# DATA 442: Neural Networks & Deep Learning

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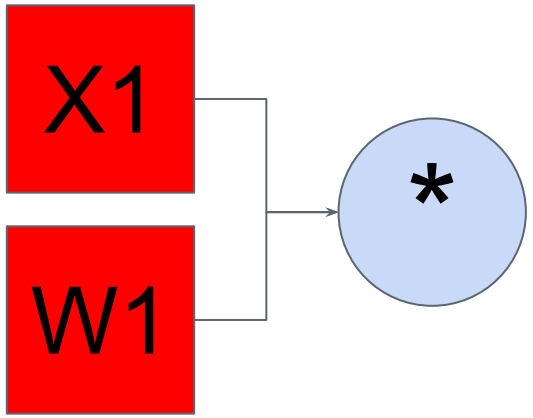
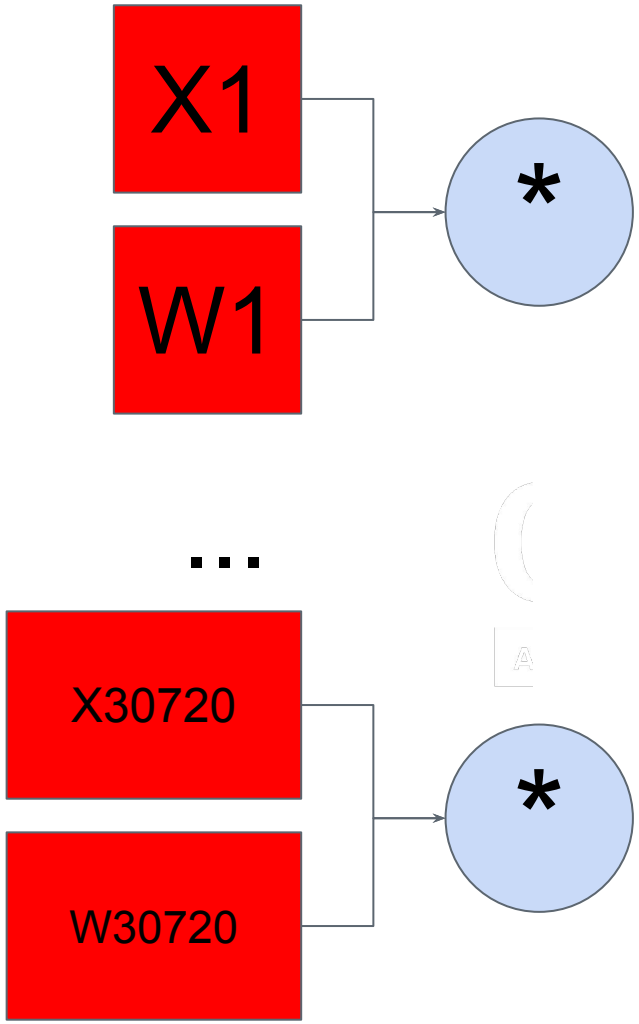
icss.wm.edu/data442/

