

# Convolutional Neural Network

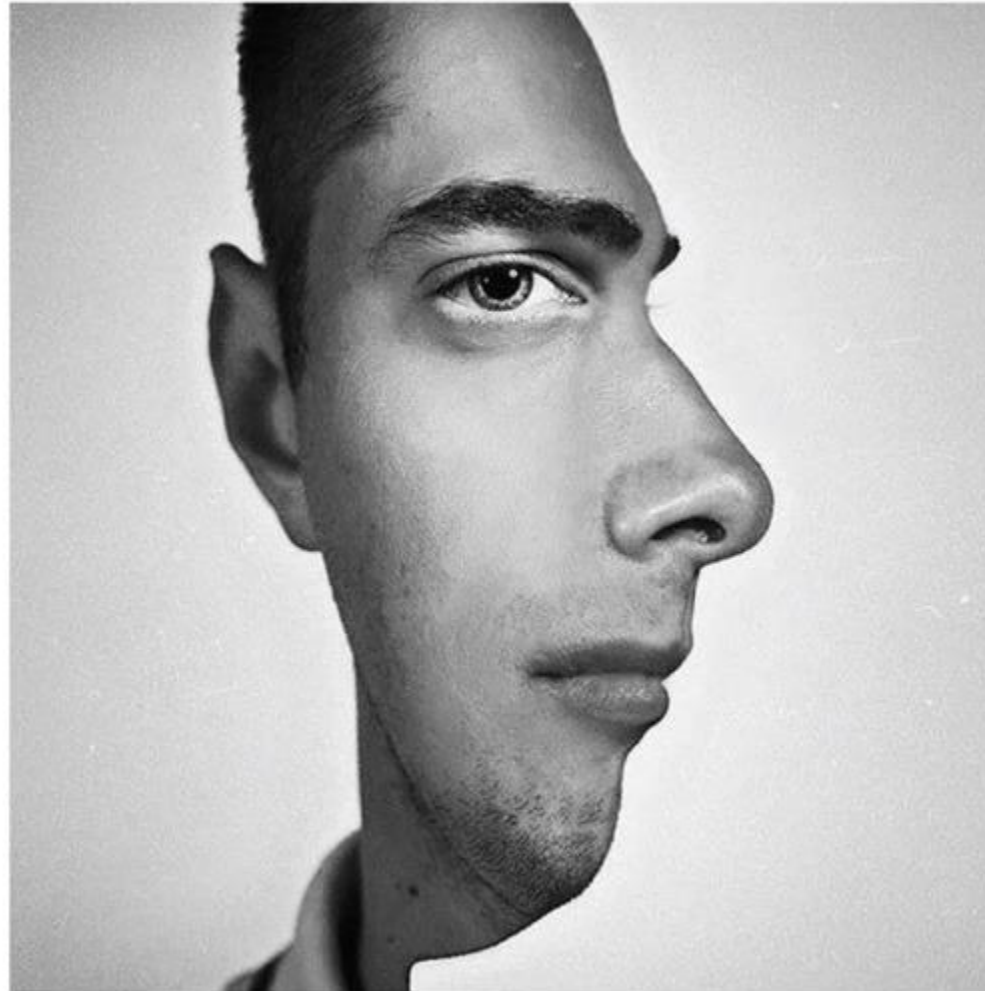
# Summary

- Convolutional Neural Network Overview
- Step 1 - Convolution
- Step 1(b) - ReLU Layer
- Step 2 - Pooling
- Step 3 - Flattening
- Step 4 - Full Connection
- Summary
- EXTRA: Softmax & Cross-Entropy

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# Convolutional Neural Network Overview



<https://www.udemy.com/course/machinelearning/>

# Convolutional Neural Network Overview



# Convolutional Neural Network Overview

Examples from the test set  
(with the network's guesses)



# Convolutional Neural Network Overview

Examples from the test set  
(with the network's guesses)



**cheetah**

|              |
|--------------|
| cheetah      |
| leopard      |
| snow leopard |
| Egyptian cat |



**bullet train**

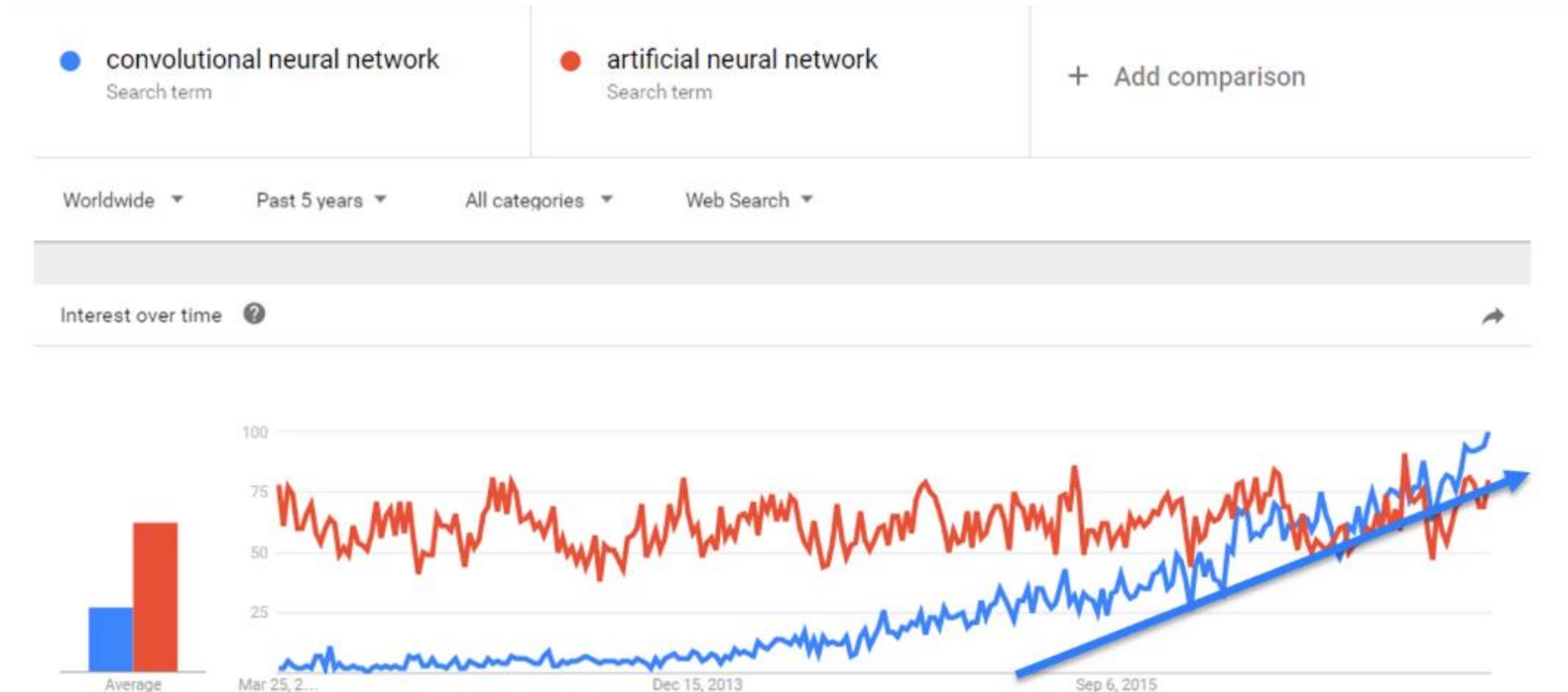
|                     |
|---------------------|
| bullet train        |
| passenger car       |
| subway train        |
| electric locomotive |



**hand glass**

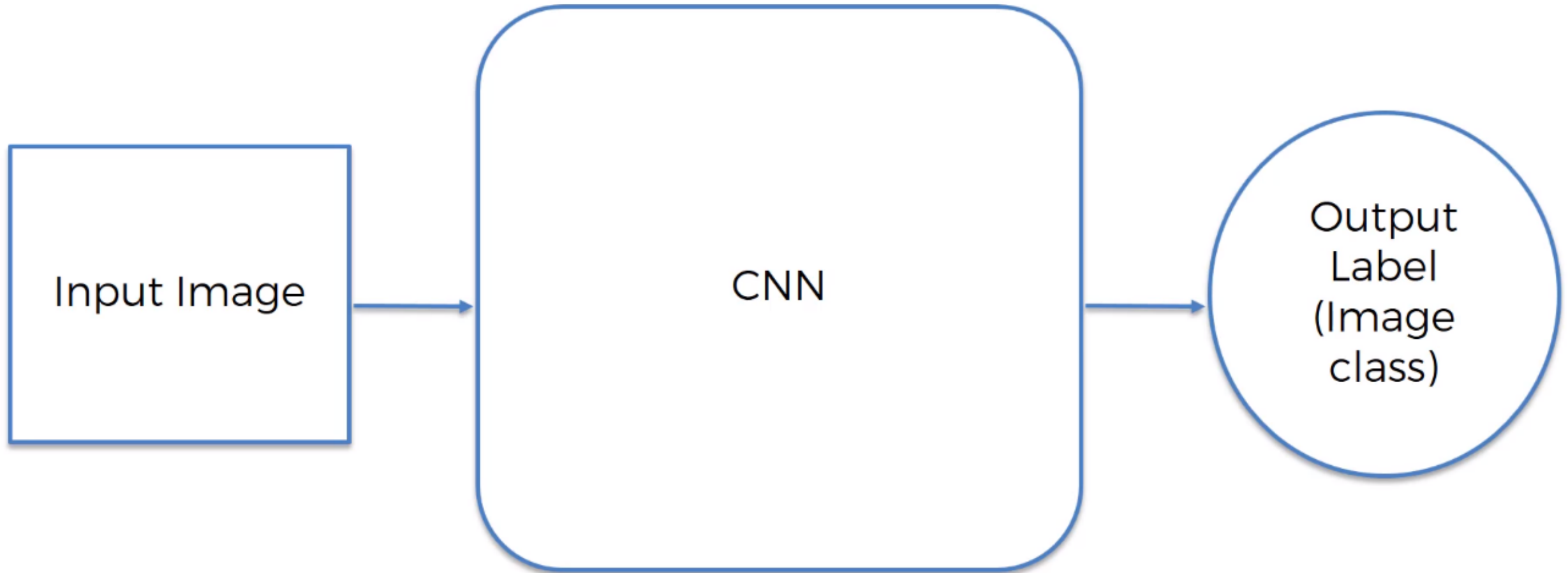
|             |
|-------------|
| scissors    |
| hand glass  |
| frying pan  |
| stethoscope |

