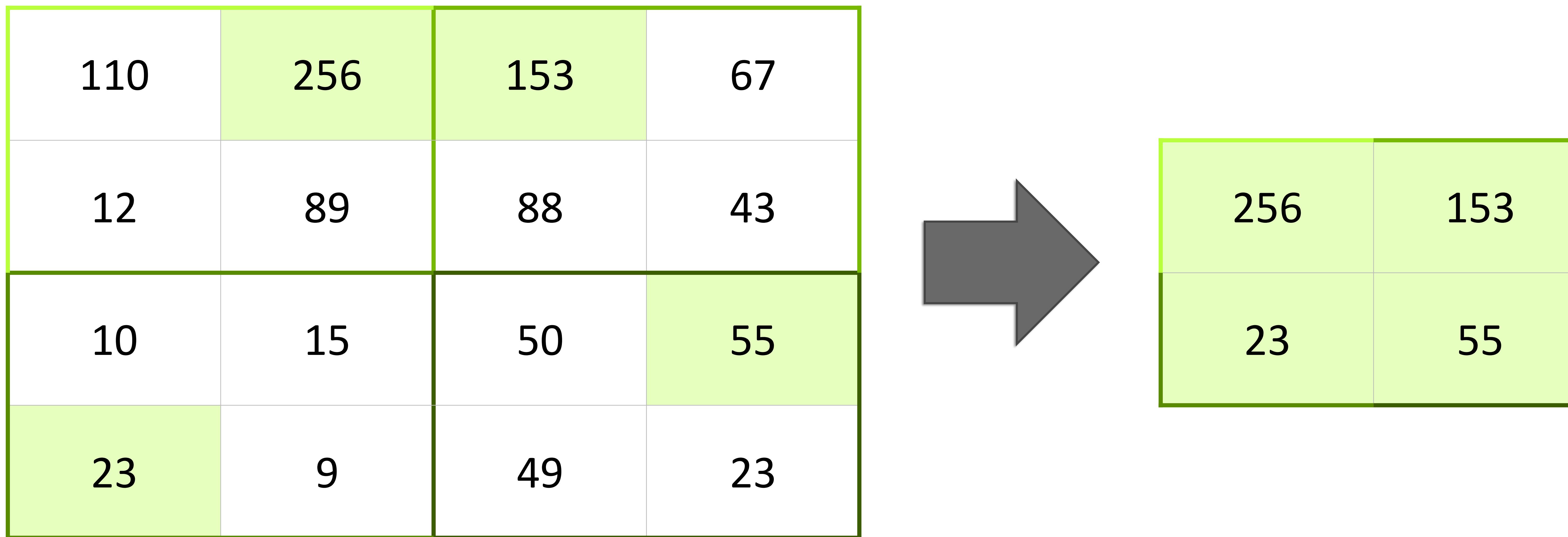


# Neural Network Perception

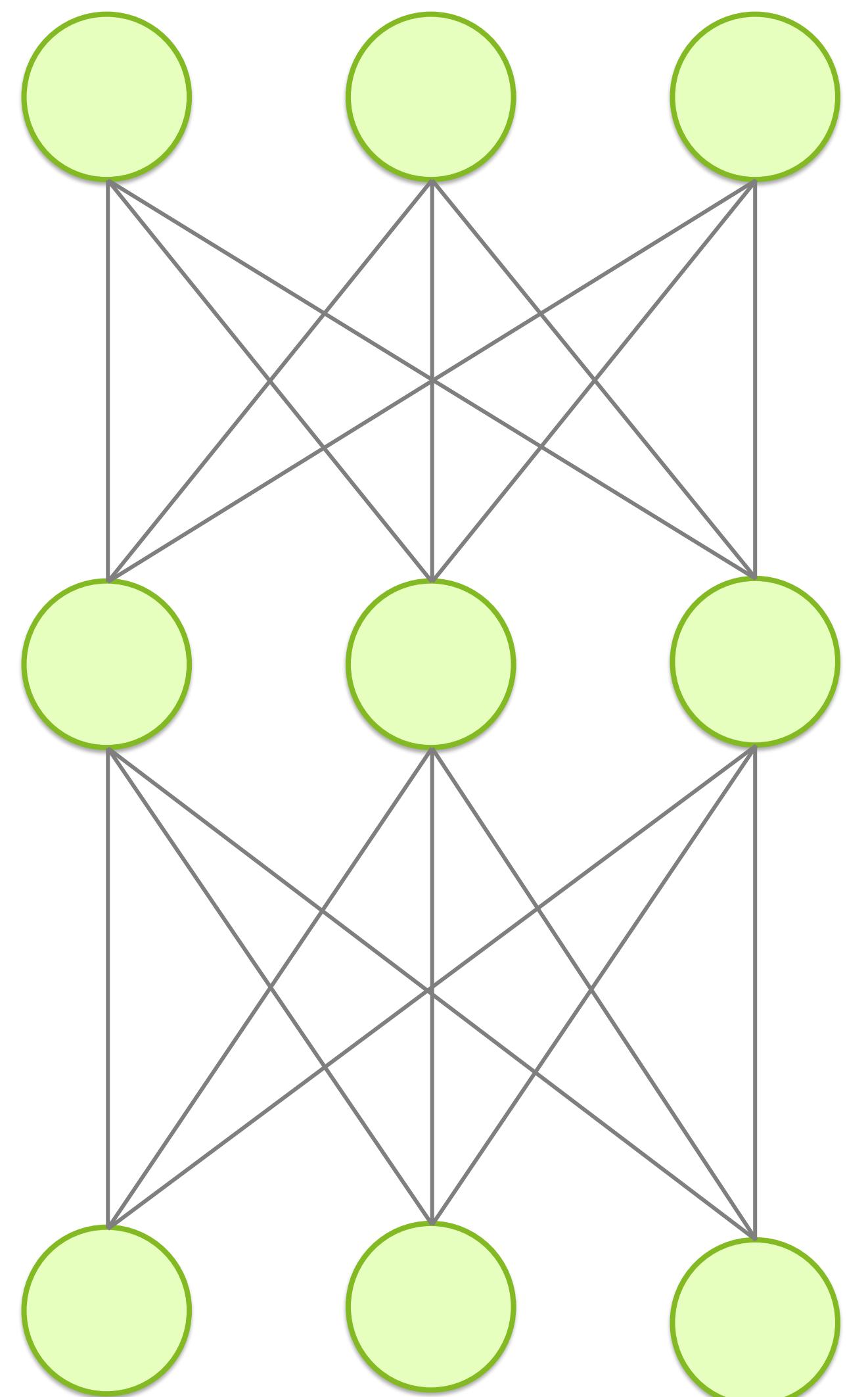