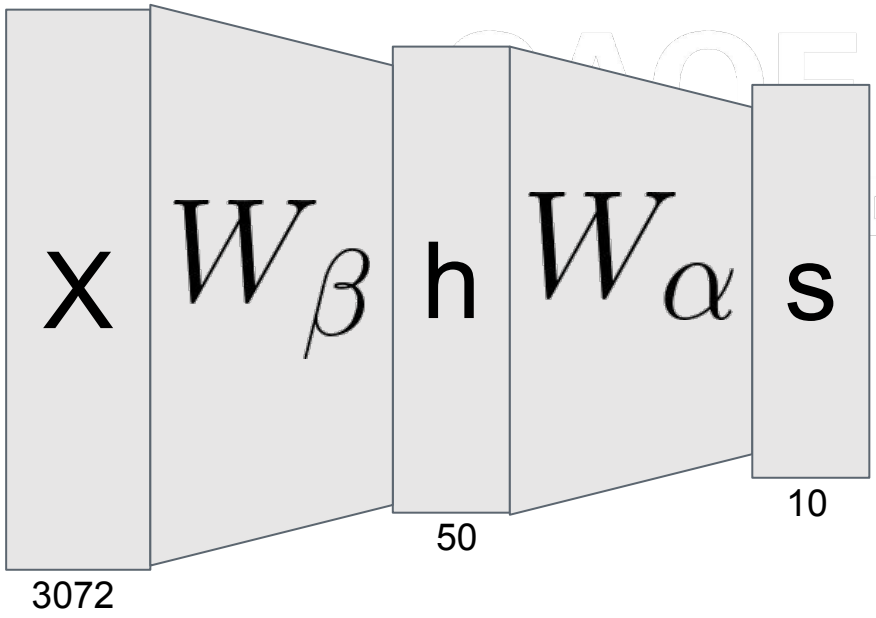


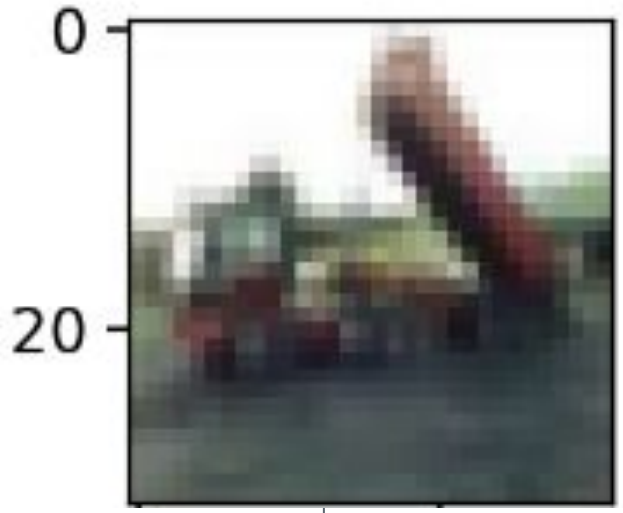

```
class MultiplicationNode():
    def forwardPass(input1,input2):
        output = input1 * input2
        self.input1 = input1
        self.input2 = input2
        return output

    def backwardPass(dOutput):
        dInput1 = self.input2 * dOutput
        dInput2 = self.input1 * dOutput
        return [dInput1, dInput2]
```


