



# Fundamentals of Deep Learning

Part 3: Convolutional Neural Networks





# Agenda

- Part 1: An Introduction to Deep Learning

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- Part 2: How a Neural Network Trains

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- Part 3: Convolutional Neural Networks
- Part 4: Data Augmentation and Deployment

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- Part 5: Pre-Trained Models

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- 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





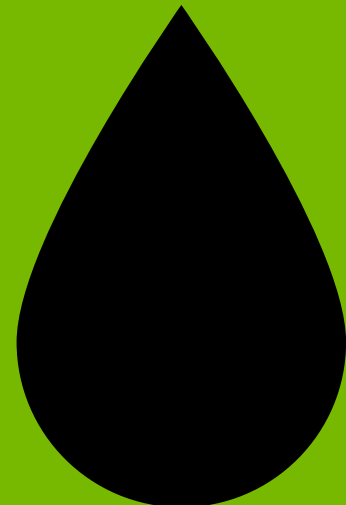
# Kernels and Convolution




# Kernels and Convolution




Original Image




Blur



Sharpen



Brighten



Darken

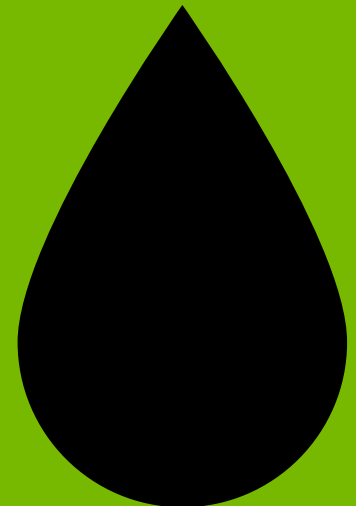




# Kernels and Convolution

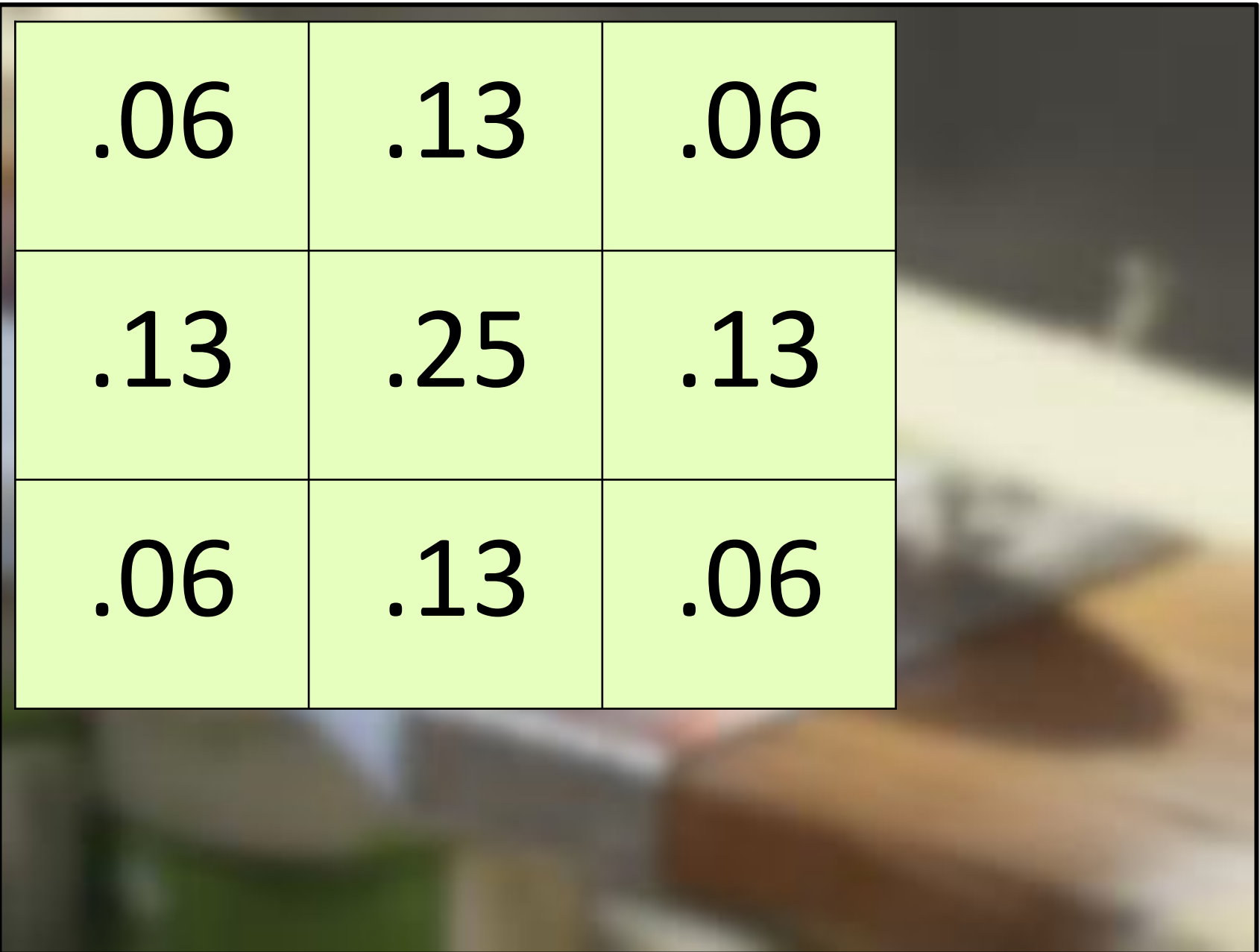



Original Image



Blur

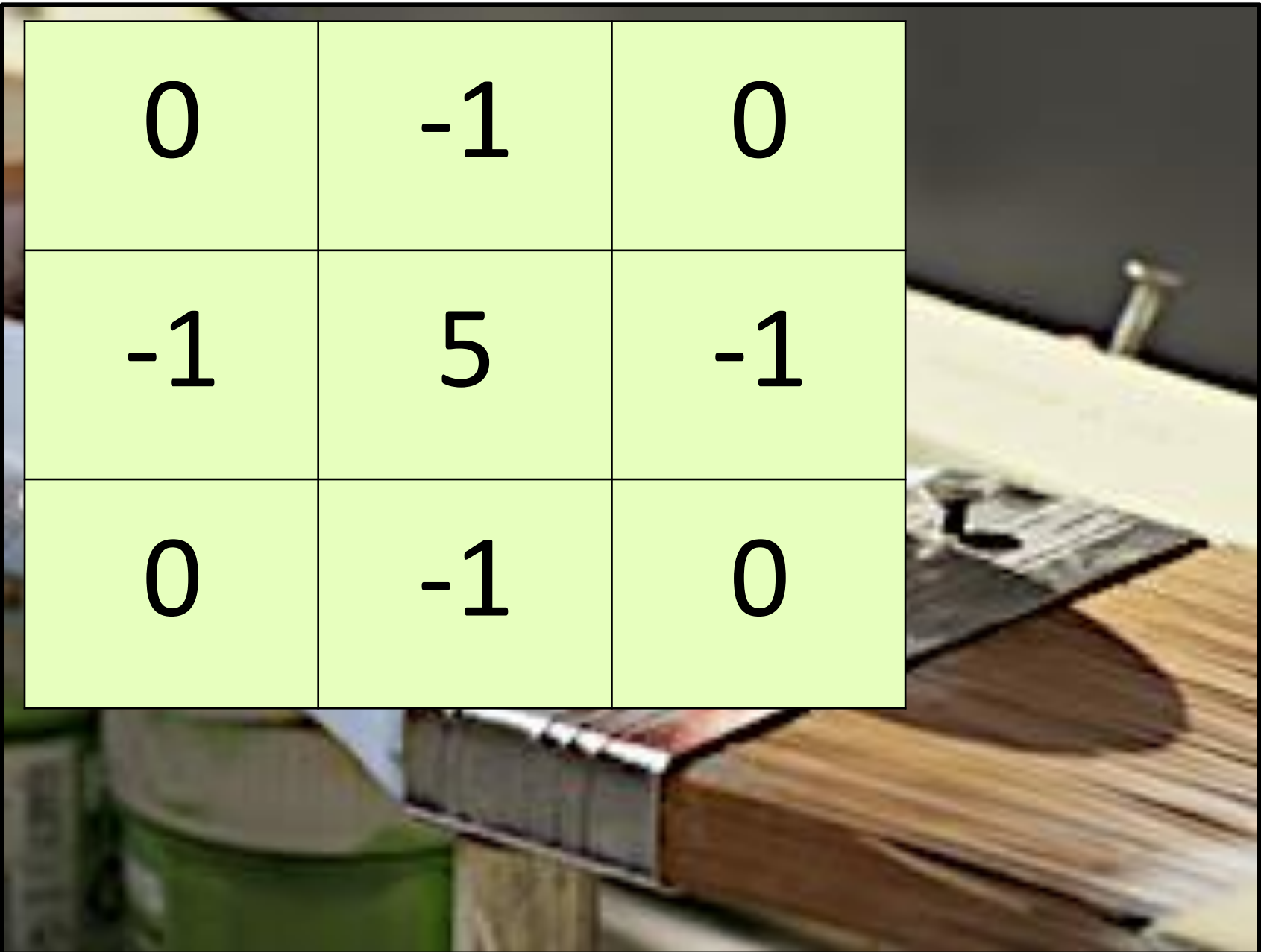
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|-----|-----|-----|
| .06 | .13 | .06 |
| .13 | .25 | .13 |
| .06 | .13 | .06 |

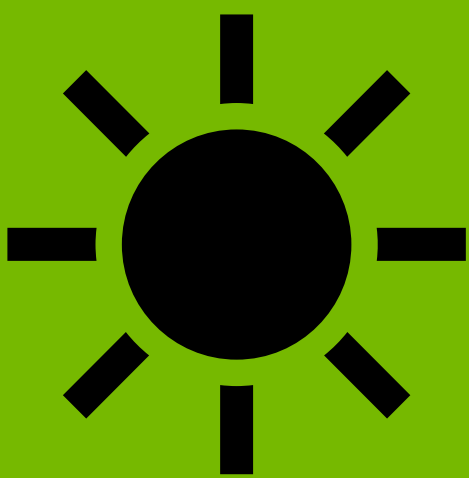




Sharpen

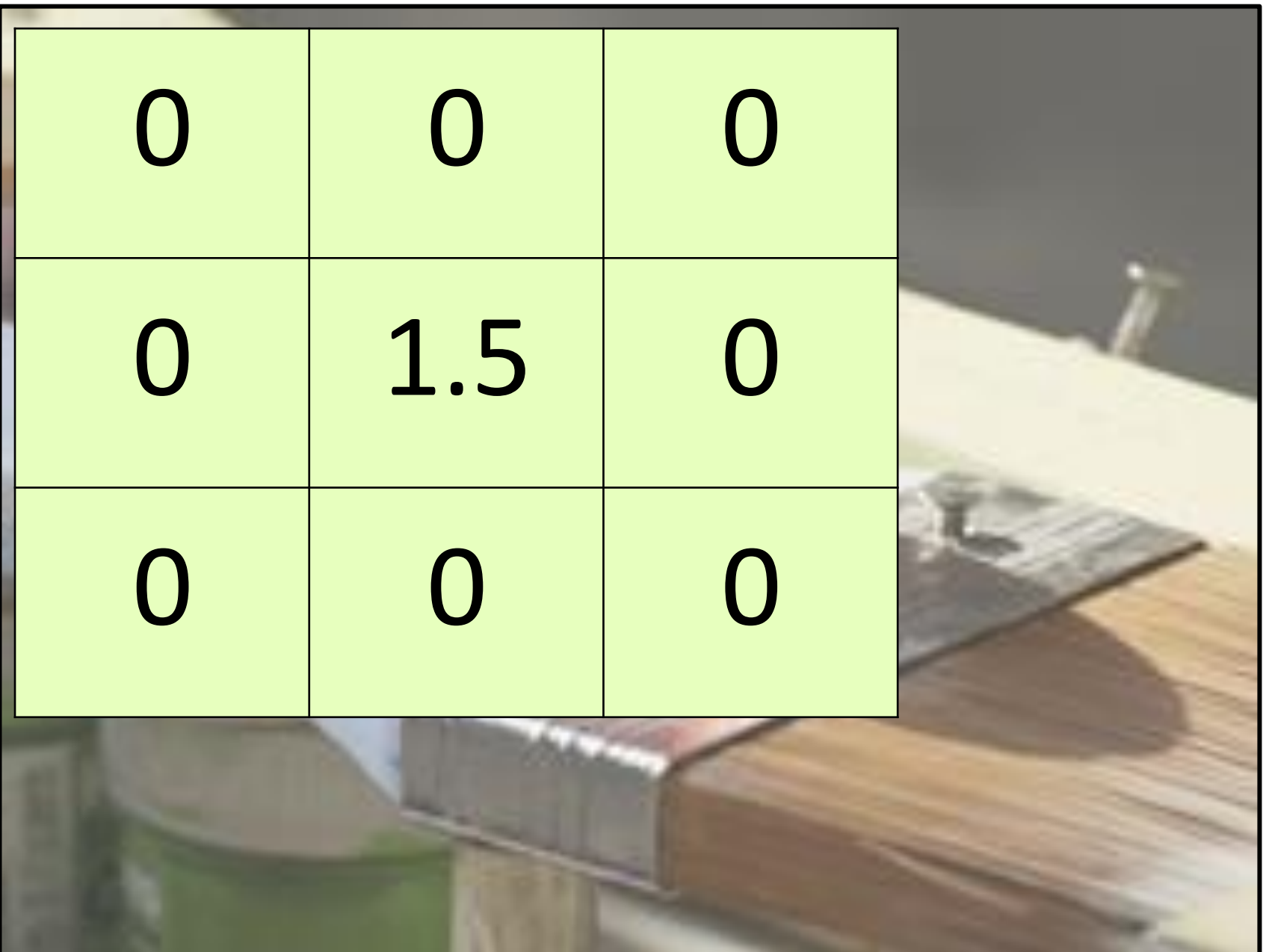
|    |    |    |
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| -1 | 5  | -1 |
| 0  | -1 | 0  |