# **Other Layers in the Model**

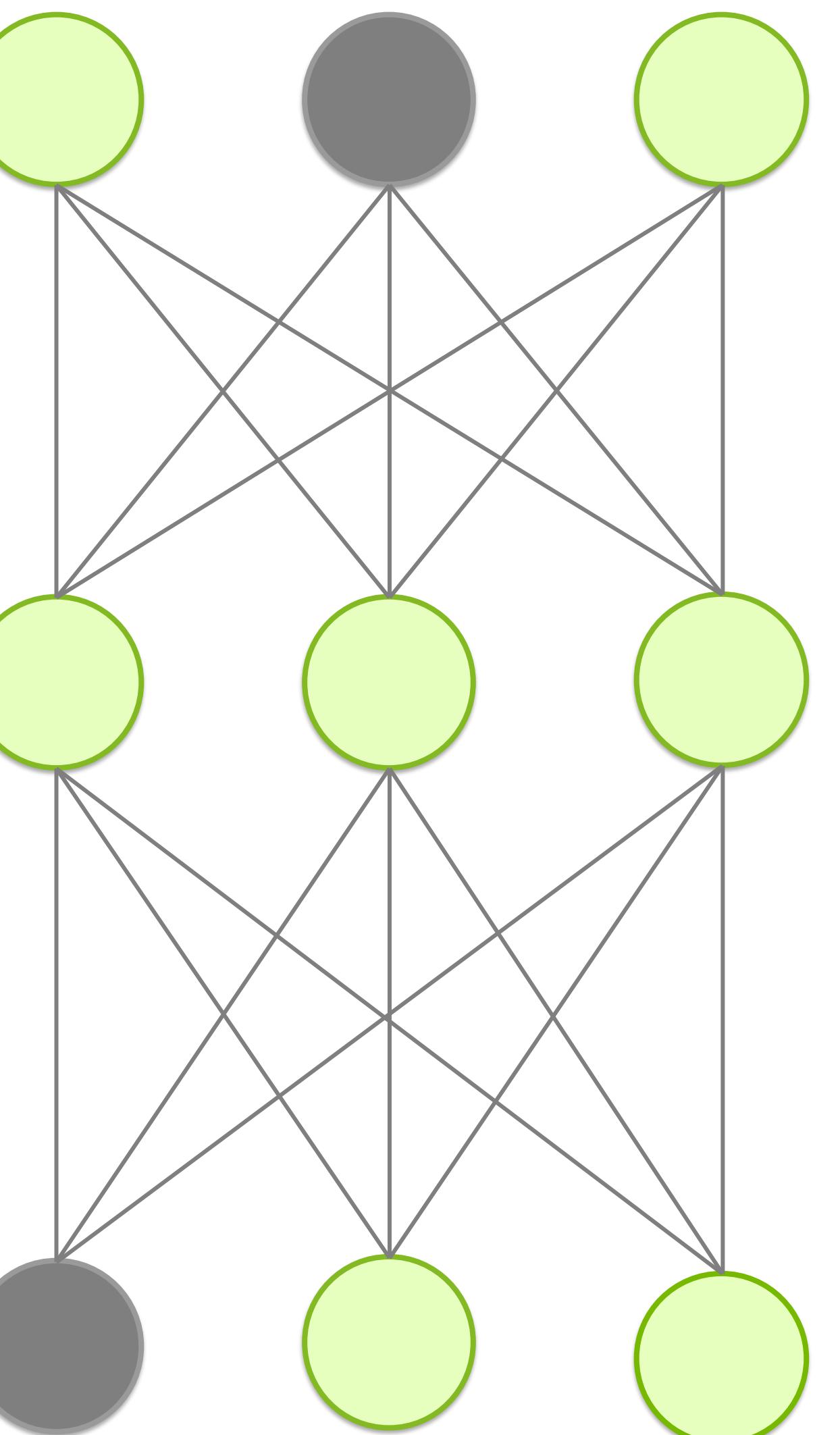