# Convolutional Neural Network Overview

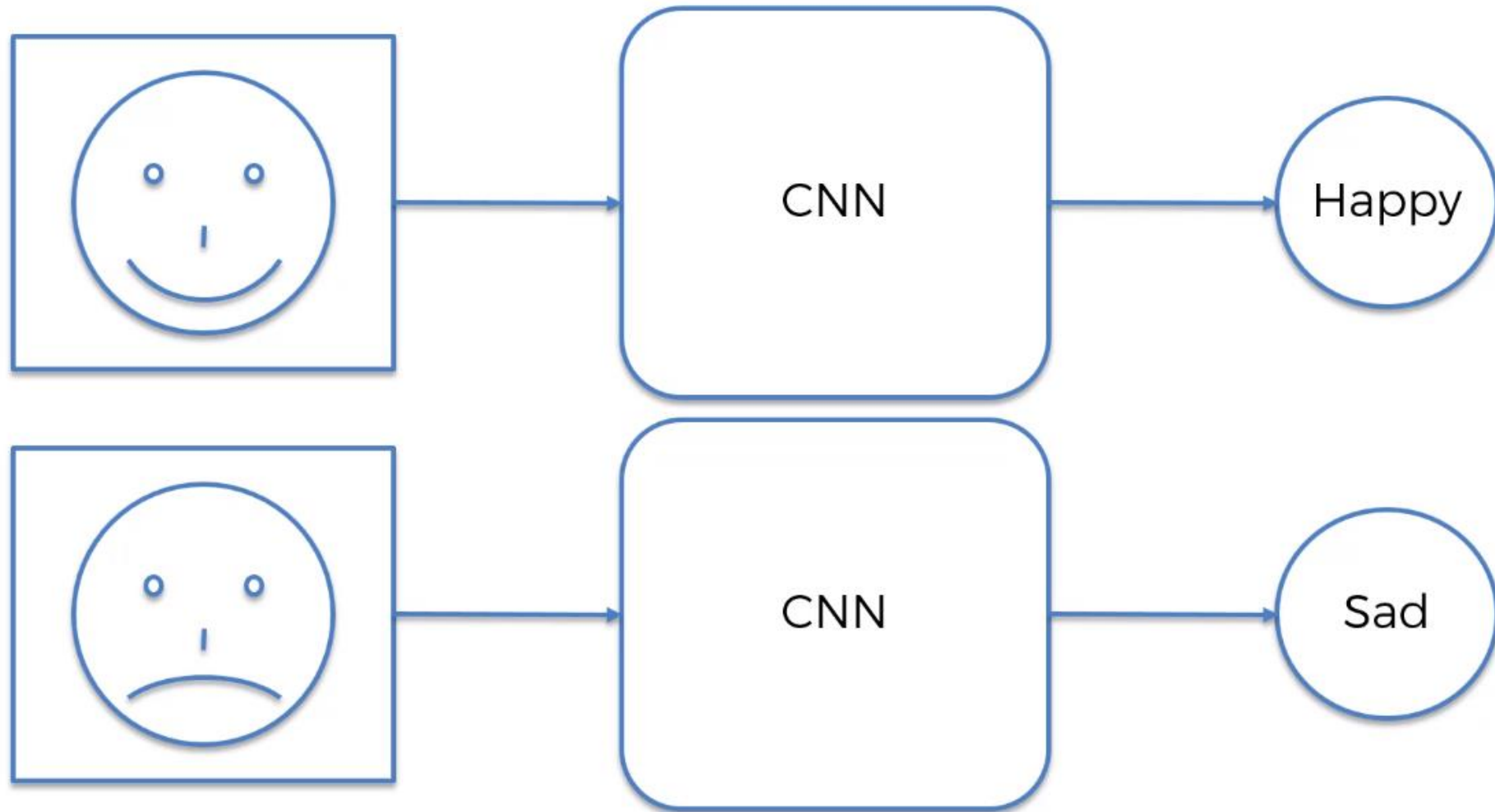




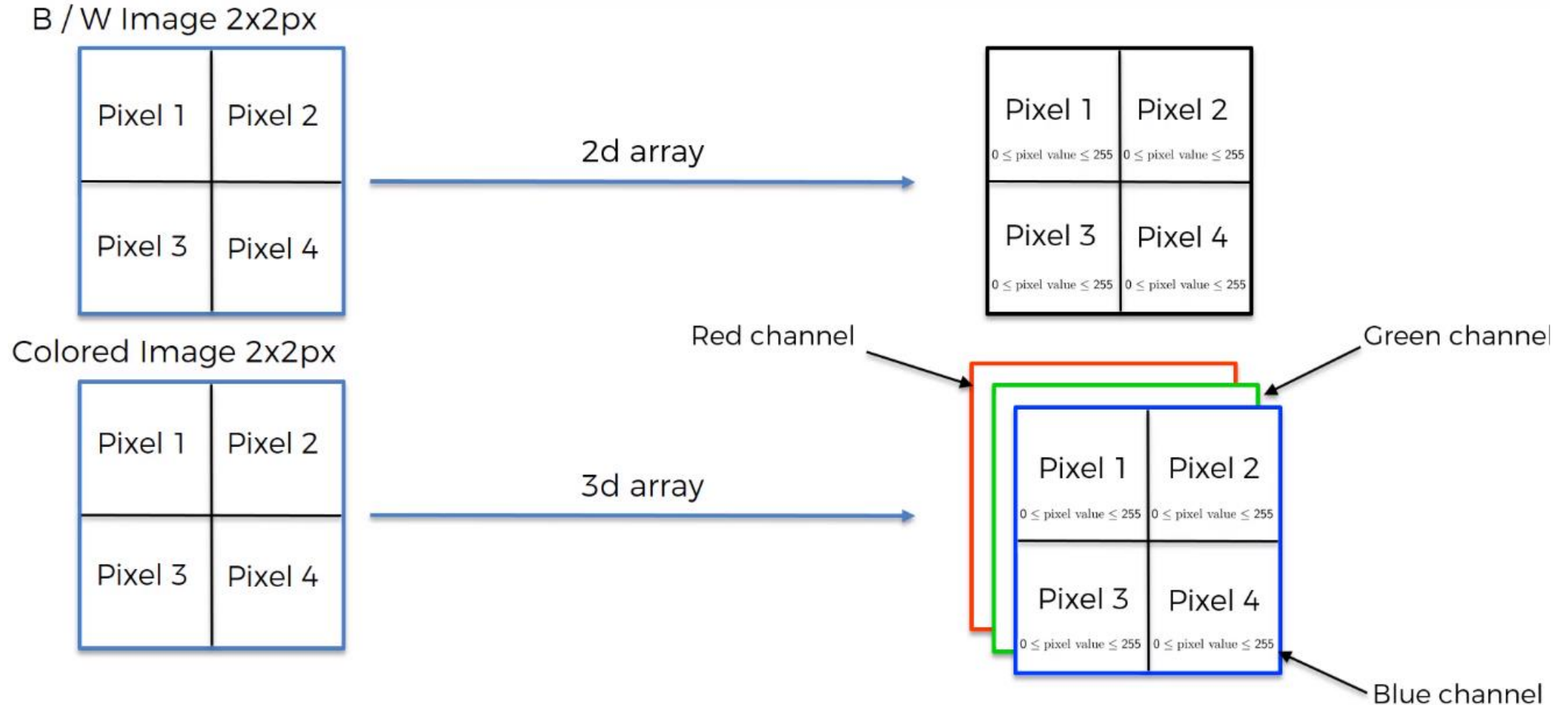
# Convolutional Neural Network Overview



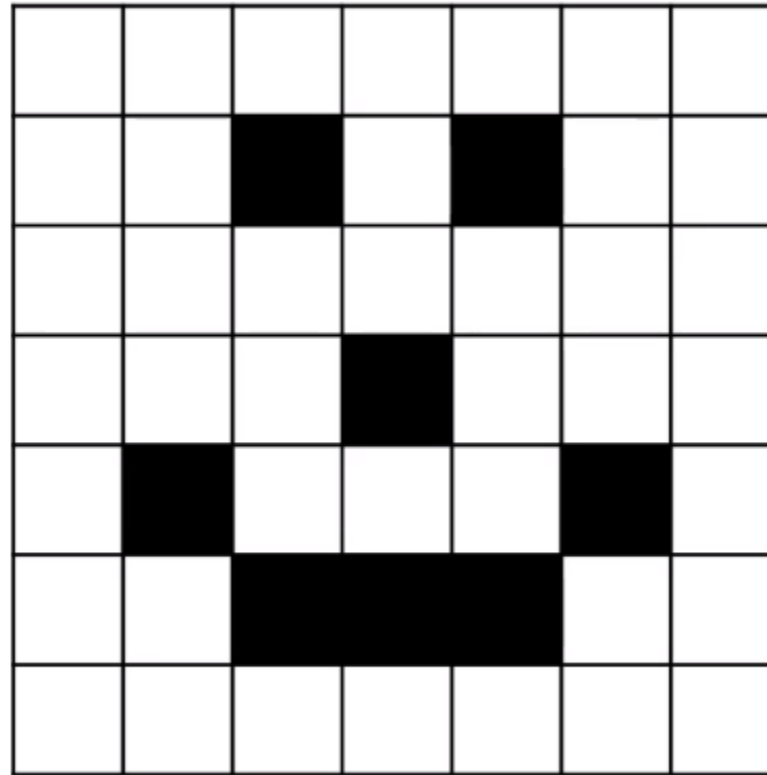
# Convolutional Neural Network Overview



# Convolutional Neural Network Overview



# Convolutional Neural Network Overview



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

# Convolutional Neural Network Overview

**STEP 1:** Convolution



**STEP 2:** Max Pooling



**STEP 3:** Flattening



**STEP 4:** Full Connection

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# Convolution

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

Input Image



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

Feature  
Detector



|   |  |  |  |  |
|---|--|--|--|--|
| 0 |  |  |  |  |
|   |  |  |  |  |
|   |  |  |  |  |
|   |  |  |  |  |
|   |  |  |  |  |

Feature Map

# Convolution

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

Input Image



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

Feature  
Detector



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

Feature Map



# Convolution

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

Input Image



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

Feature  
Detector



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

Feature Map

# Convolution

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

Input Image



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

Feature  
Detector



|   |   |   |   |   |
|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 1 | 2 | 1 |
| 1 | 4 | 2 | 1 | 0 |
| 0 | 0 | 1 | 2 | 1 |