Brighten

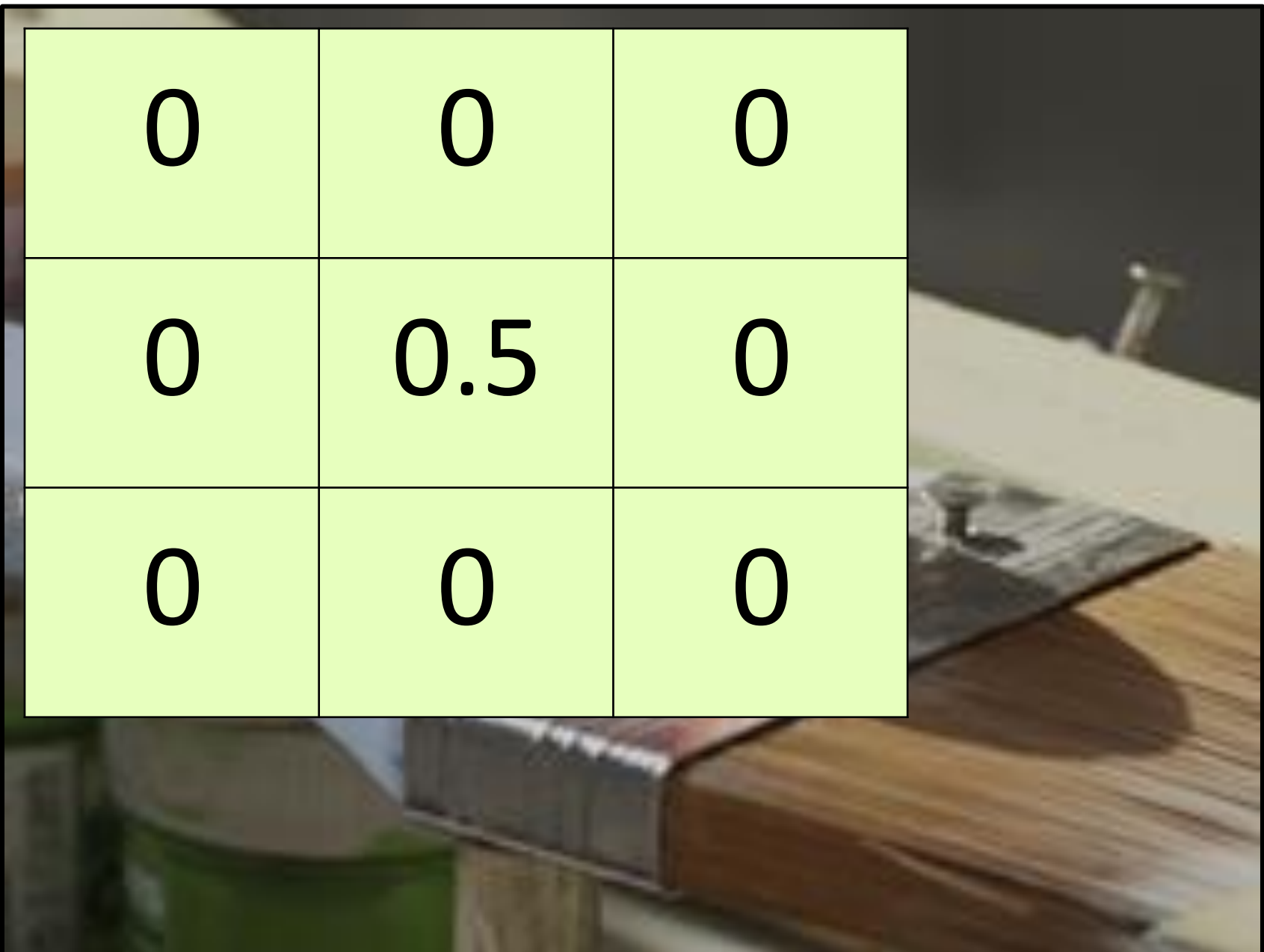
|   |     |   |
|---|-----|---|
| 0 | 0   | 0 |
| 0 | 1.5 | 0 |
| 0 | 0   | 0 |





Darken

|   |     |   |
|---|-----|---|
| 0 | 0   | 0 |
| 0 | 0.5 | 0 |
| 0 | 0   | 0 |



# 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 |

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Convolved Image

|  |  |  |  |
|--|--|--|--|
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

# 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

|  |  |  |  |
|--|--|--|--|
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |
|  |  |  |  |

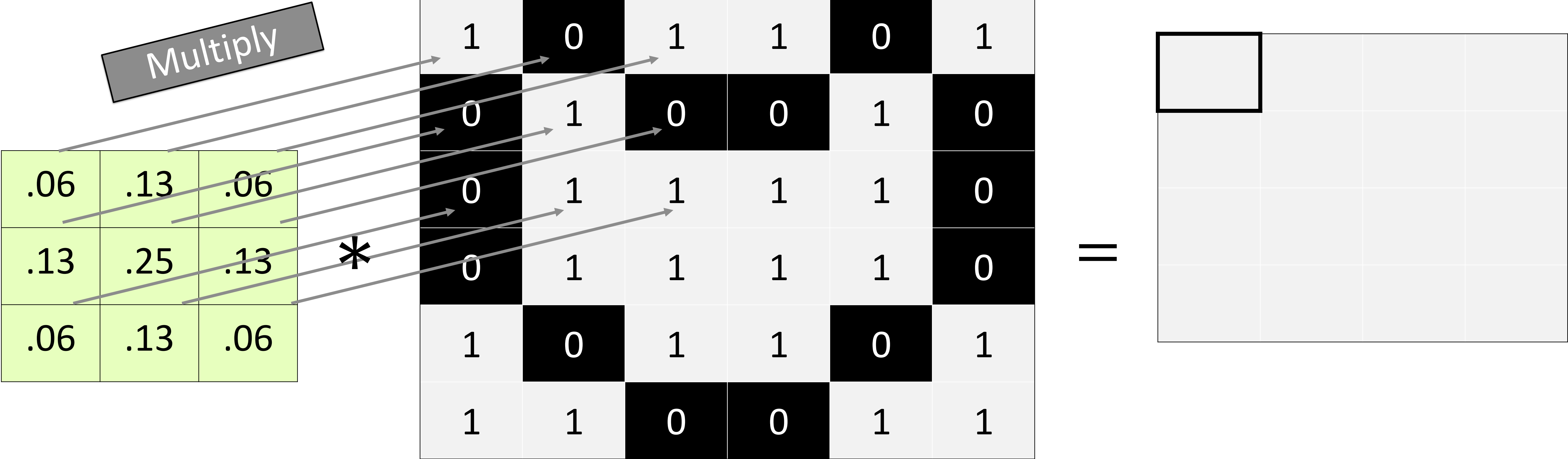


# Kernels and Convolution

Blur Kernel

Original Image

Convolved Image





# Kernels and Convolution

Blur Kernel

Original Image

Convolved Image

|     |     |     |
|-----|-----|-----|
| .06 | .13 | .06 |
| .13 | .25 | .13 |
| .06 | .13 | .06 |

\*

|     |     |     |       |   |   |
|-----|-----|-----|-------|---|---|
| .06 | 0   | .06 | 1     | 0 | 1 |
| 0   | .25 | 0   | 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 |

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|     |  |  |  |
|-----|--|--|--|
| .56 |  |  |  |
|     |  |  |  |
|     |  |  |  |
|     |  |  |  |



# Kernels and Convolution

Blur Kernel

|     |     |     |
|-----|-----|-----|
| .06 | .13 | .06 |
| .13 | .25 | .13 |
| .06 | .13 | .06 |

\*

Original Image

|   |     |     |     |   |   |
|---|-----|-----|-----|---|---|
| 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 |

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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 |