X1
W1
*
...
X30720
W30720
*

$$f = W_\alpha * max(0, W_\beta * X)$$




Input Image Array

3072

1

Weights for each Pixel, for each of 10 CIFAR classes

3072

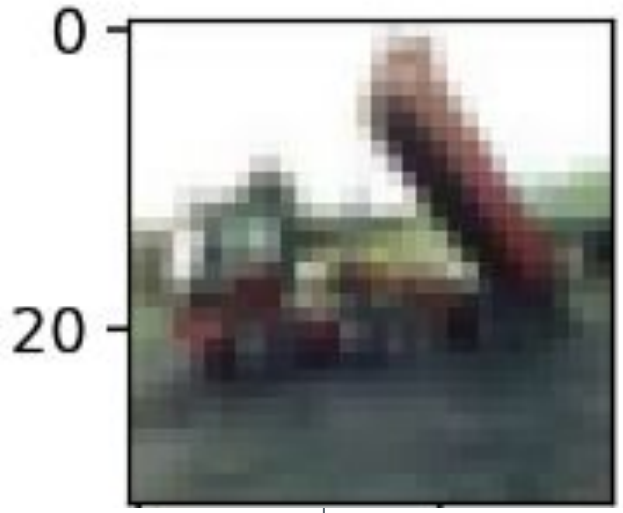
10

=

Output Scores Array

10

1




Input Image Array

3072

1

Weights for each Pixel, for each of 10 CIFAR classes

3072

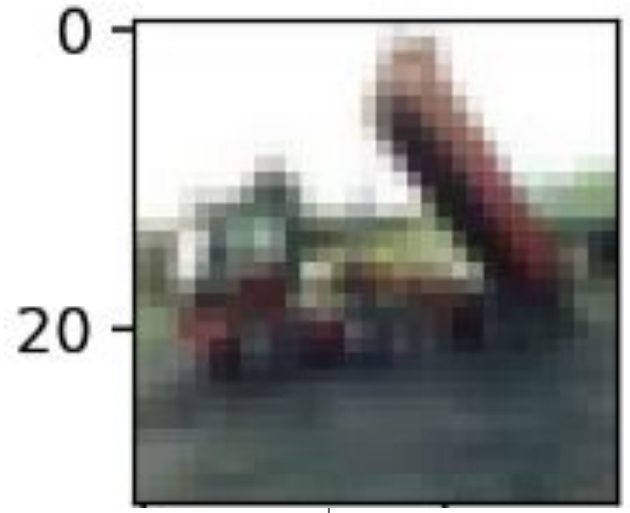
10

Output Scores Array

10

1

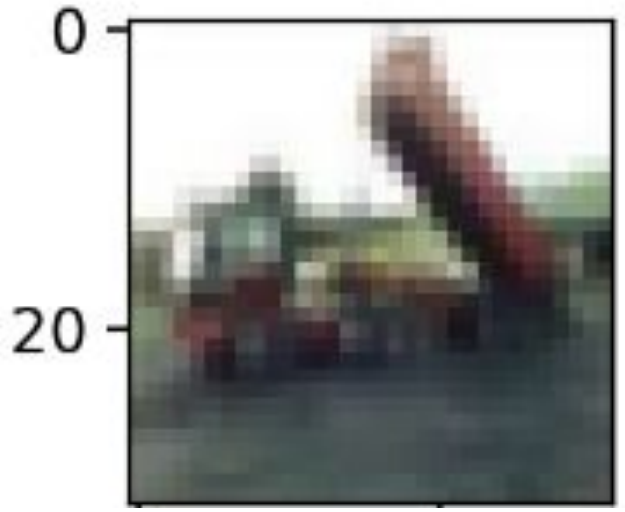
Each of the individual scores is the result of the dot product between a row of the weights matrix and the input array.