Feature Map

# Convolution

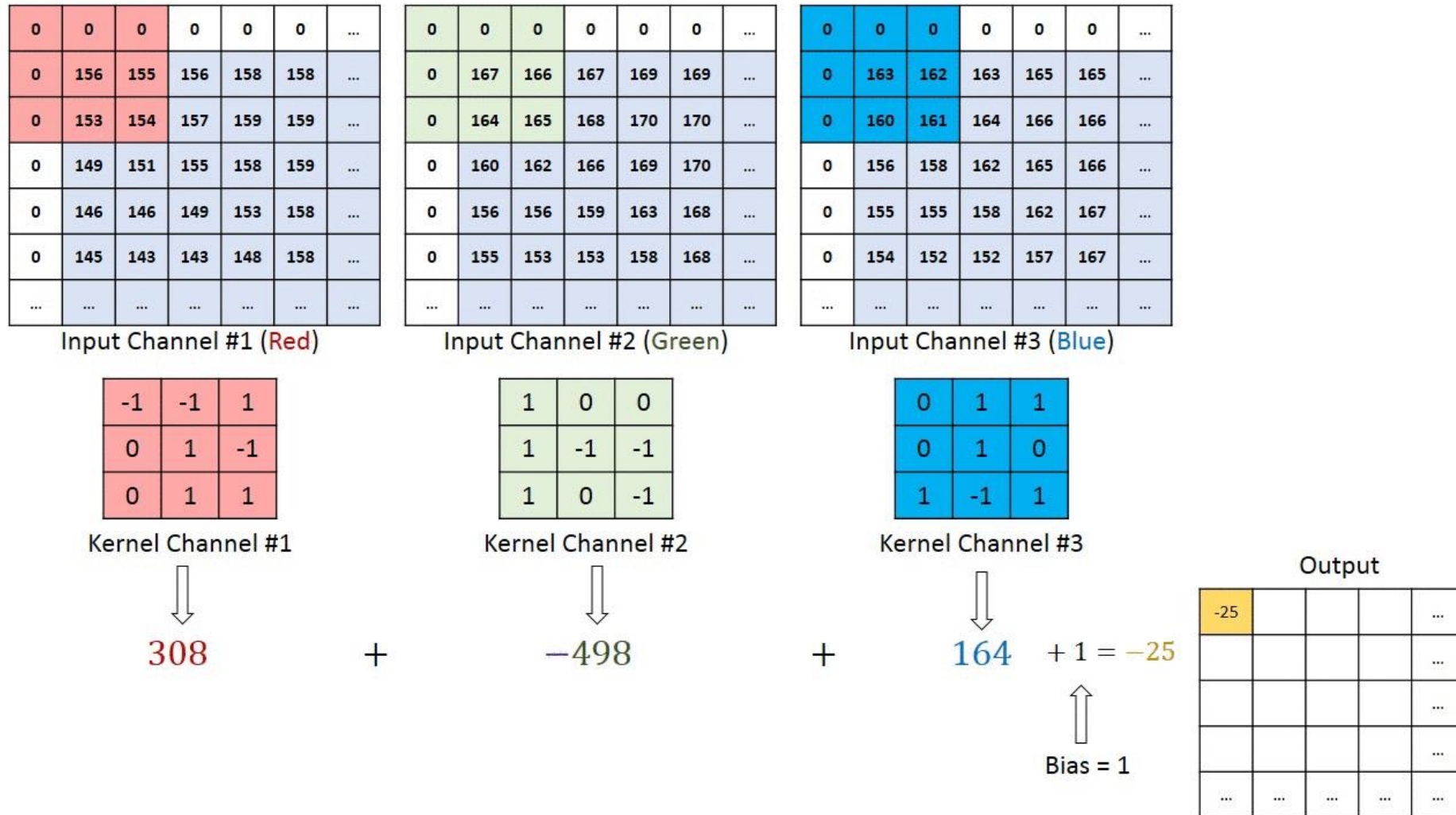
|                 |                 |                 |   |   |
|-----------------|-----------------|-----------------|---|---|
| 1 <sub>x1</sub> | 1 <sub>x0</sub> | 1 <sub>x1</sub> | 0 | 0 |
| 0 <sub>x0</sub> | 1 <sub>x1</sub> | 1 <sub>x0</sub> | 1 | 0 |
| 0 <sub>x1</sub> | 0 <sub>x0</sub> | 1 <sub>x1</sub> | 1 | 1 |
| 0               | 0               | 1               | 1 | 0 |
| 0               | 1               | 1               | 0 | 0 |

Image

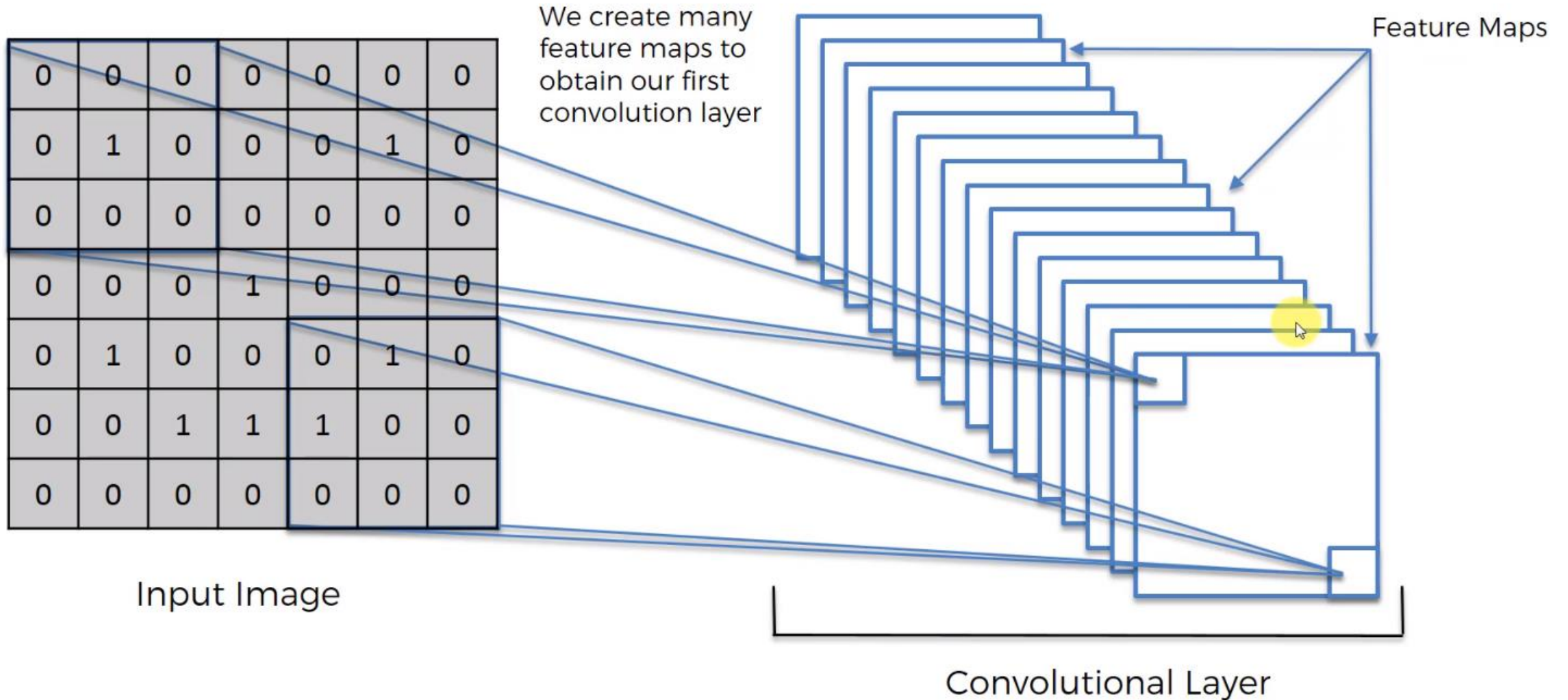
|   |  |  |
|---|--|--|
| 4 |  |  |
|   |  |  |
|   |  |  |

Convolved  
Feature

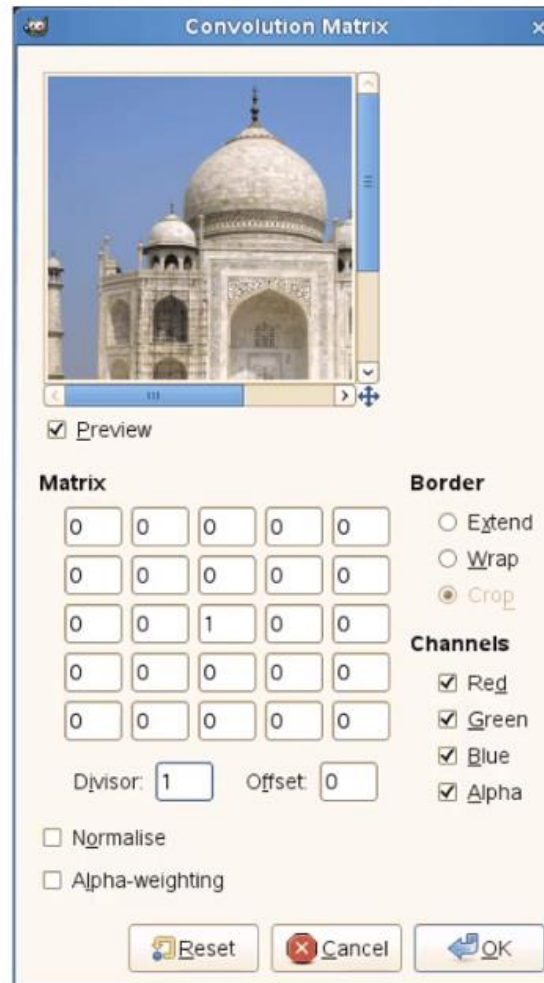
# Convolution



# Convolution



# Convolution





# Convolution

Emboss:

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



# Convolution

Edge Detect:

|  |   |    |   |  |
|--|---|----|---|--|
|  |   |    |   |  |
|  | 0 | 1  | 0 |  |
|  | 1 | -4 | 1 |  |
|  | 0 | 1  | 0 |  |
|  |   |    |   |  |





# Convolution



\*

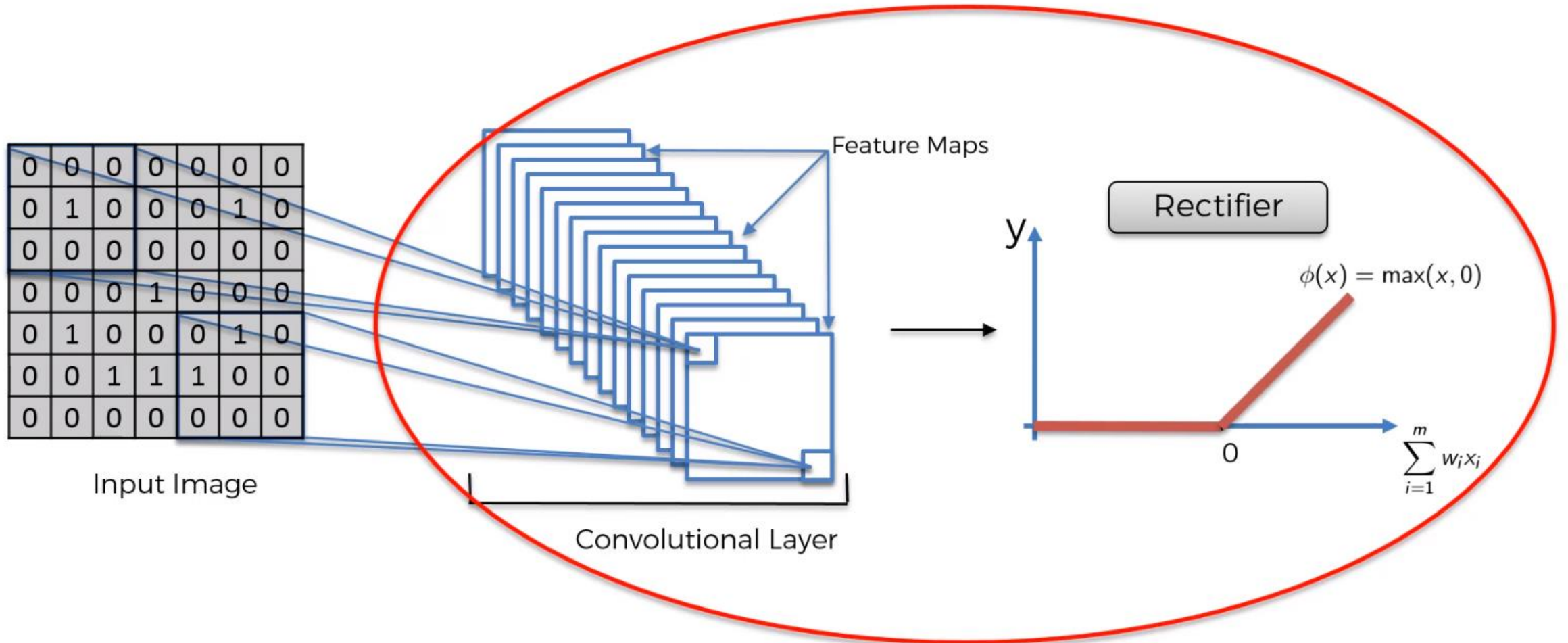
|   |   |    |
|---|---|----|
| 1 | 0 | -1 |
| 2 | 0 | -2 |
| 1 | 0 | -1 |