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Convolved Image

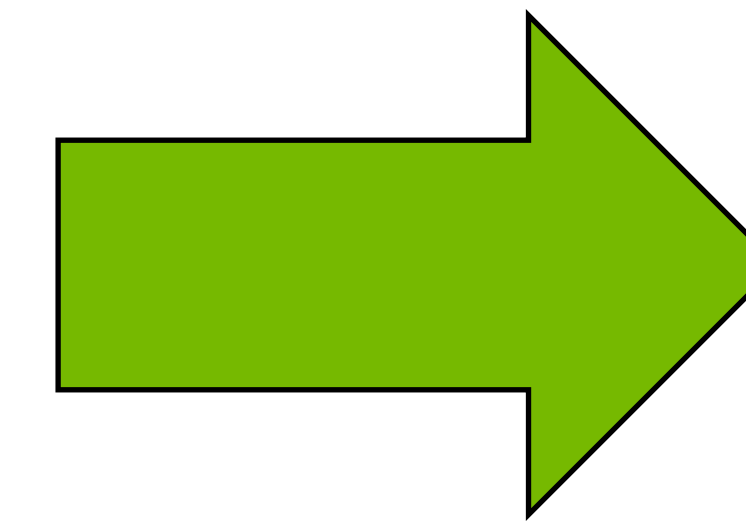
|     |     |     |     |
|-----|-----|-----|-----|
| .56 | .57 | .57 | .56 |
| .7  | .82 | .82 | .7  |
| .69 | .95 | .95 | .69 |
| .64 | .69 | .69 | .64 |



# Stride

Stride 1

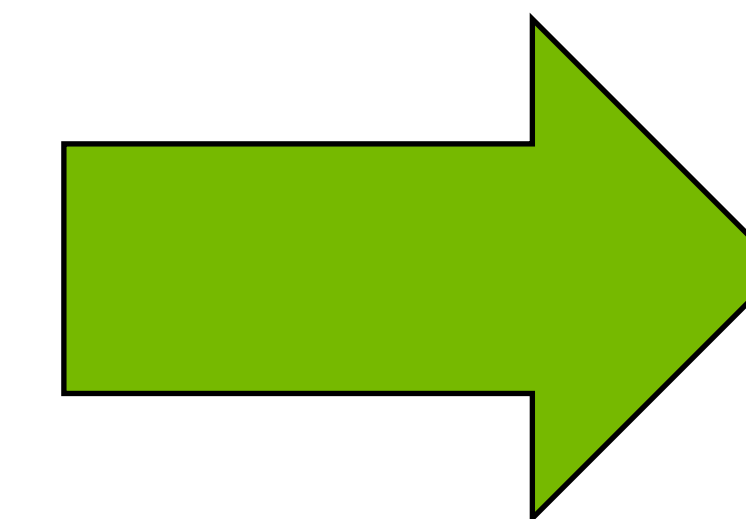
|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 0 | 1 |
| 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 |



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

Stride 2

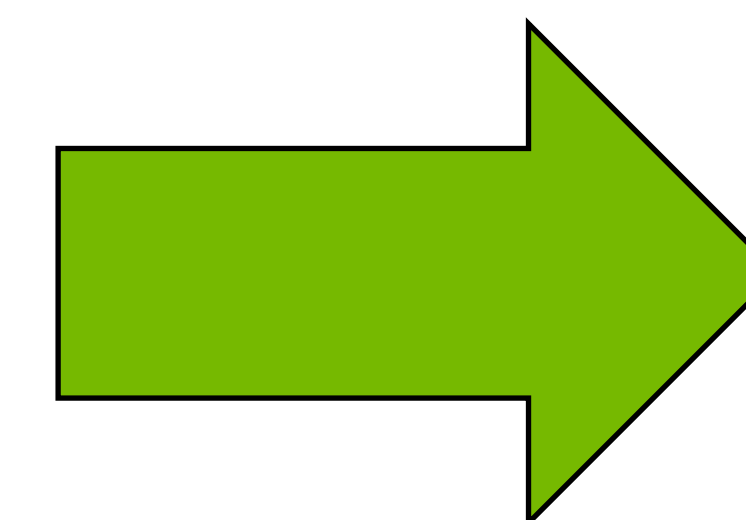
|   |   |   |   |   |   |
|---|---|---|---|---|---|
| 1 | 0 | 1 | 1 | 0 | 1 |
| 0 | 1 | 0 | 0 | 1 | 0 |
| 0 | 1 | 1 | 1 | 1 | 0 |



|     |     |
|-----|-----|
| .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

|       |       |       |
|-------|-------|-------|
| $W_1$ | $W_2$ | $W_3$ |
| $W_4$ | $W_5$ | $W_6$ |
| $W_7$ | $W_8$ | $W_9$ |