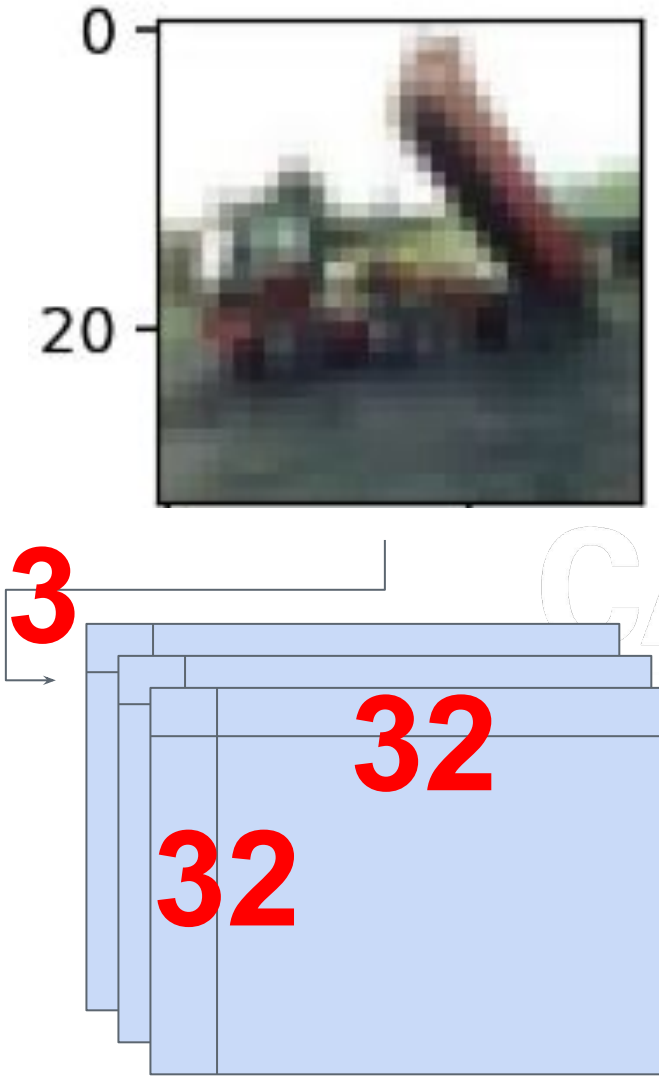

Input Image Array

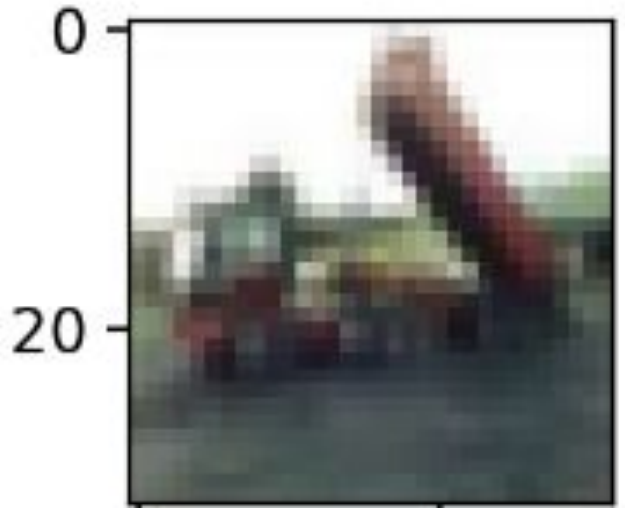
1

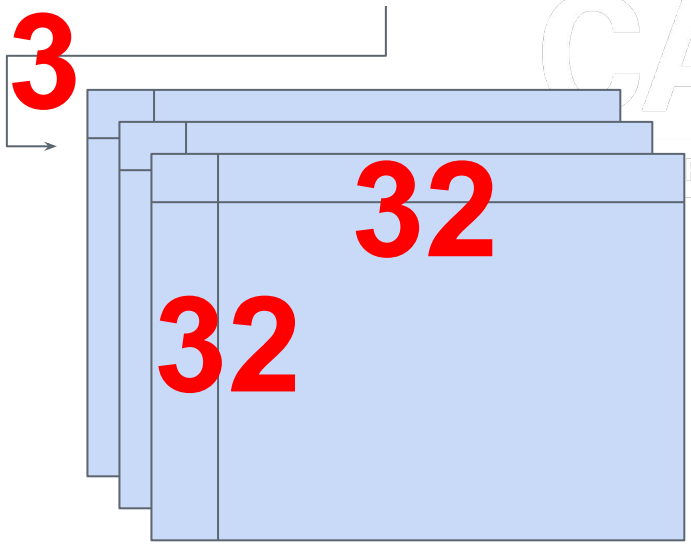
3072



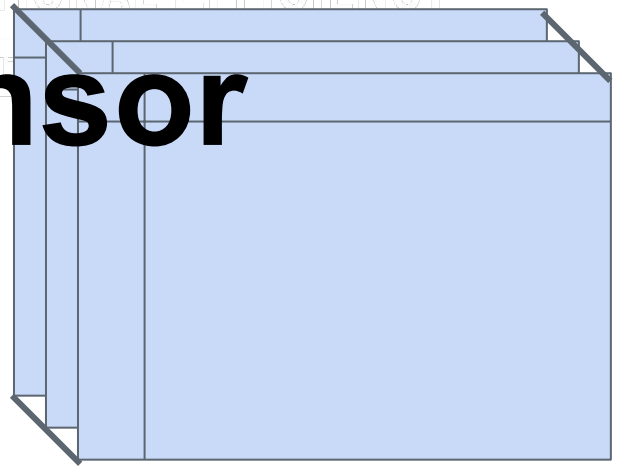

?