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# ReLU Layer

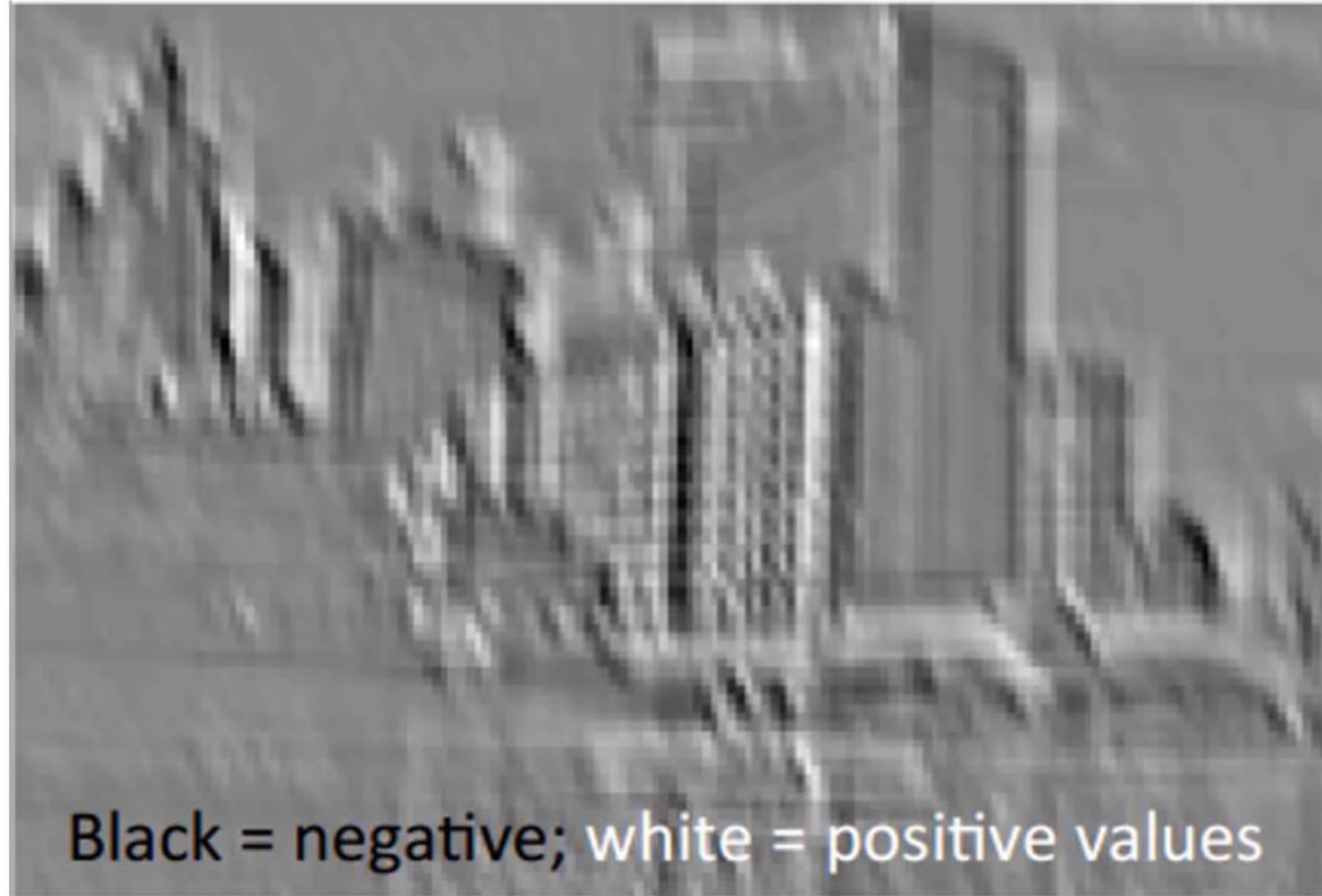


# ReLU Layer



<https://www.udemy.com/course/machinelearning/>

# ReLU Layer



# ReLU Layer



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# Pooling





# Pooling



*Image Source: Wikipedia*

<https://www.udemy.com/course/machinelearning/>

# Pooling

|   |   |   |   |   |
|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 1 | 2 | 1 |
| 1 | 4 | 2 | 1 | 0 |
| 0 | 0 | 1 | 2 | 1 |

Feature Map

Max Pooling



|   |  |  |
|---|--|--|
| 1 |  |  |
|   |  |  |
|   |  |  |

Pooled Feature Map

# Pooling

|   |   |   |   |   |
|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 1 | 2 | 1 |
| 1 | 4 | 2 | 1 | 0 |
| 0 | 0 | 1 | 2 | 1 |

Feature Map

Max Pooling



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

Pooled Feature Map

# Pooling

|   |   |   |   |   |
|---|---|---|---|---|
| 0 | 1 | 0 | 0 | 0 |
| 0 | 1 | 1 | 1 | 0 |
| 1 | 0 | 1 | 2 | 1 |
| 1 | 4 | 2 | 1 | 0 |
| 0 | 0 | 1 | 2 | 1 |