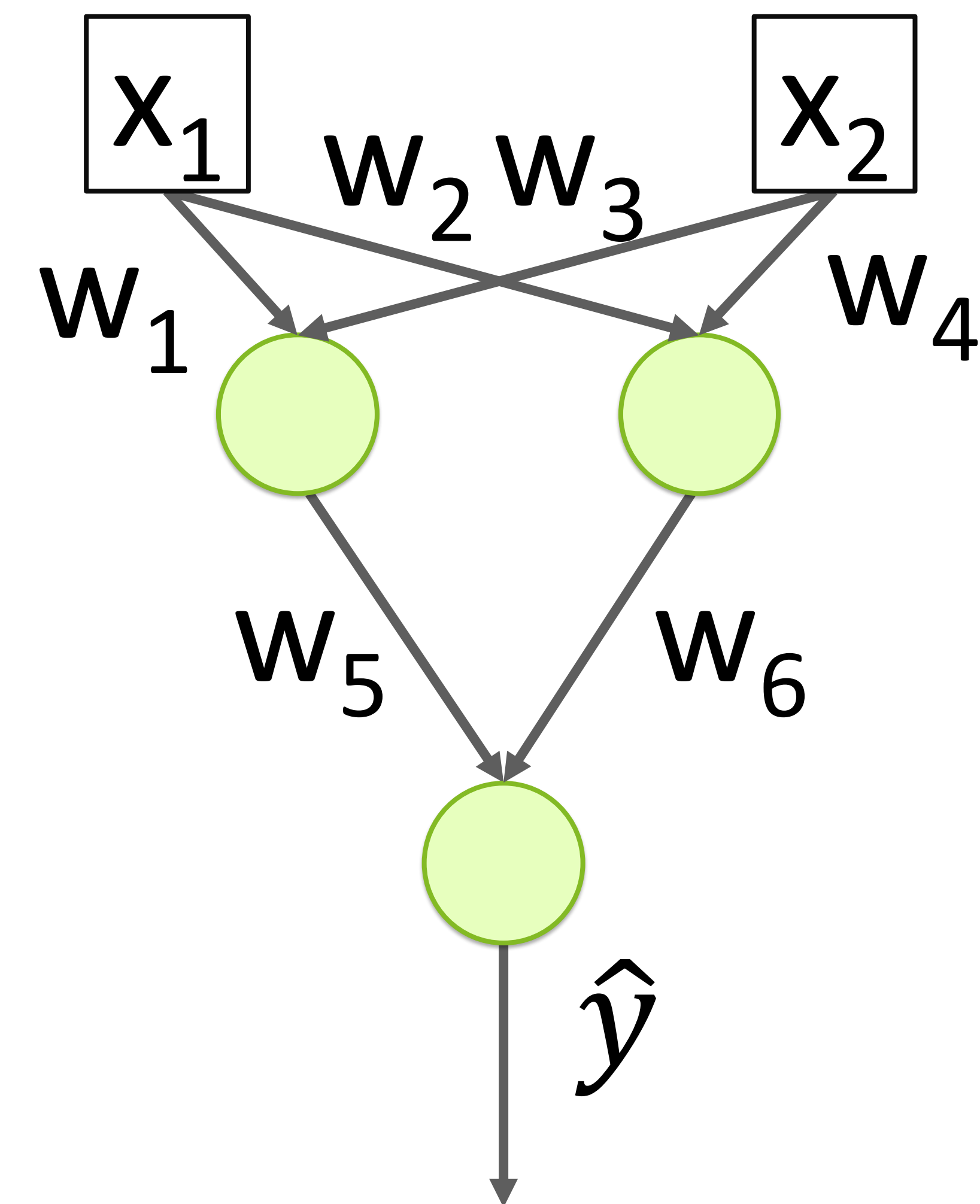


# Kernels and Neural Networks

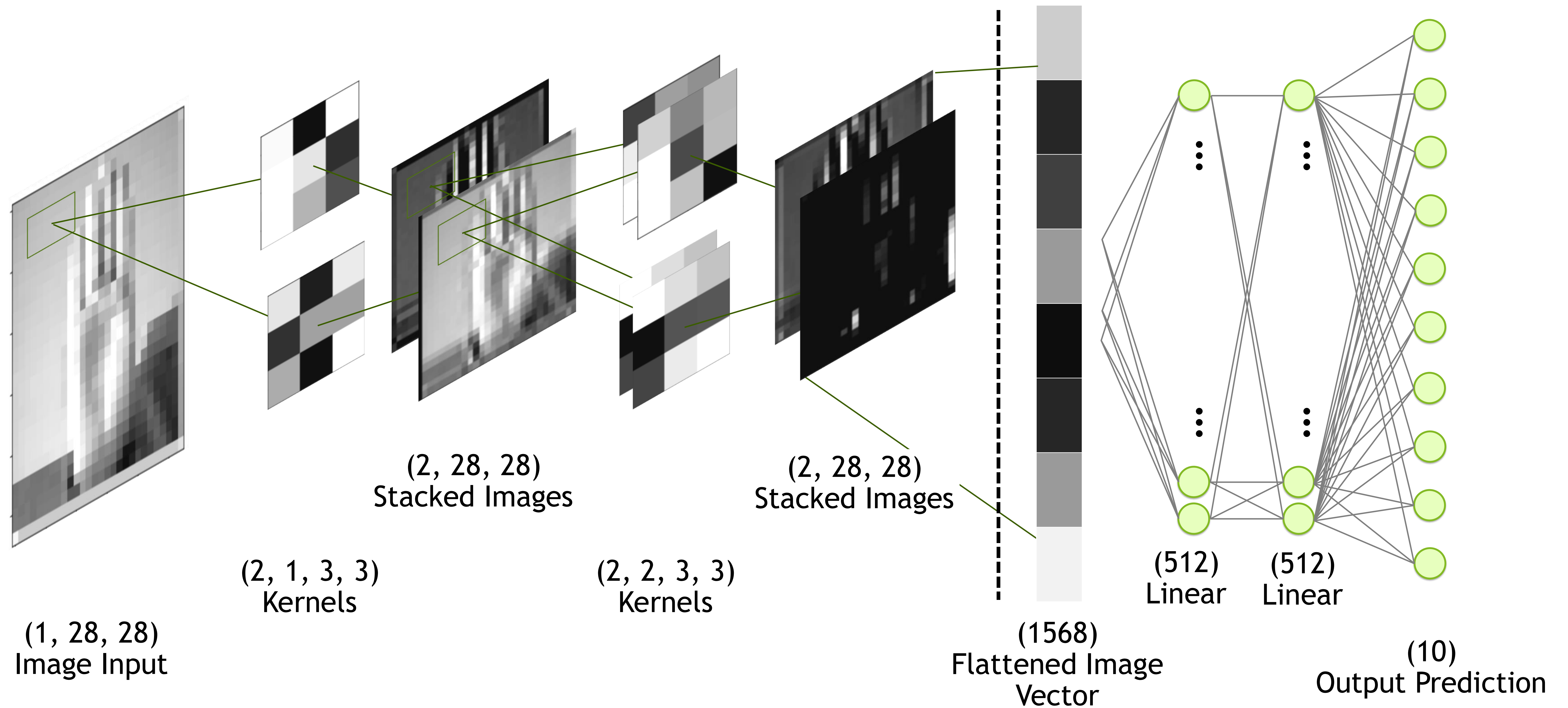
Kernel

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

Neuron



# Kernels and Neural Networks





Finding Edges

Vertical Edges



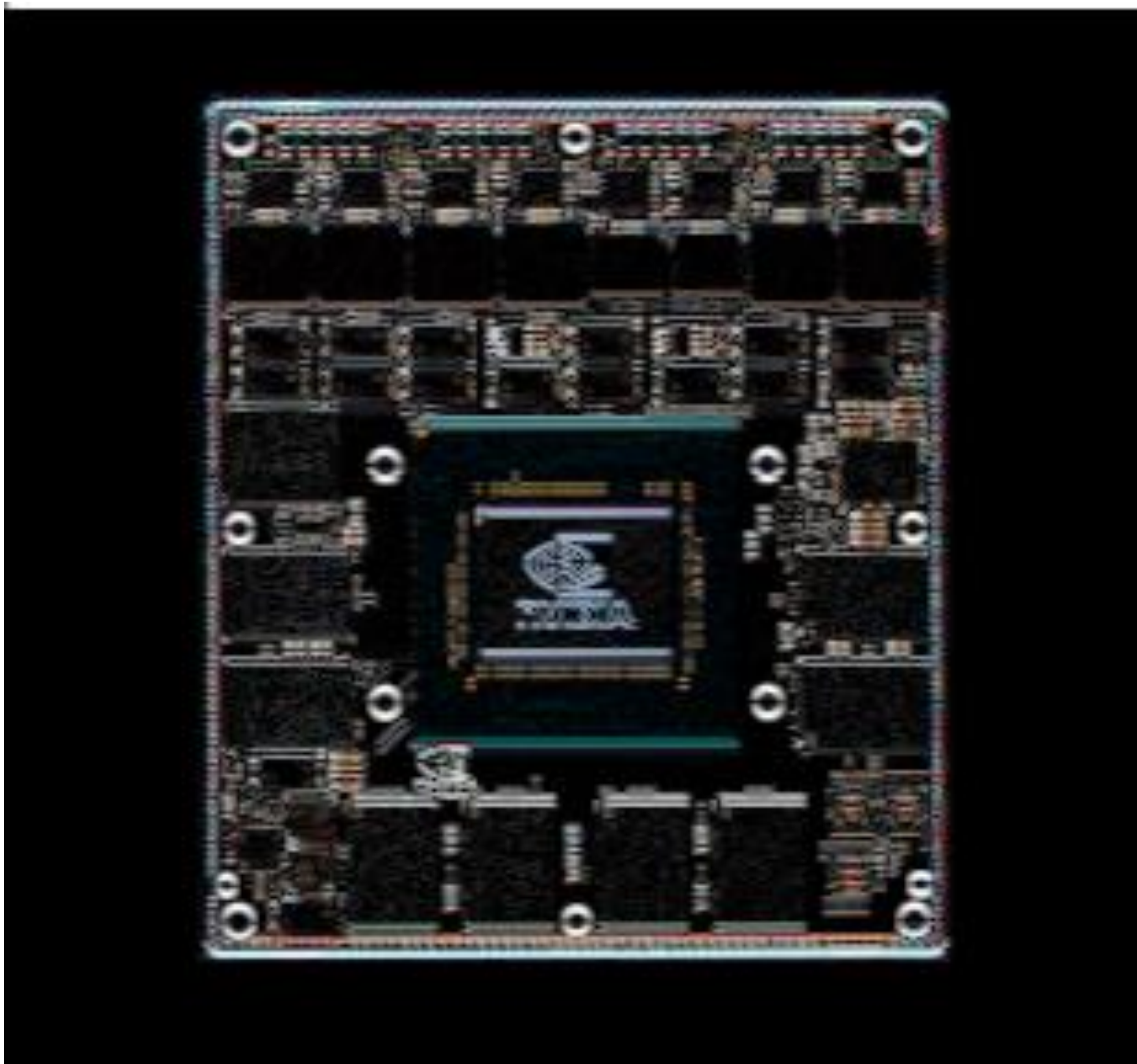
|   |   |    |
|---|---|----|
| 1 | 0 | -1 |
| 2 | 0 | -2 |
| 1 | 0 | -1 |