# Max Pooling



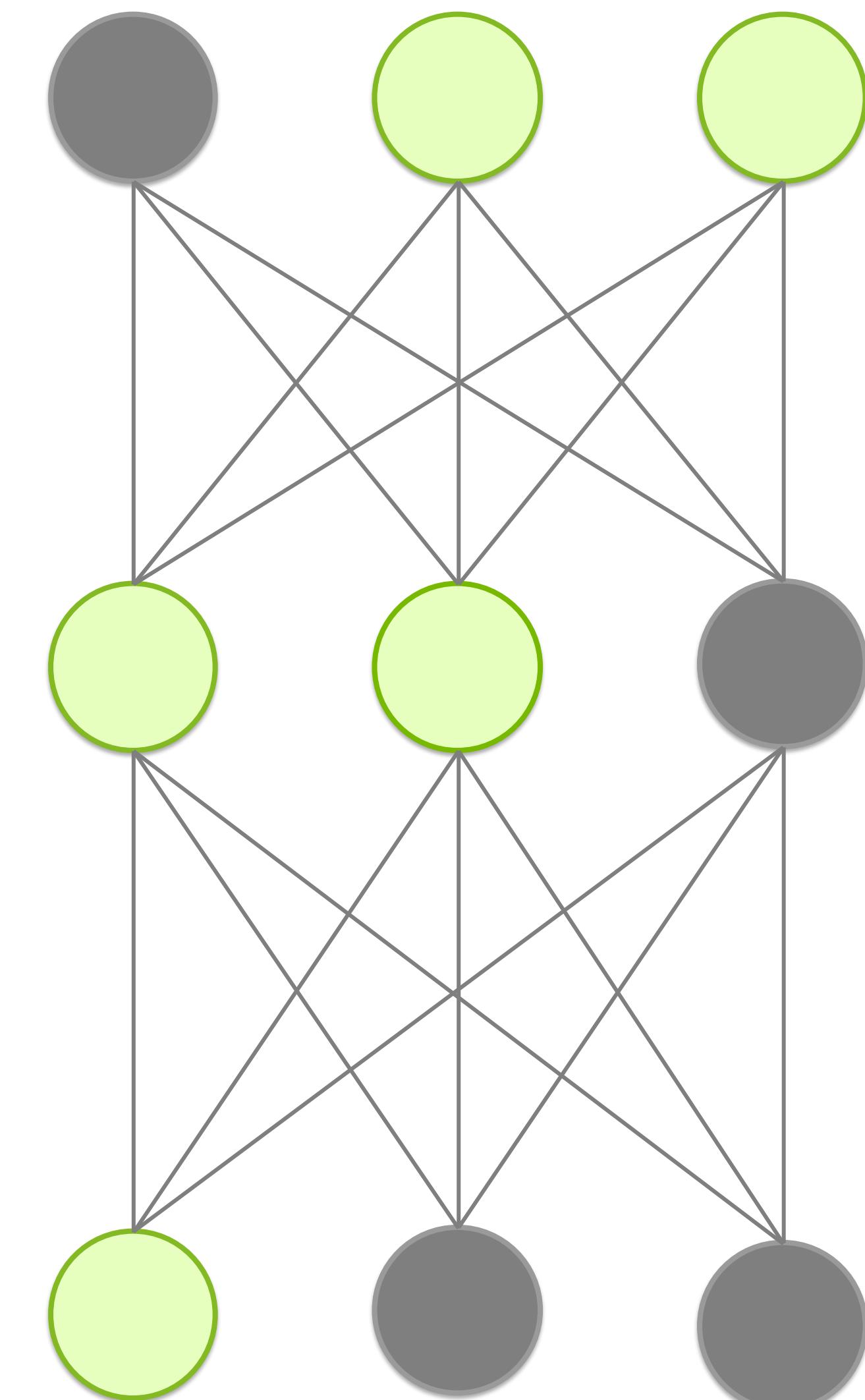
# Dropout



**rate = 0**