Feature Map

Max Pooling

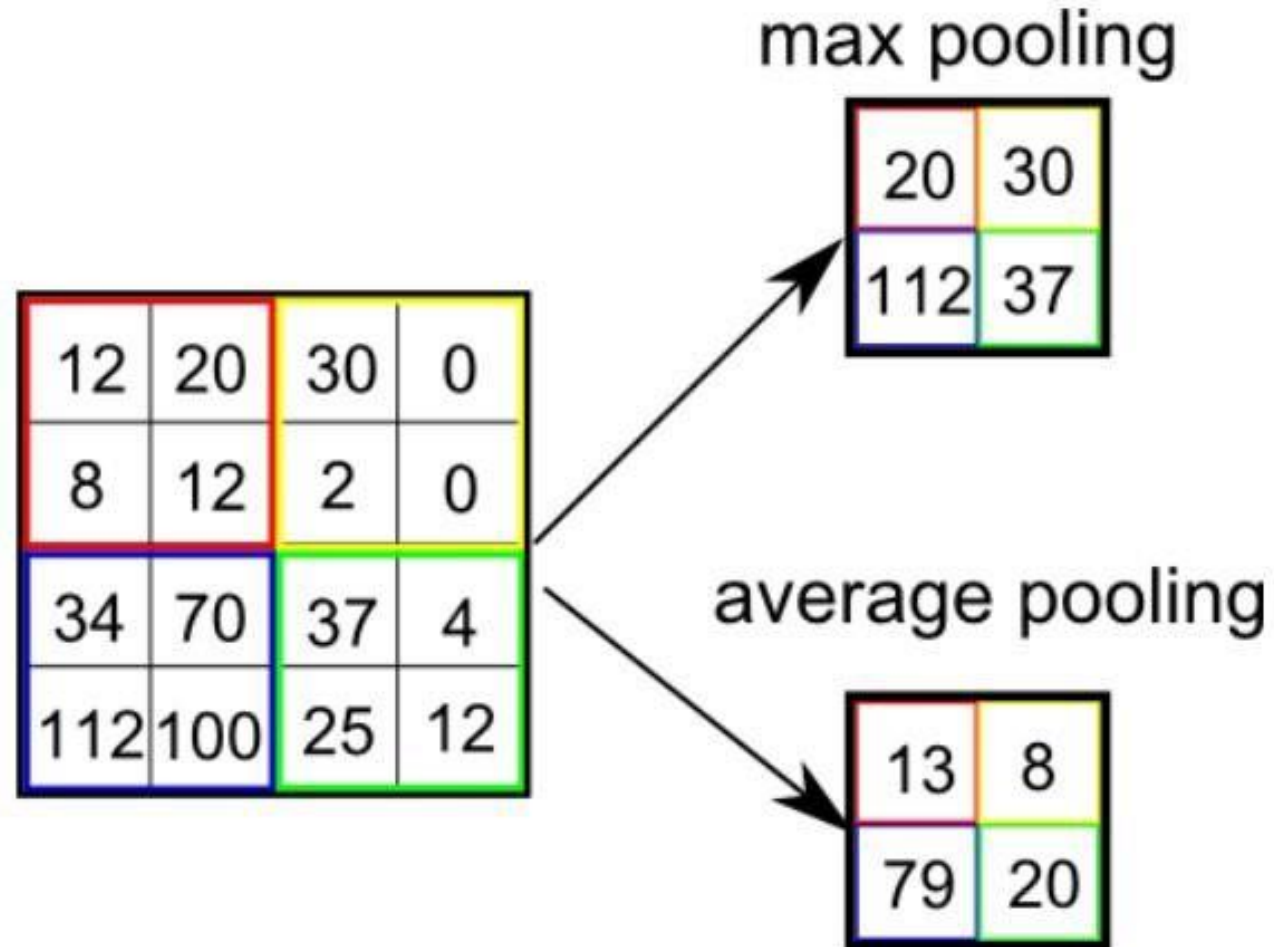


|   |   |   |
|---|---|---|
| 1 | 1 | 0 |
| 4 | 2 | 1 |
| 0 | 2 | 1 |

Pooled Feature Map



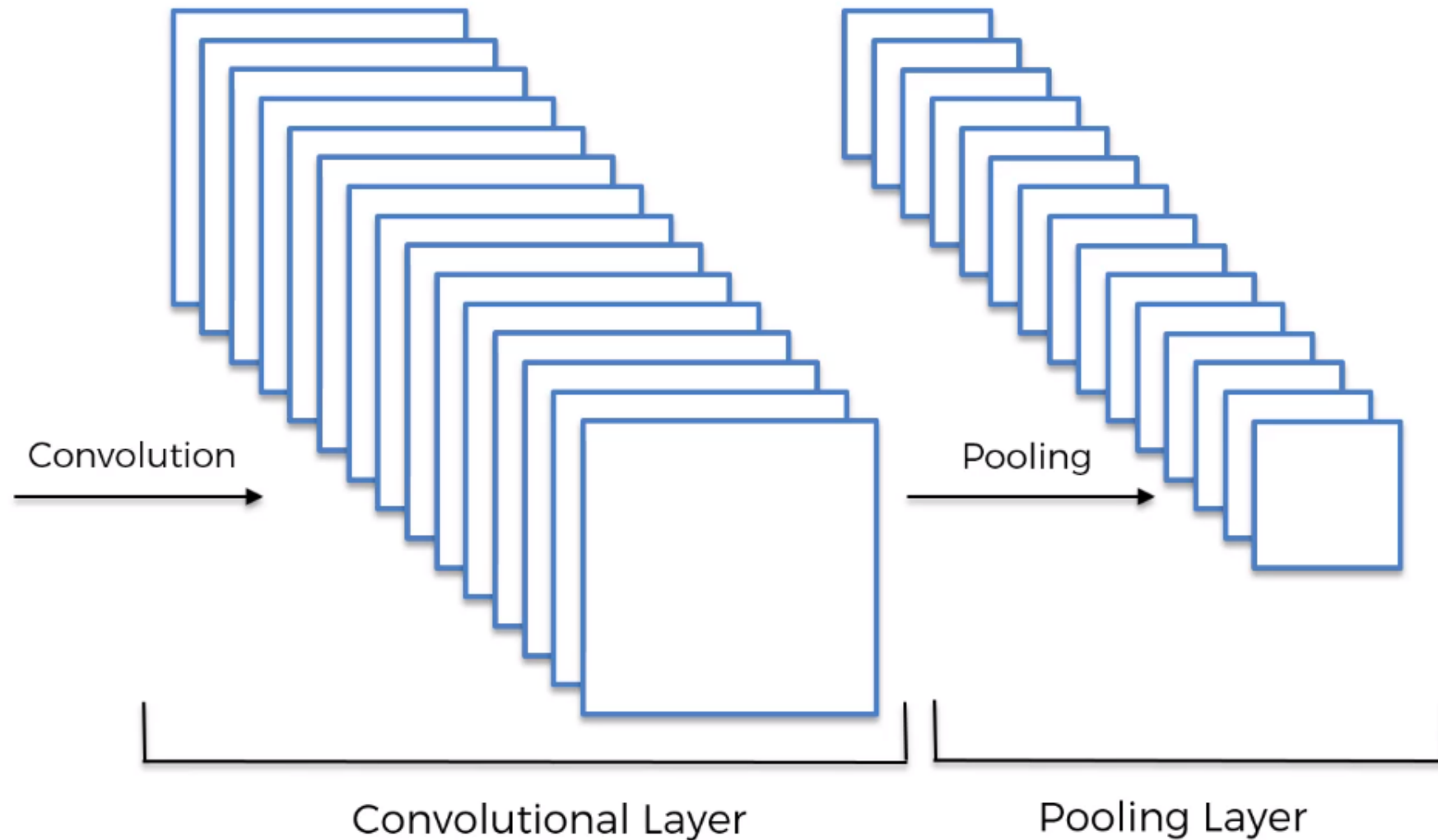
# Pooling



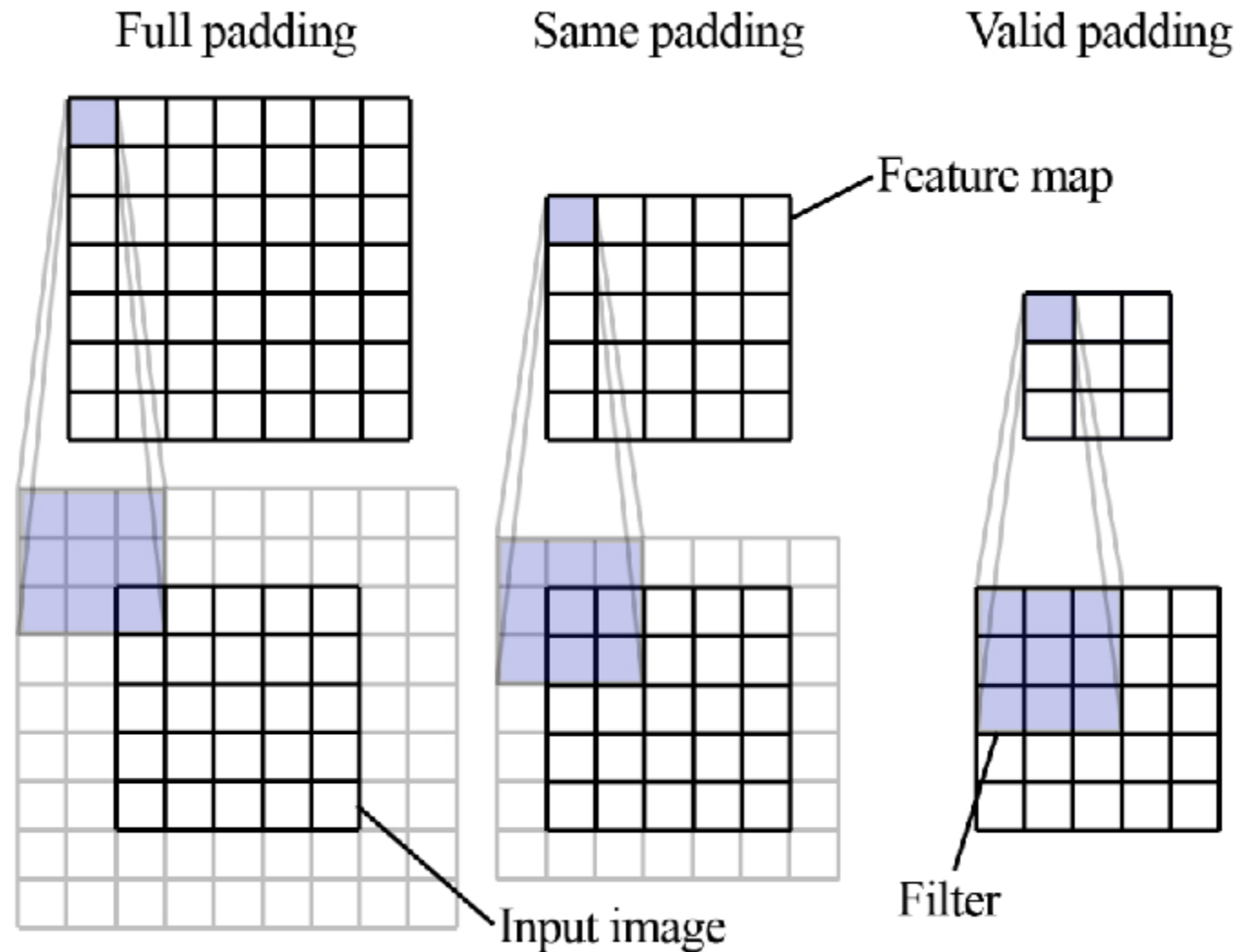
# Pooling

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

Input Image



# Pooling



# Pooling

<https://www.cs.ryerson.ca/~aharley/vis/conv/flat.html>



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# Flattening