Original Image



|   |   |   |
|---|---|---|
| 0 | 0 | 0 |
| 0 | 1 | 0 |
| 0 | 0 | 0 |

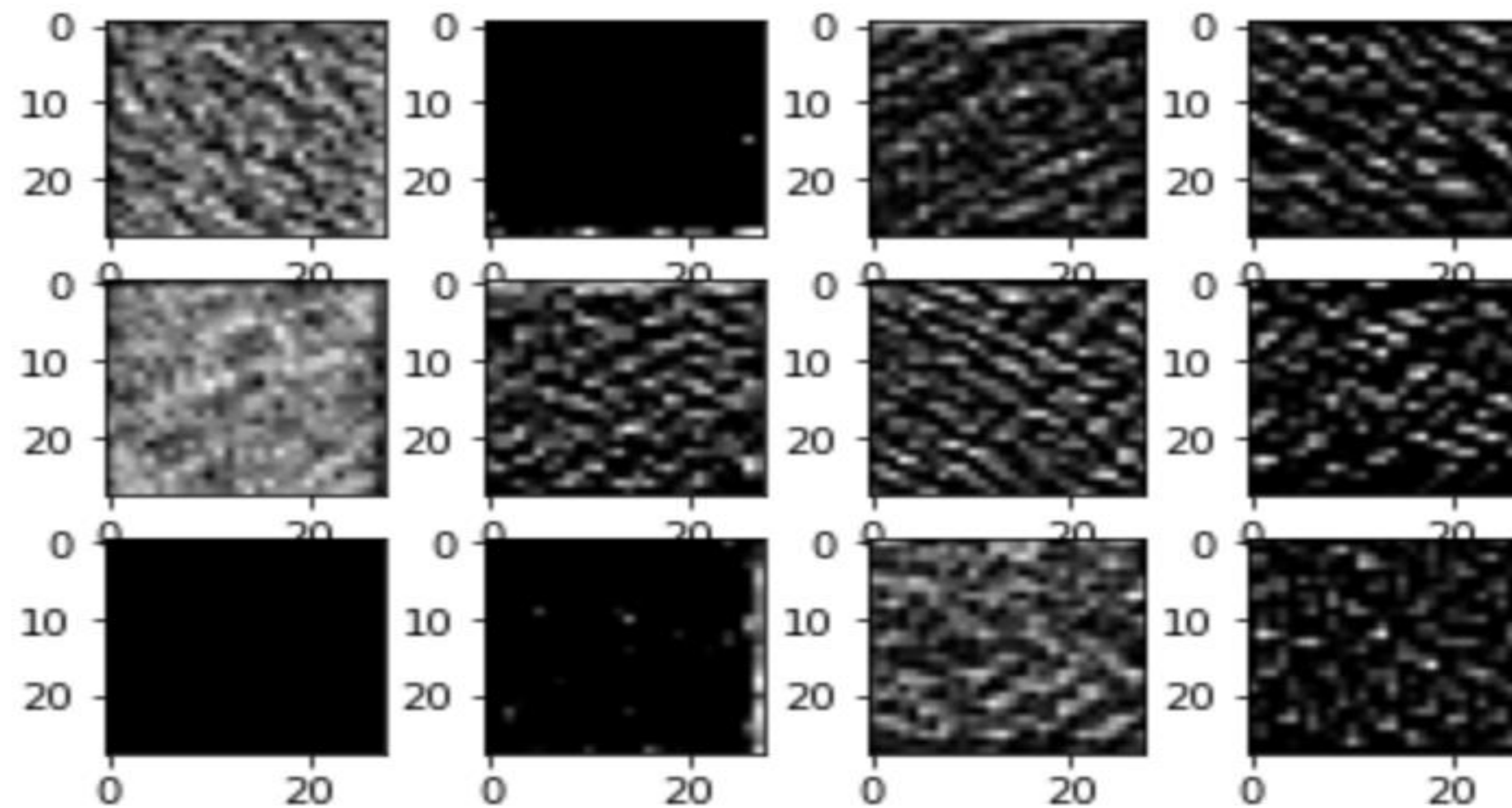
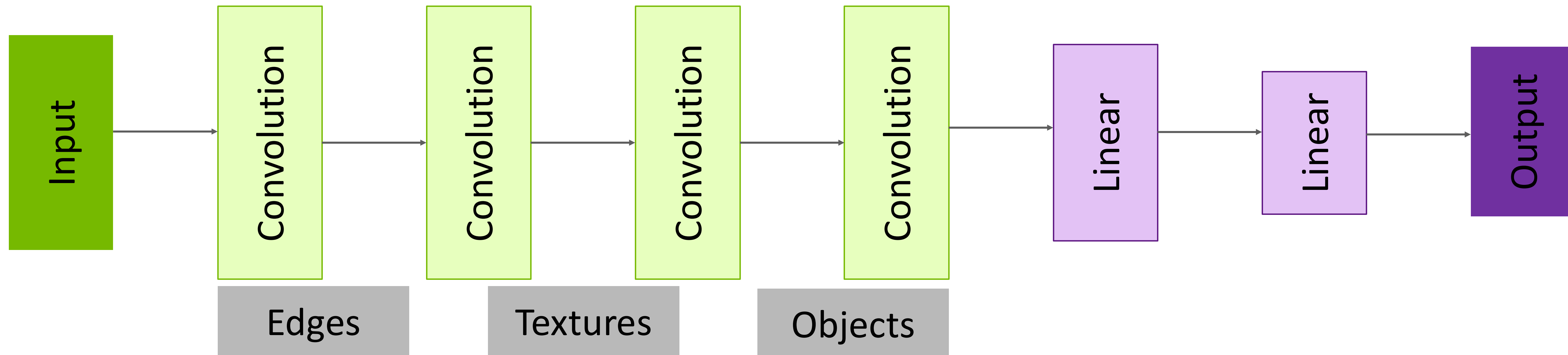
Horizontal Edges