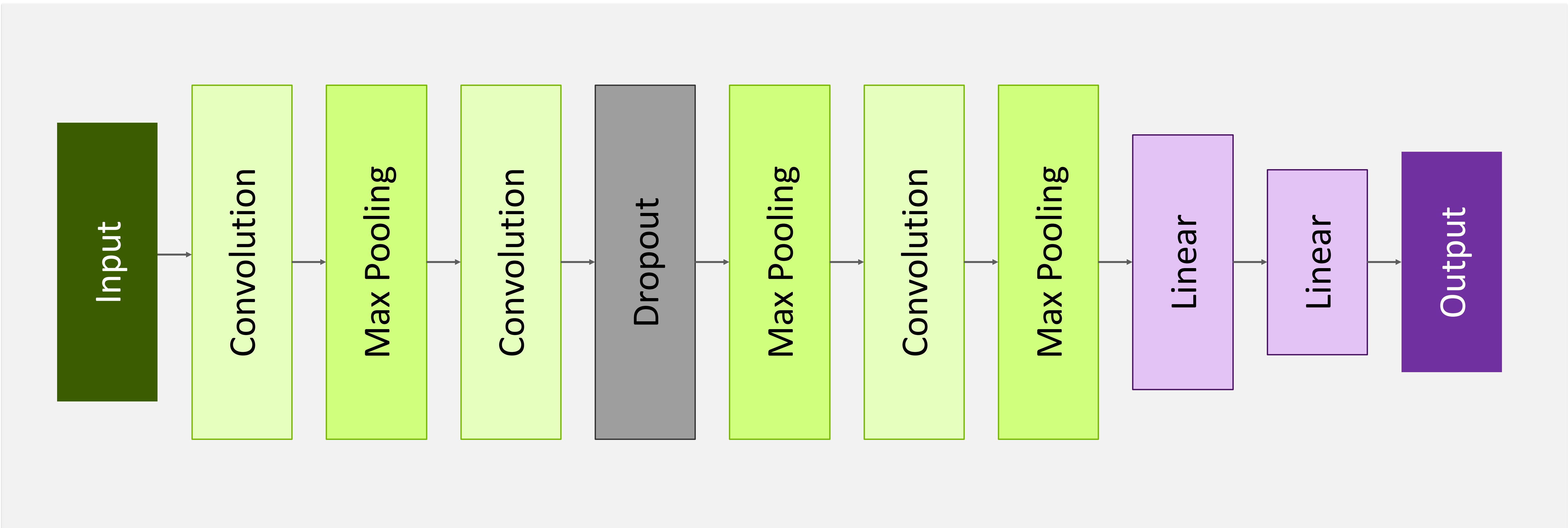


**rate = .2**



**rate = .4**

# Whole Architecture





**Let's go!**