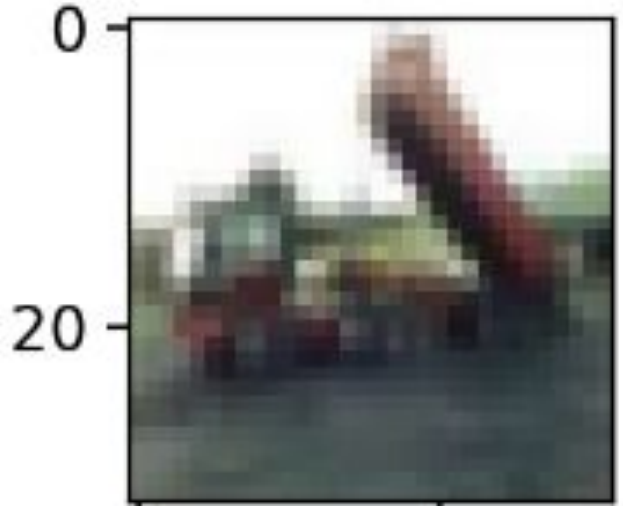




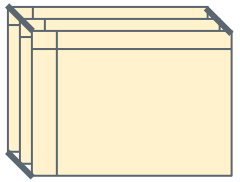

# 32 x 32 x 3 Tensor



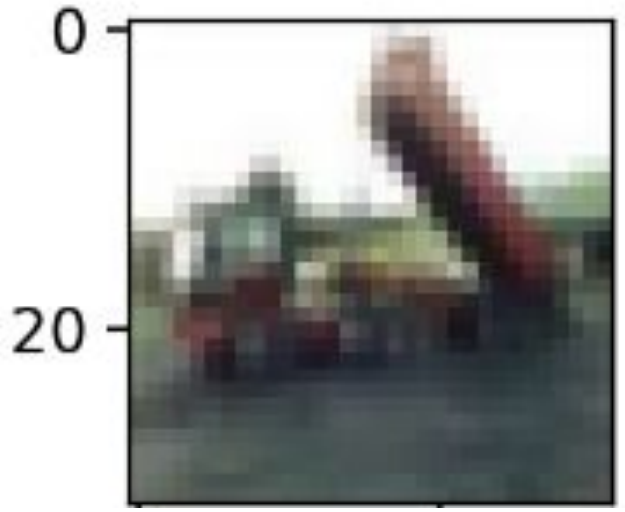





32 x 32 x 3
**Tensor**



5x5x3
**Filter**



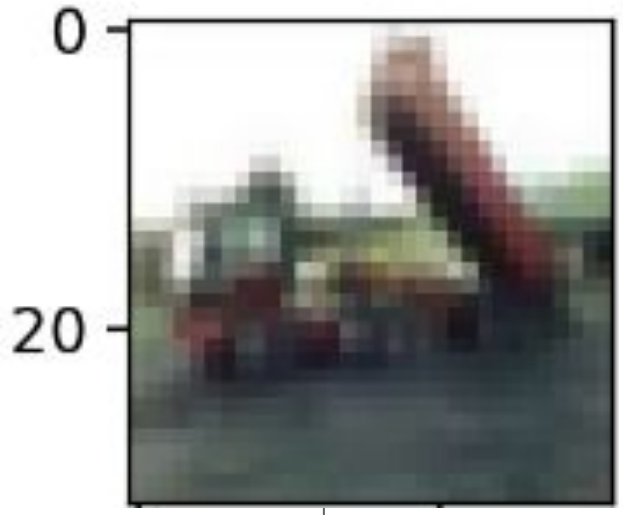



32 x 32 x 3
**Tensor**

5x5x3
**Filter**

**Activation Layer**

28 x 28 x 1
**Matrix**






Convolution (5x5x3 Filter)

Activation Layer (28 x 28 x 1 Matrix)