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



# Neural Network Perception





# Neural Network Perception





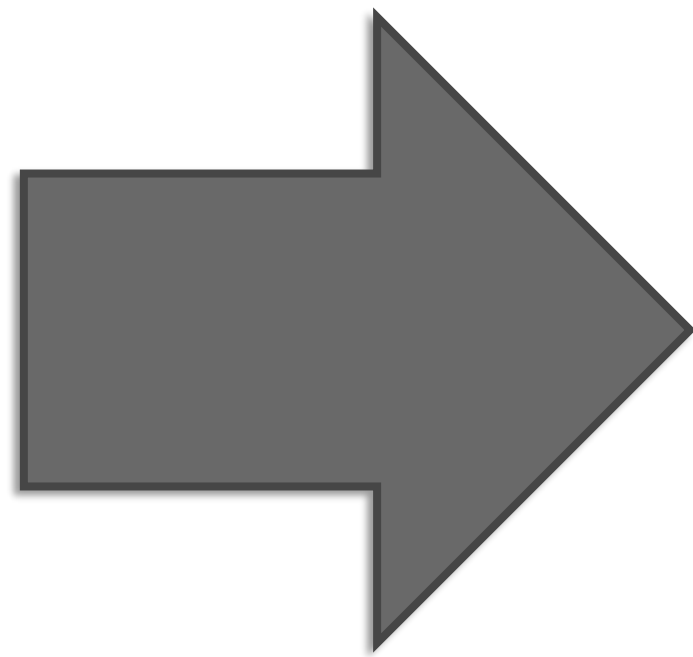


## **Other Layers in the Model**



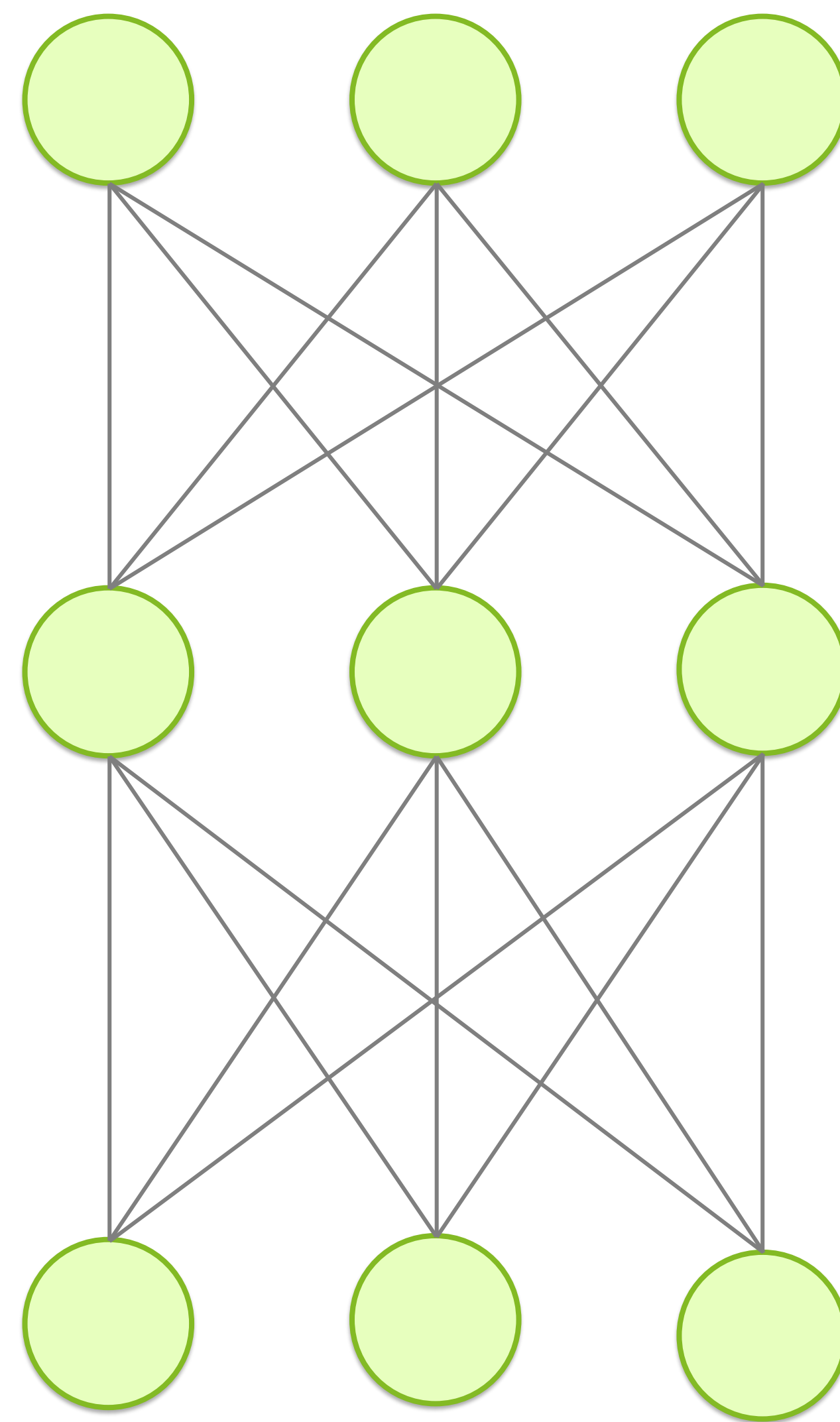
# Max Pooling

|     |     |     |    |
|-----|-----|-----|----|
| 110 | 256 | 153 | 67 |
| 12  | 89  | 88  | 43 |
| 10  | 15  | 50  | 55 |
| 23  | 9   | 49  | 23 |