|   |   |   |
|---|---|---|
| 1 | 1 | 0 |
| 4 | 2 | 1 |
| 0 | 2 | 1 |

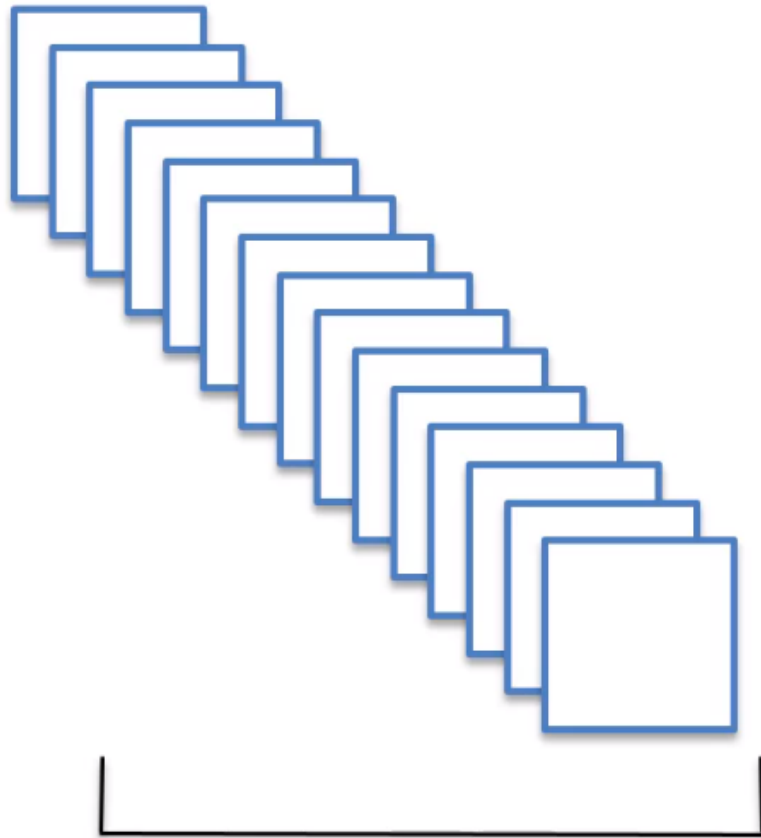
Pooled Feature Map

Flattening



|   |
|---|
| 1 |
| 1 |
| 0 |
| 4 |
| 2 |
| 1 |
| 0 |
| 2 |
| 1 |

# Flattening



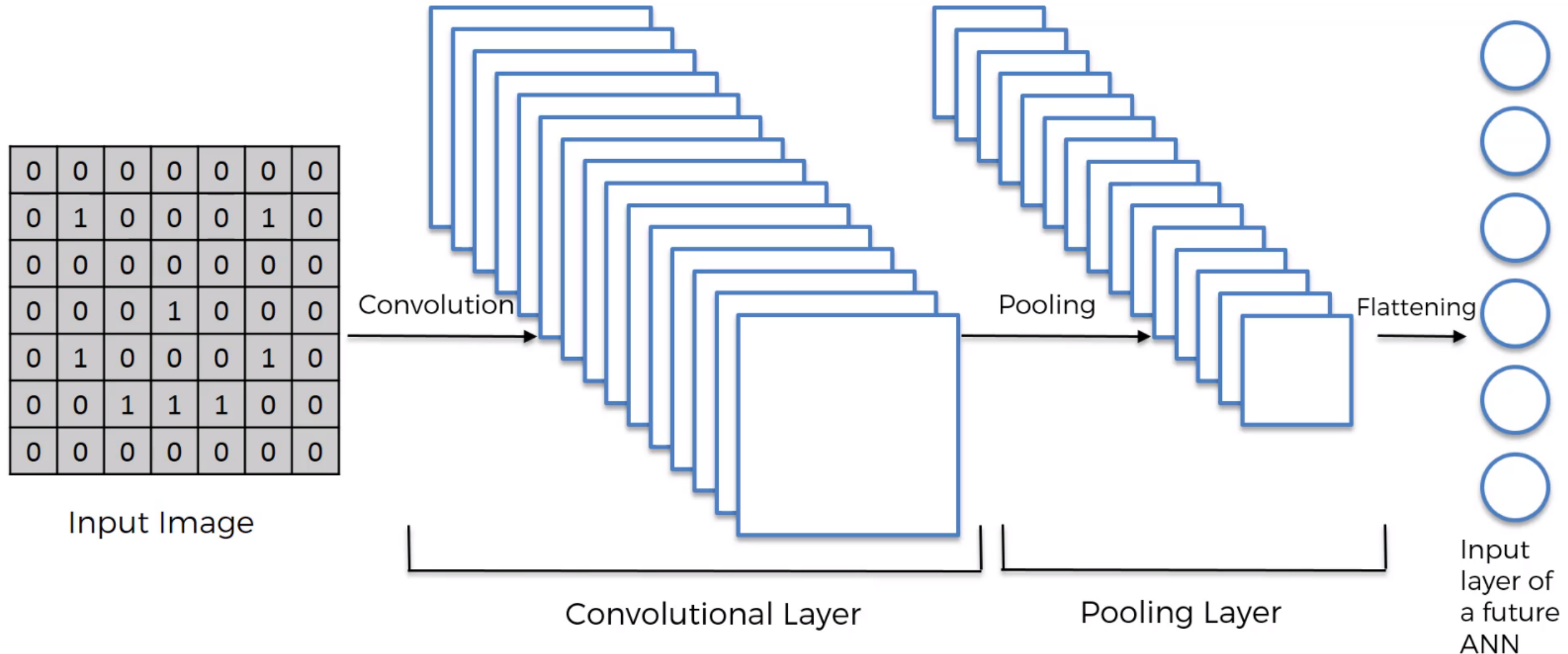
Pooling Layer

Flattening



Input layer of a future ANN

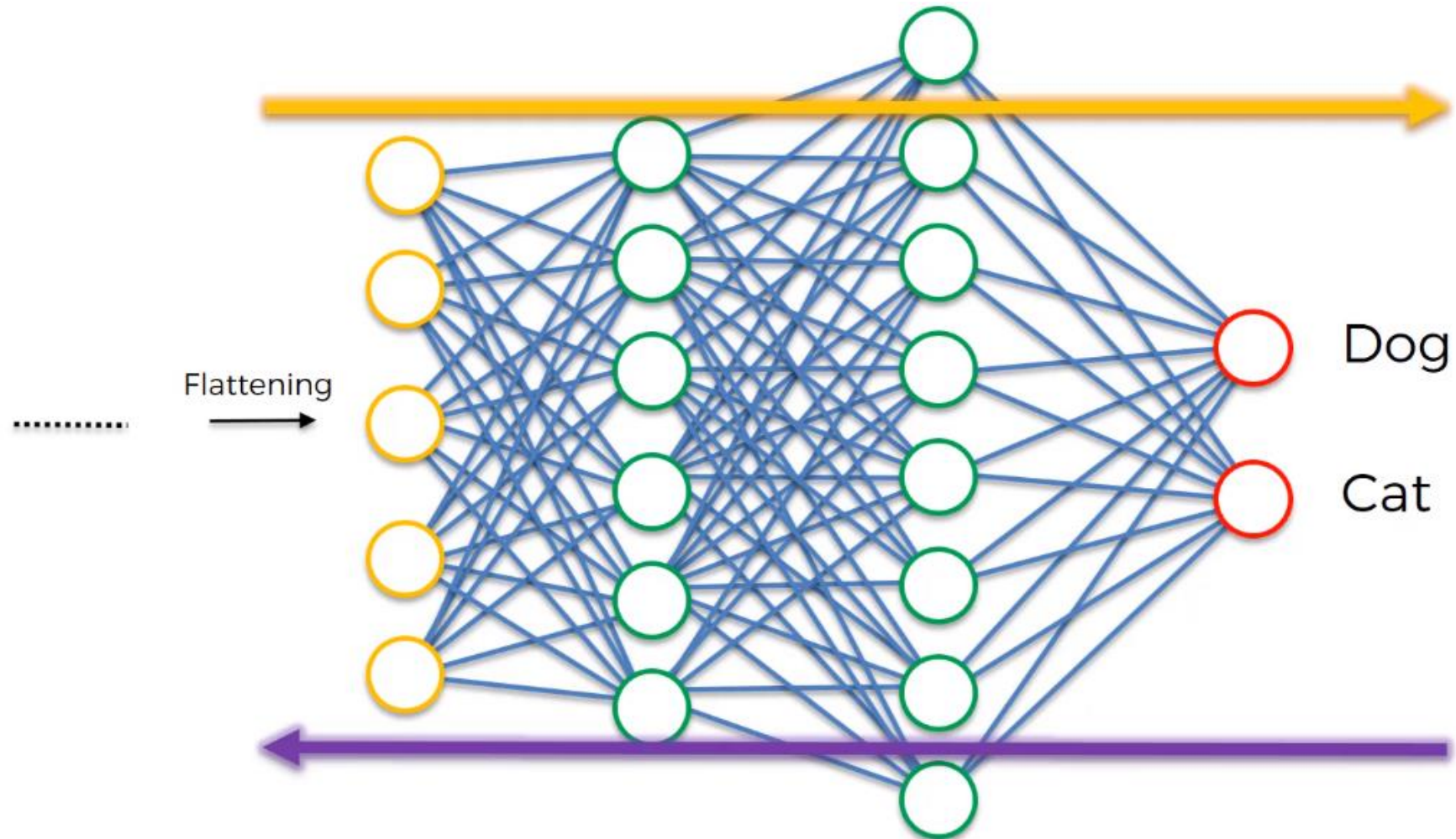
# Flattening



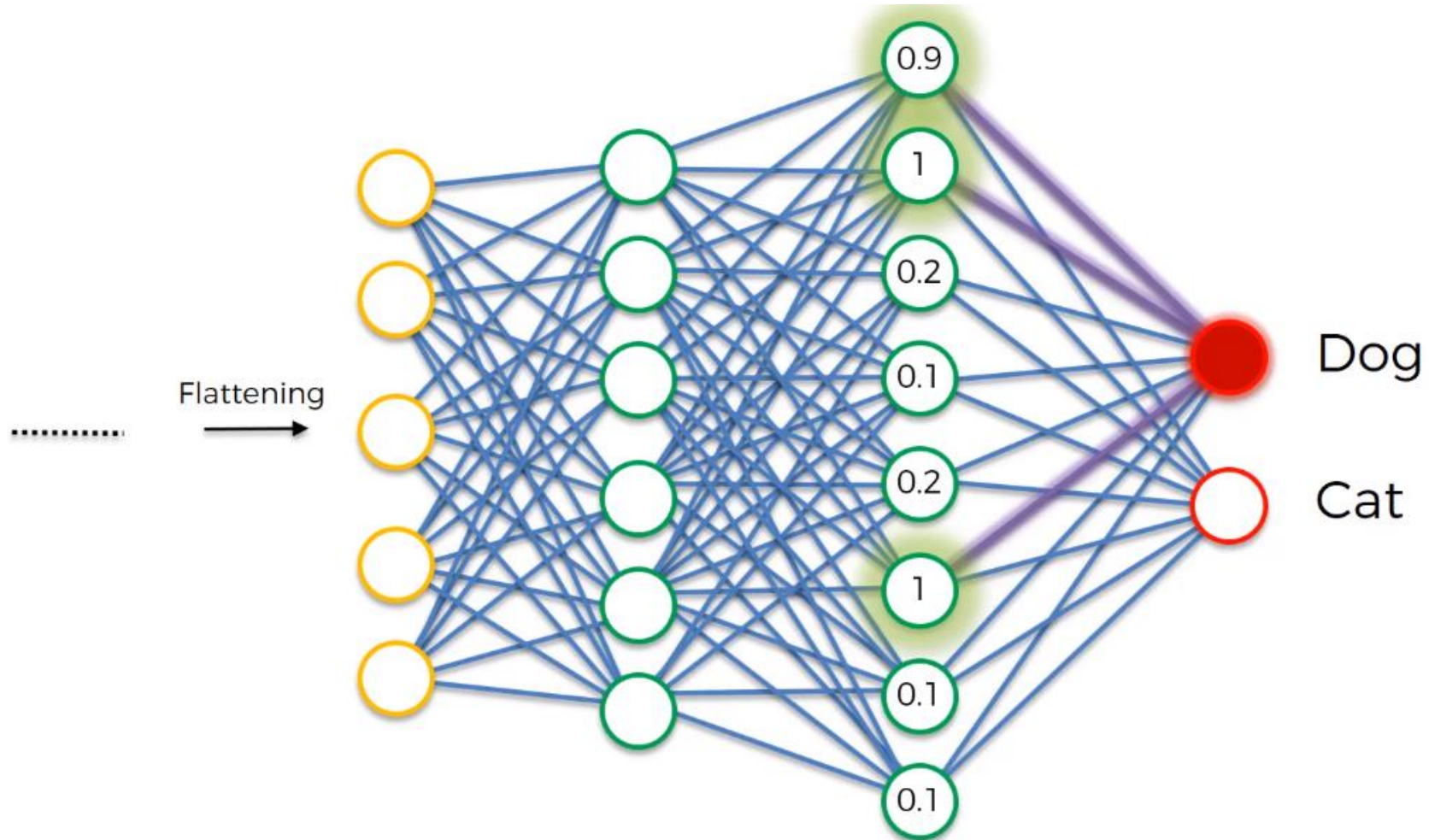
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# Full Connection