1

Input Activation Array

784

1

●

Weights for each Pixel, for each of 10 CIFAR classes

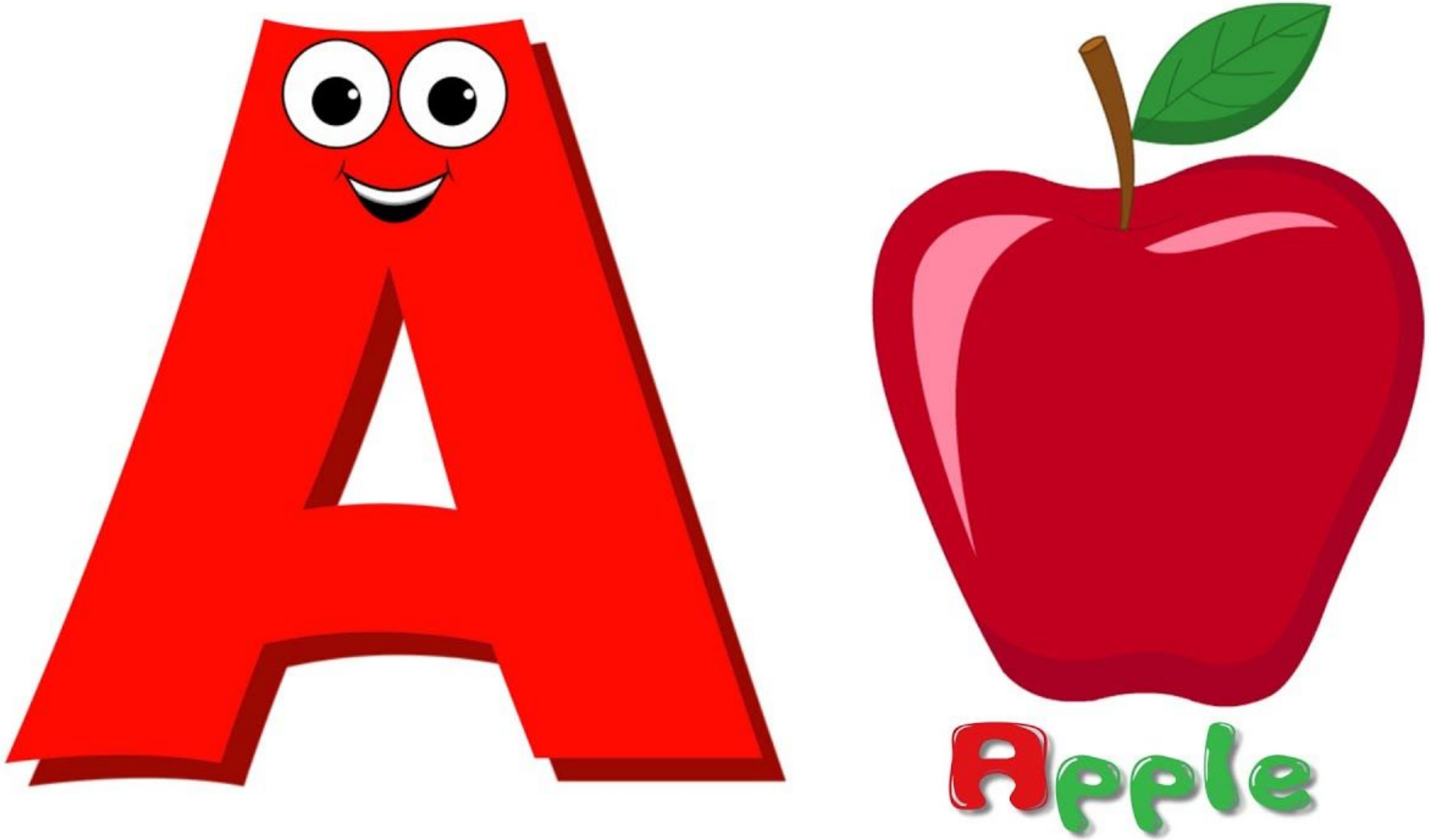
784