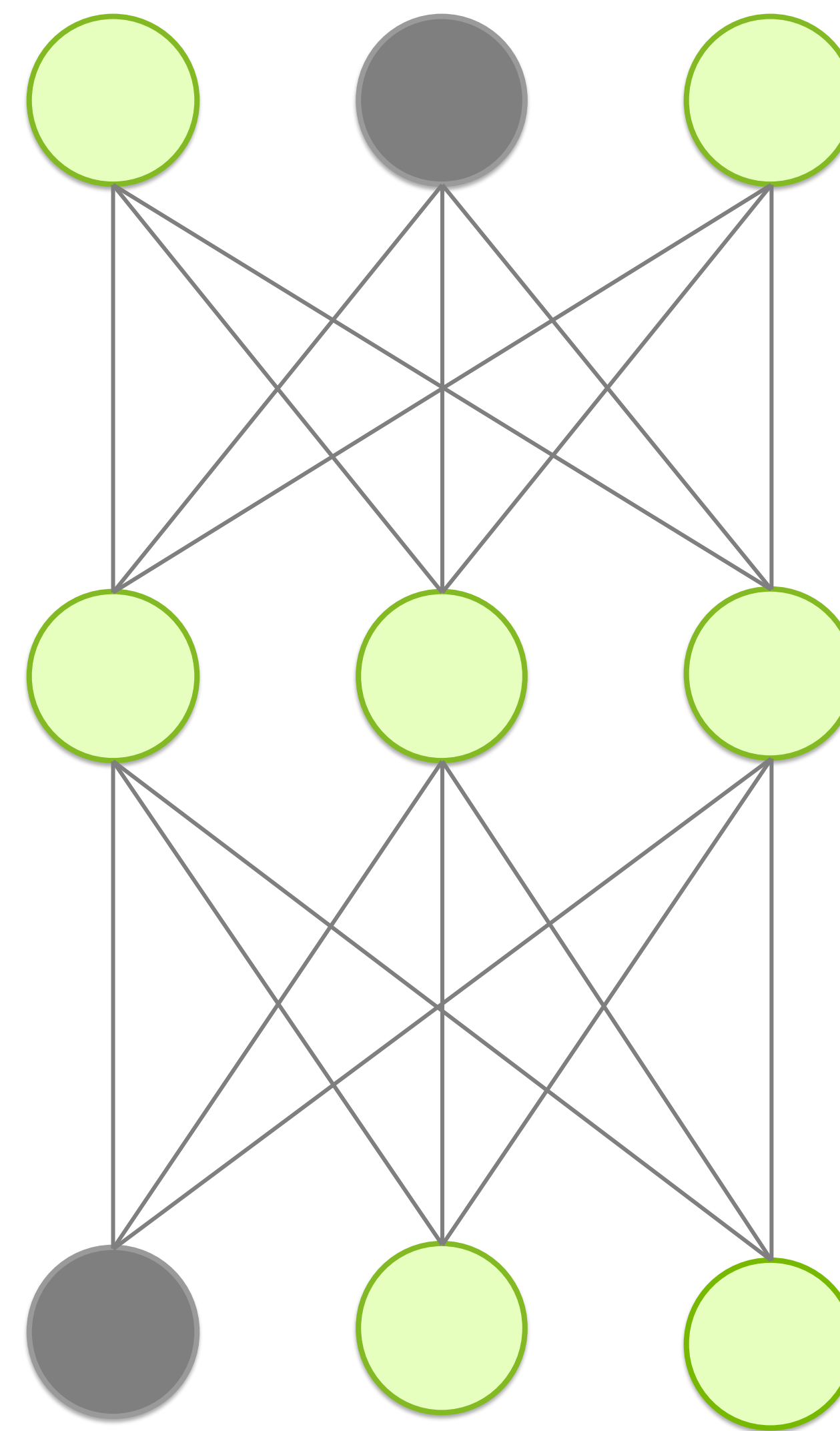


|     |     |
|-----|-----|
| 256 | 153 |
| 23  | 55  |

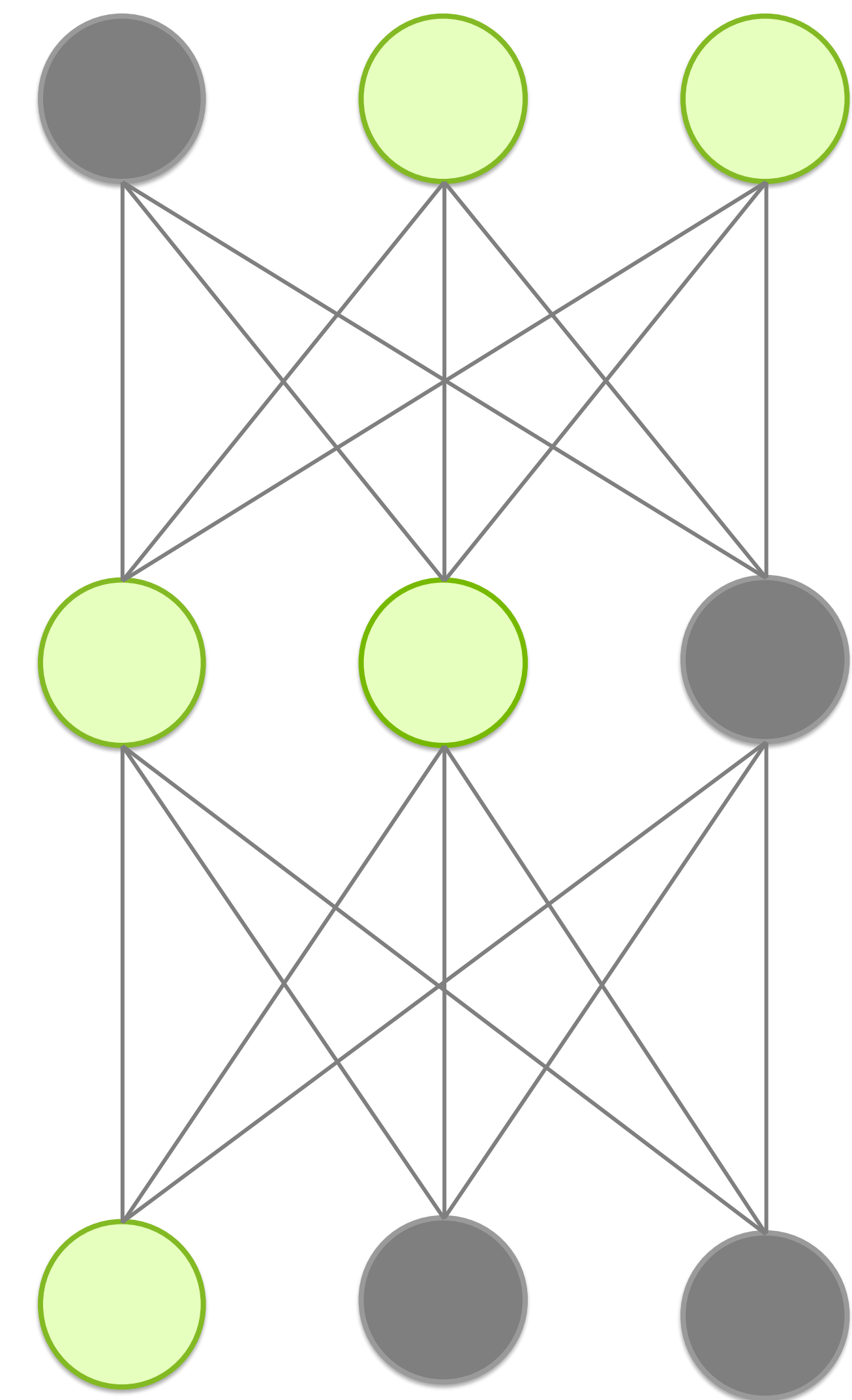
# Dropout



rate = 0



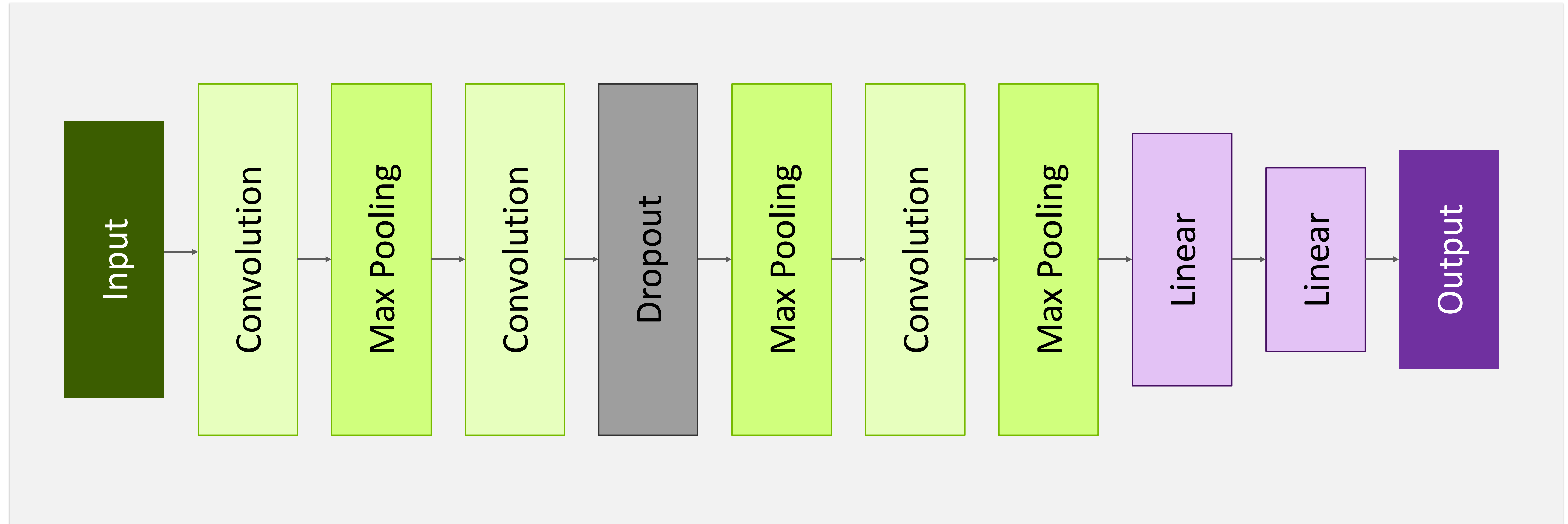
rate = .2



rate = .4



# Whole Architecture







**Let's go!**