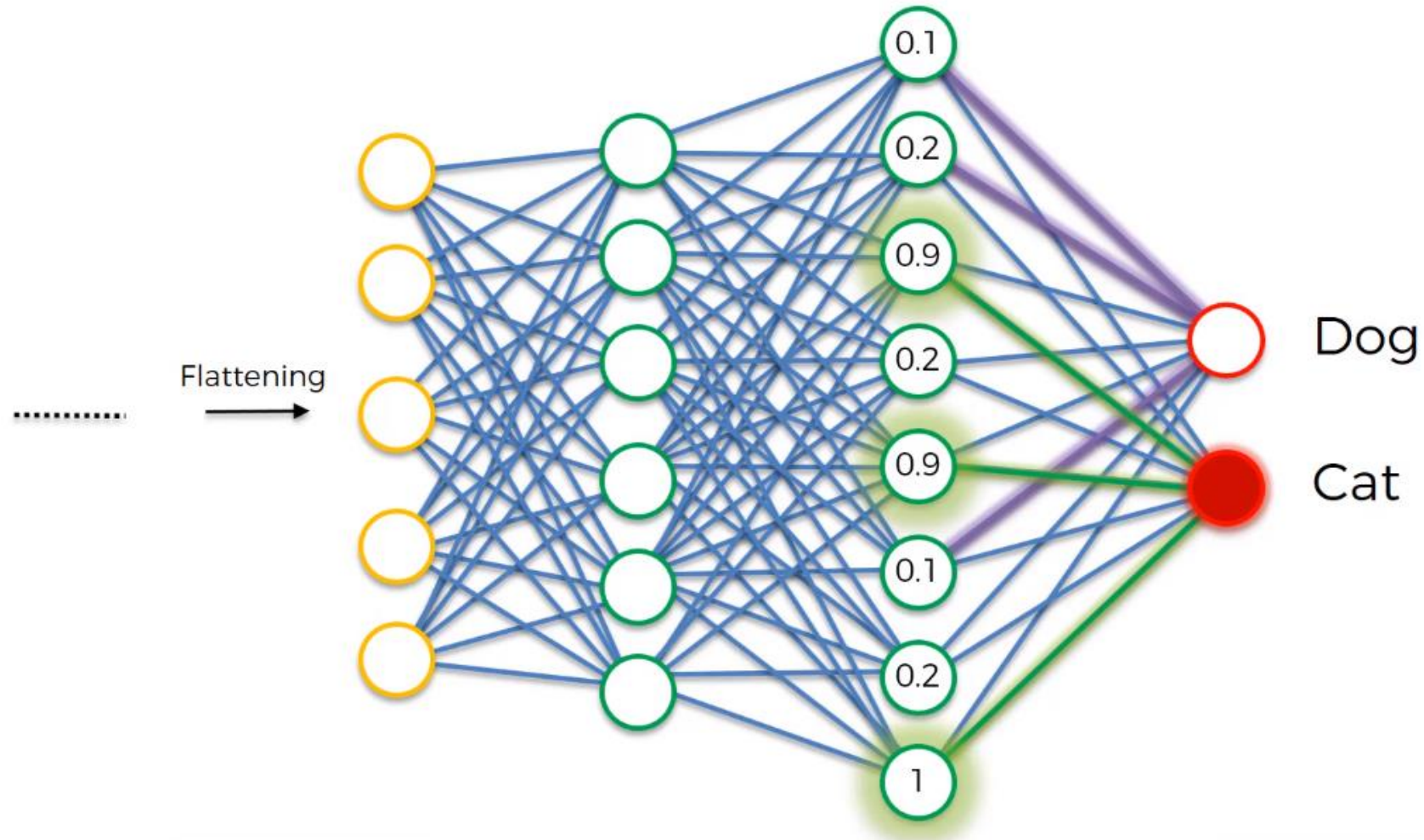


# Full Connection





# Full Connection

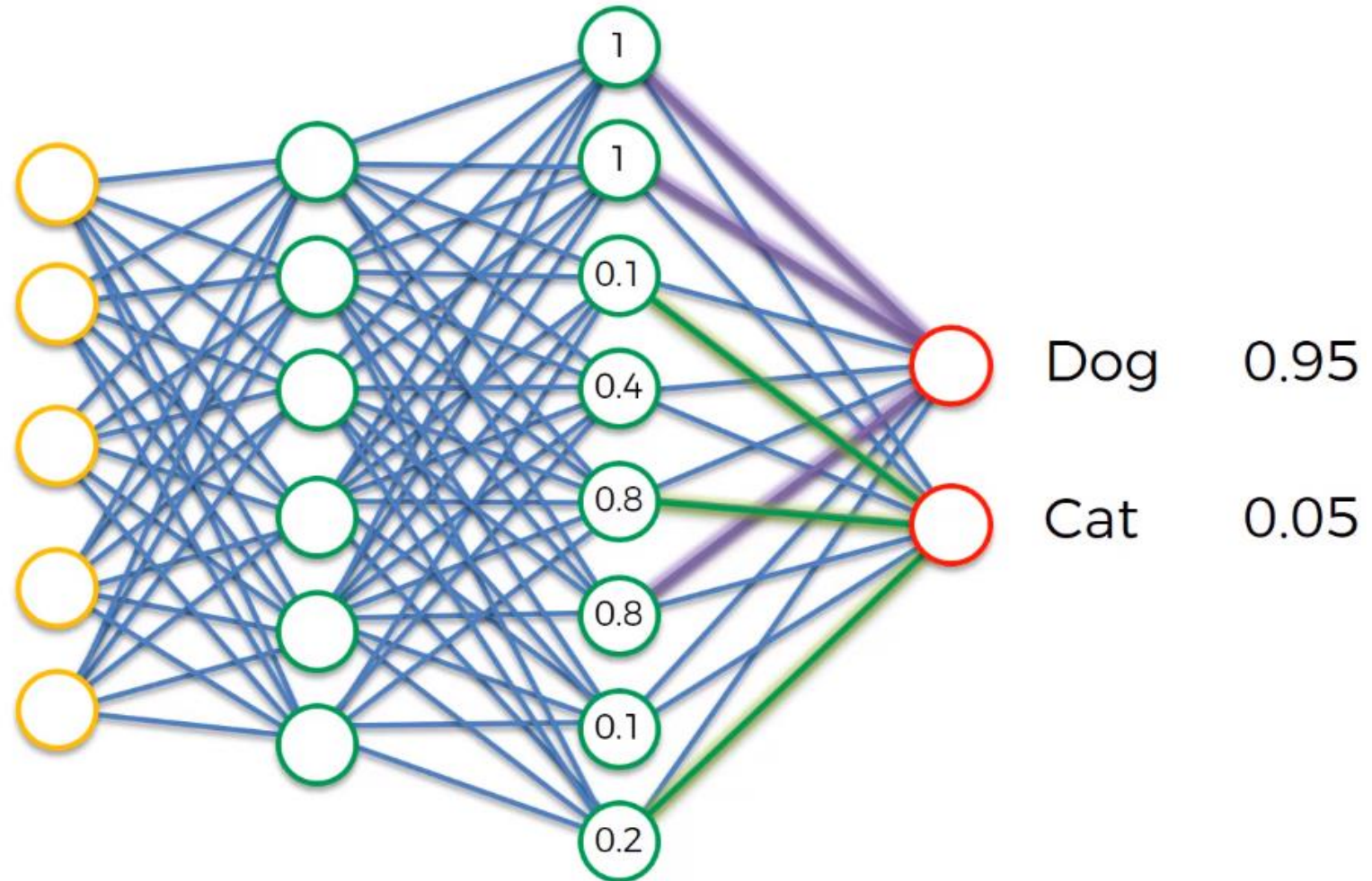




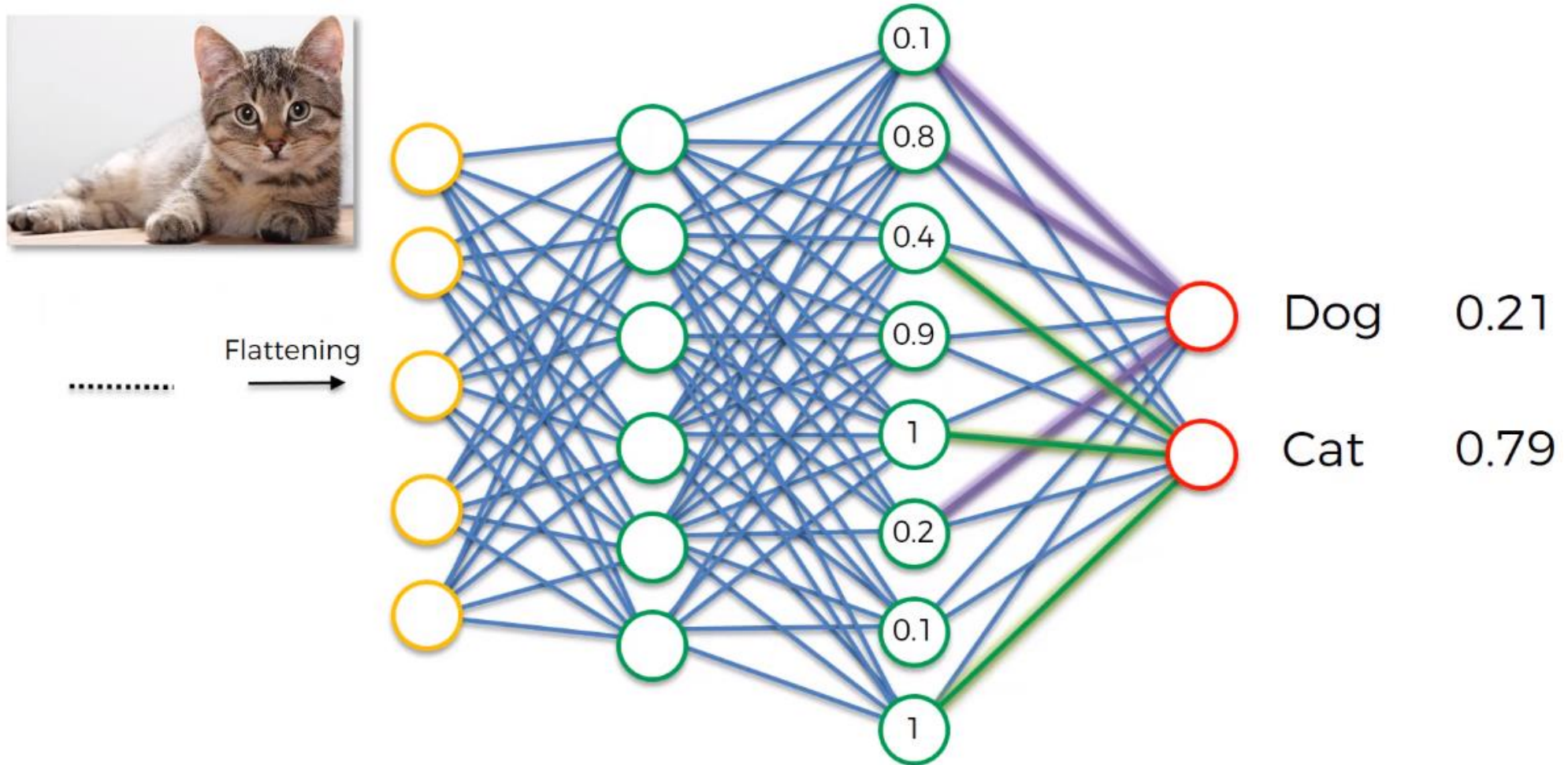
# Full Connection



.....  
Flattening  
→



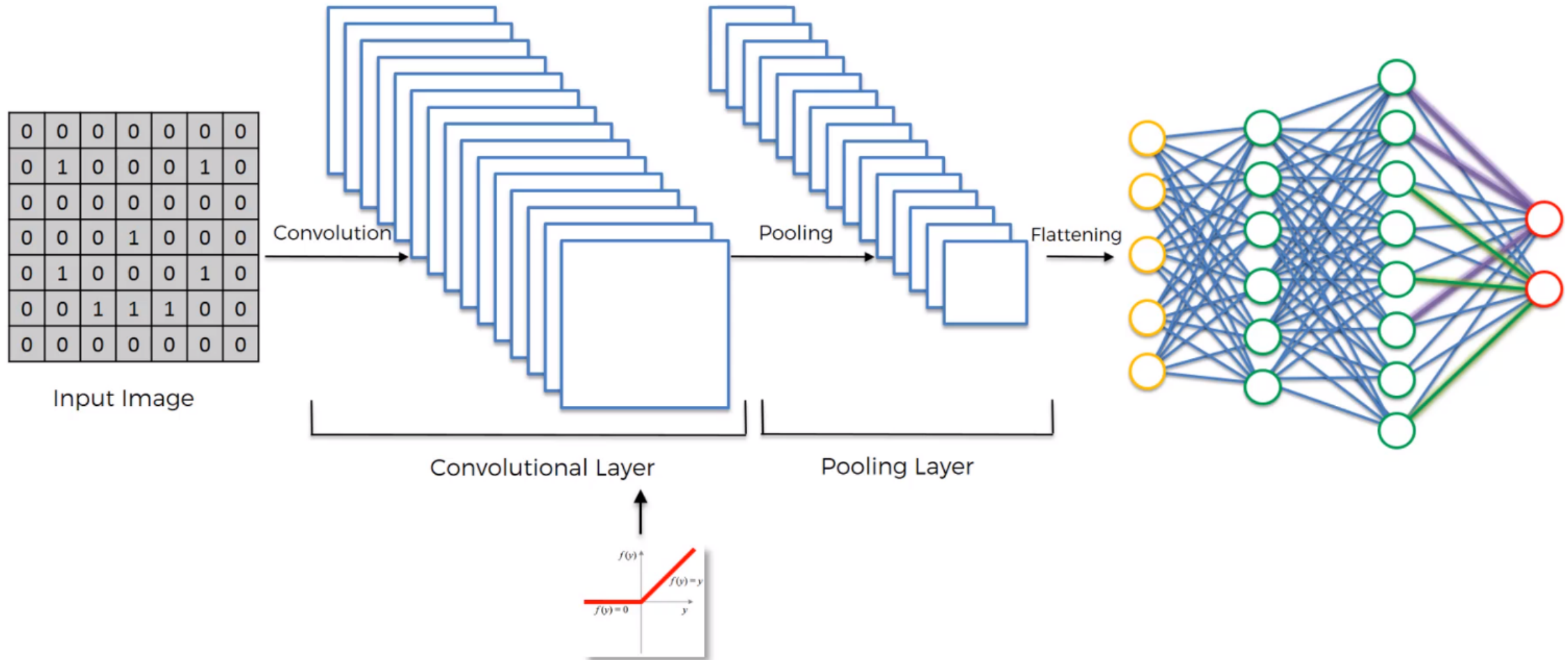
# Full Connection



# Summary

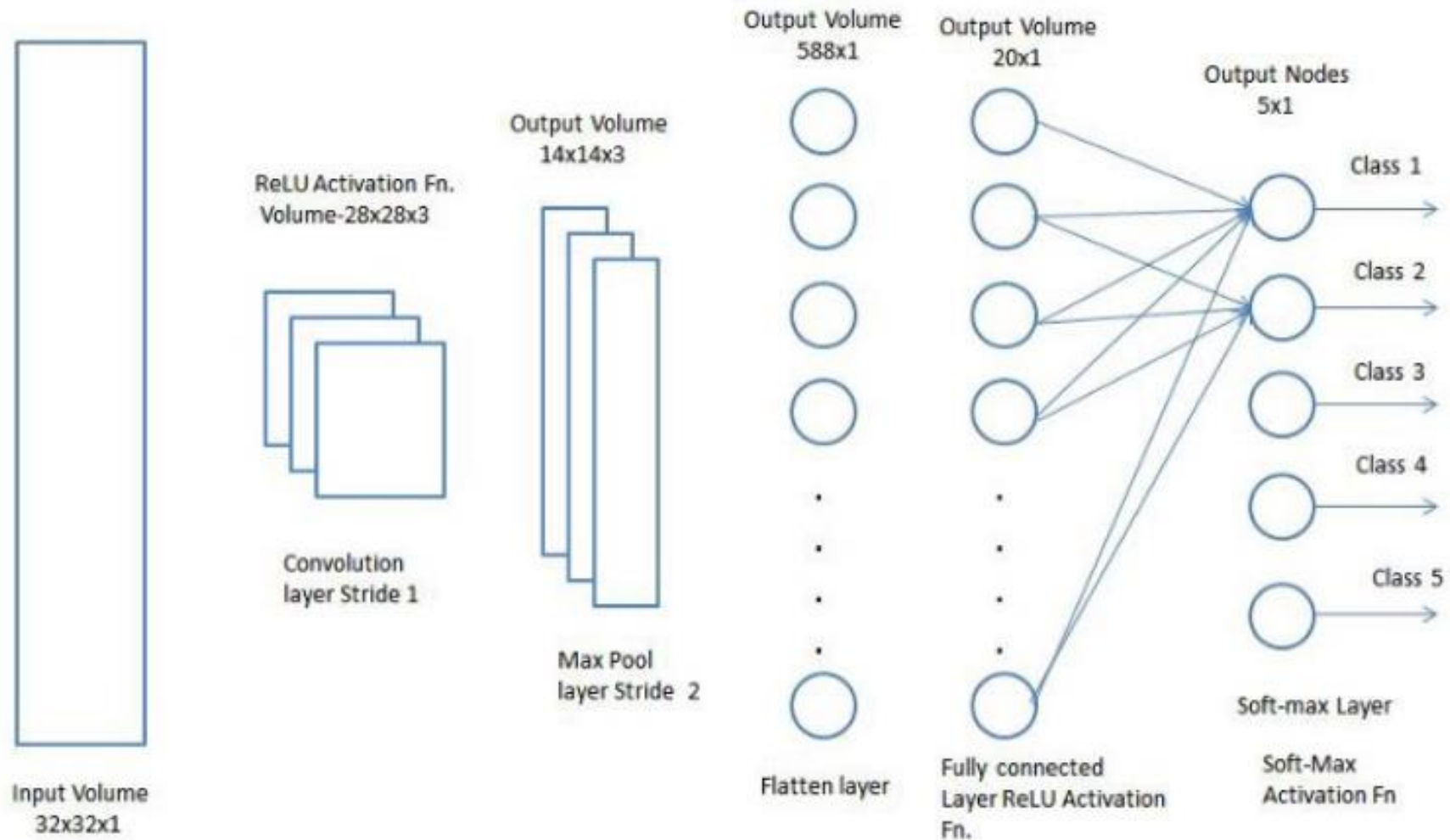
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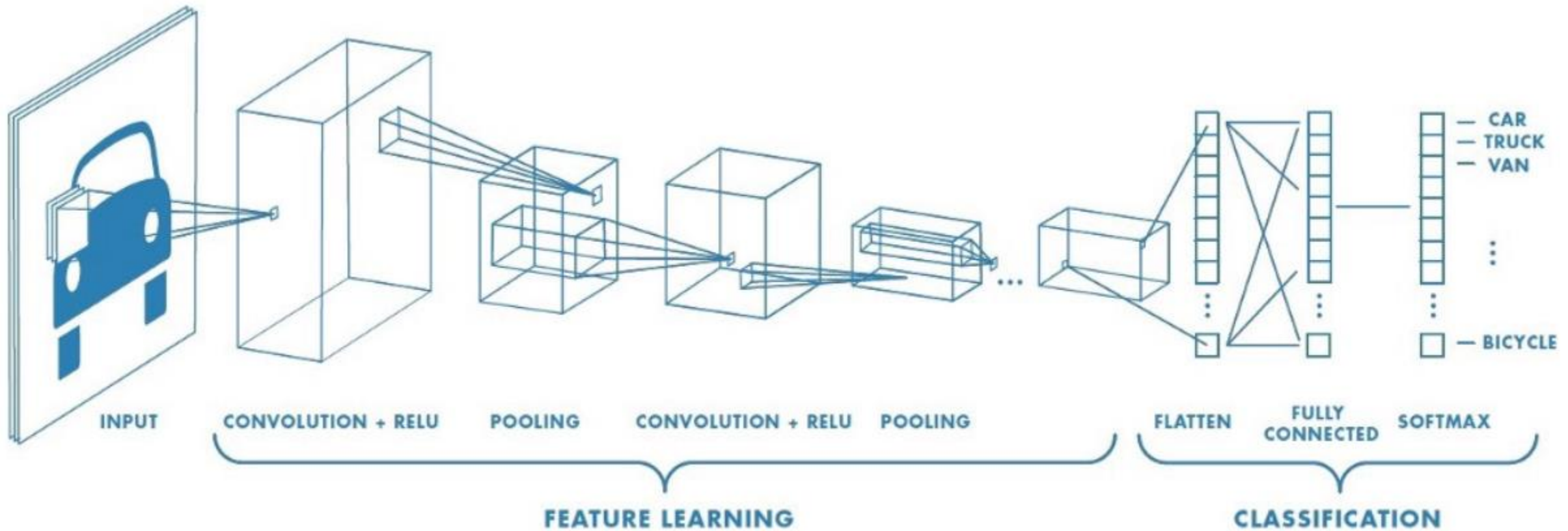




# Summary



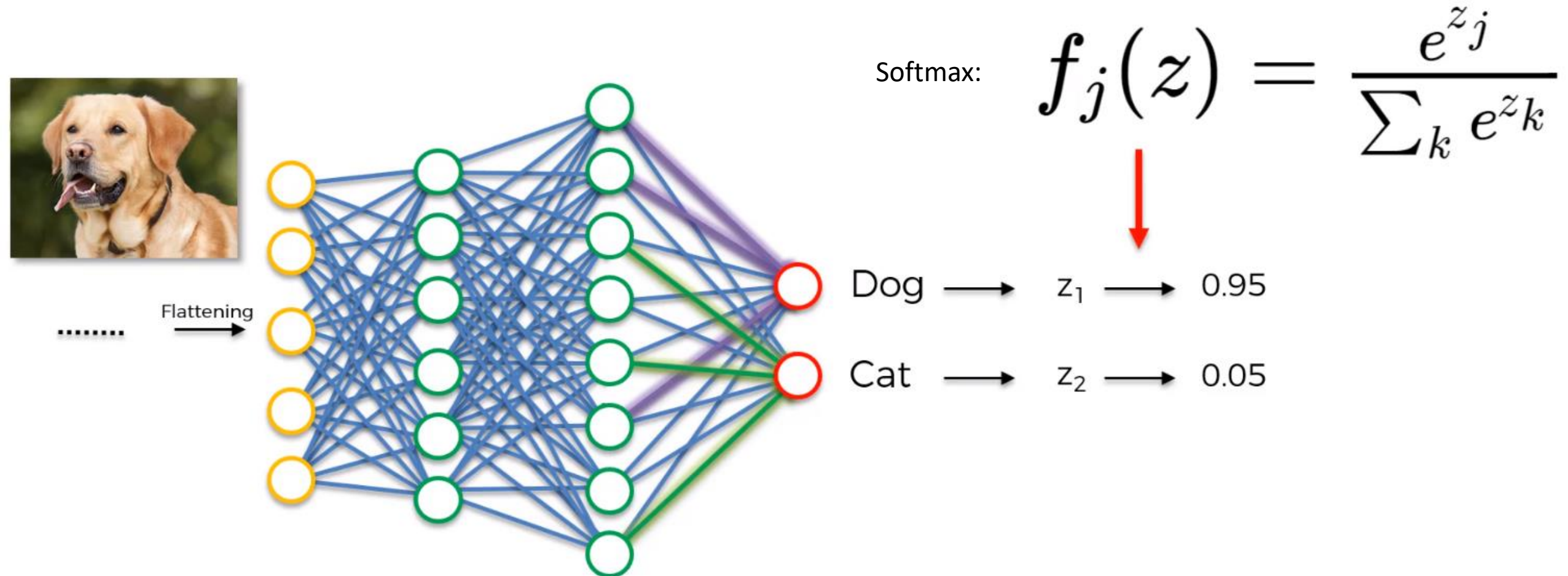
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# Softmax & Cross-Entropy





# Softmax & Cross-Entropy

Cross-Entropy:

$$L_i = -\log \left( \frac{e^{f_{y_i}}}{\sum_j e^{f_j}} \right)$$

$$H(p, q) = - \sum_x p(x) \log q(x)$$

# Softmax & Cross-Entropy



Dog

0.9

Cat