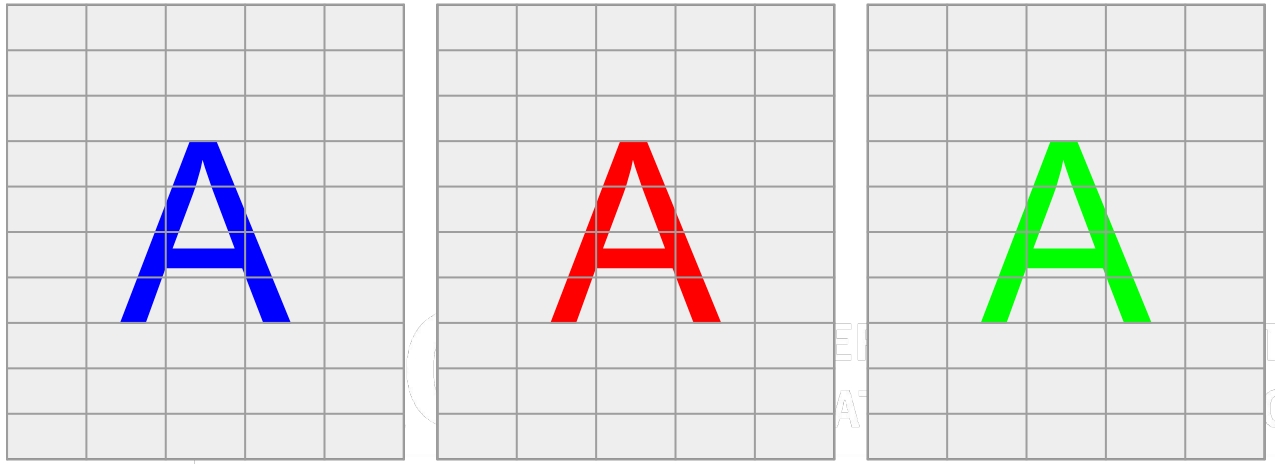
10

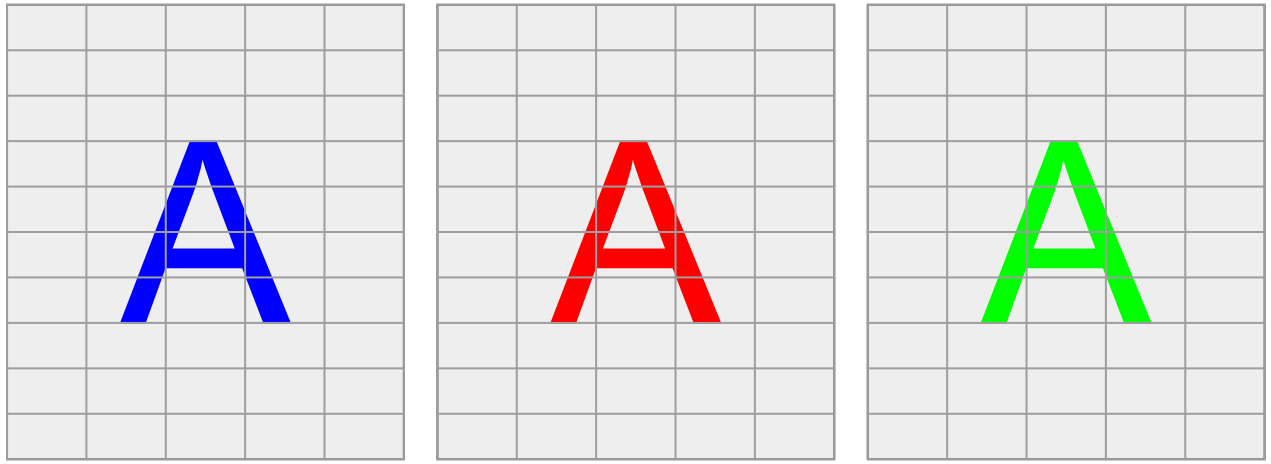
=

Output Scores Array

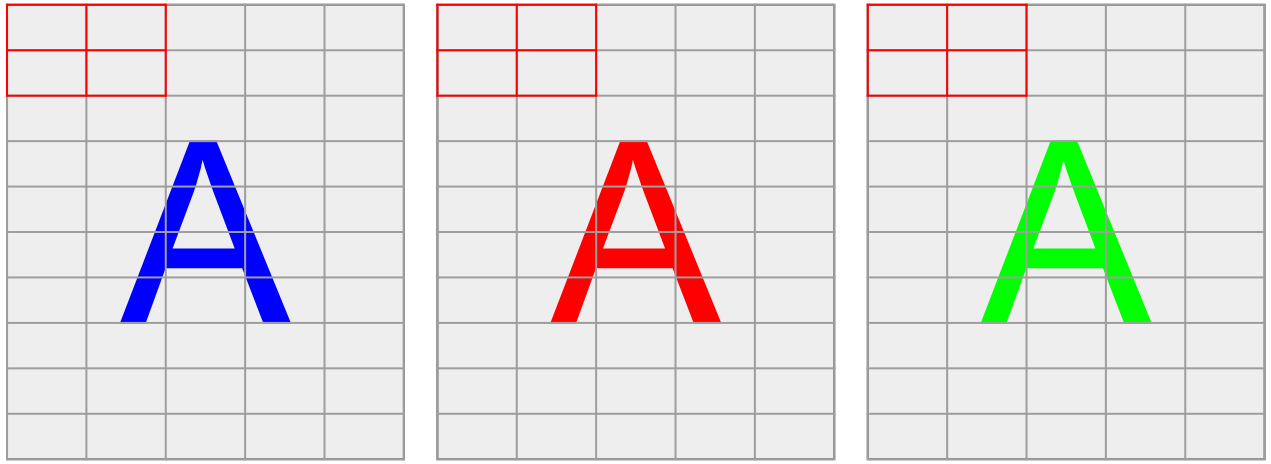