0.1

$$H(p, q) = - \sum_x p(x) \log q(x)$$

1

0

# Softmax & Cross-Entropy

|   |     | NN1 | NN2 |
|---|-----|-----|-----|
|    | Dog | 1   | 0.9 |
|   | Cat | 0   | 0.1 |
|   | Dog | 0   | 0.1 |
|   | Cat | 1   | 0.9 |
|  | Dog | 1   | 0.4 |
|   | Cat | 0   | 0.6 |

# Softmax & Cross-Entropy

NN1

| Row | Dog^ | Cat^ | Dog | Cat |
|-----|------|------|-----|-----|
| #1  | 0.9  | 0.1  | 1   | 0   |
| #2  | 0.1  | 0.9  | 0   | 1   |
| #3  | 0.4  | 0.6  | 1   | 0   |

Classification Error

$$1/3 = 0.33$$

Mean Squared Error

0.25

Cross-Entropy

0.38

NN2

| Row | Dog^ | Cat^ | Dog | Cat |
|-----|------|------|-----|-----|
| #1  | 0.6  | 0.4  | 1   | 0   |
| #2  | 0.3  | 0.7  | 0   | 1   |
| #3  | 0.1  | 0.9  | 1   | 0   |

$$1/3 = 0.33$$

0.71

1.06