10


A
Apple

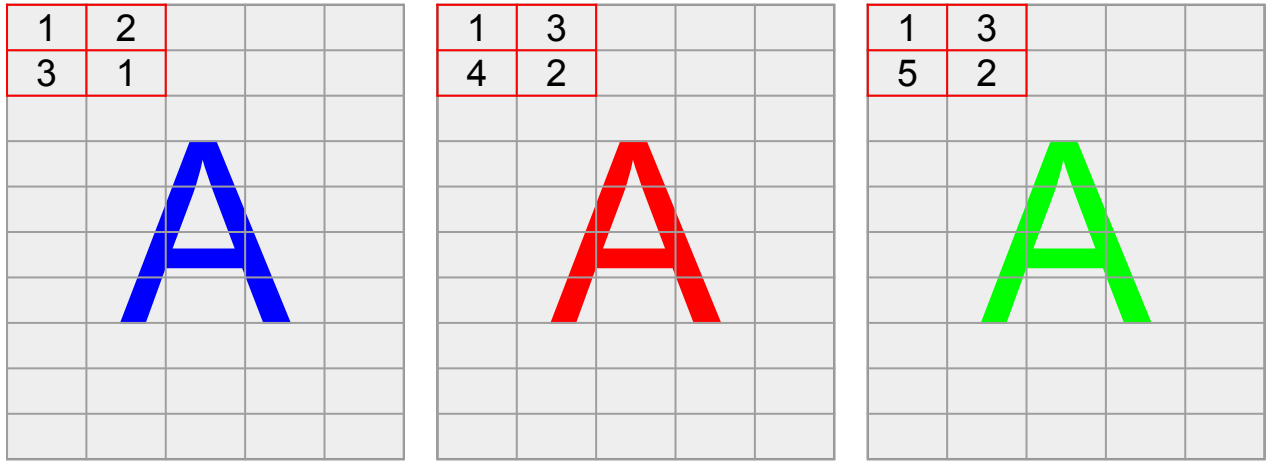





First, a *filter* is defined. This example is a 2x2x3 filter.

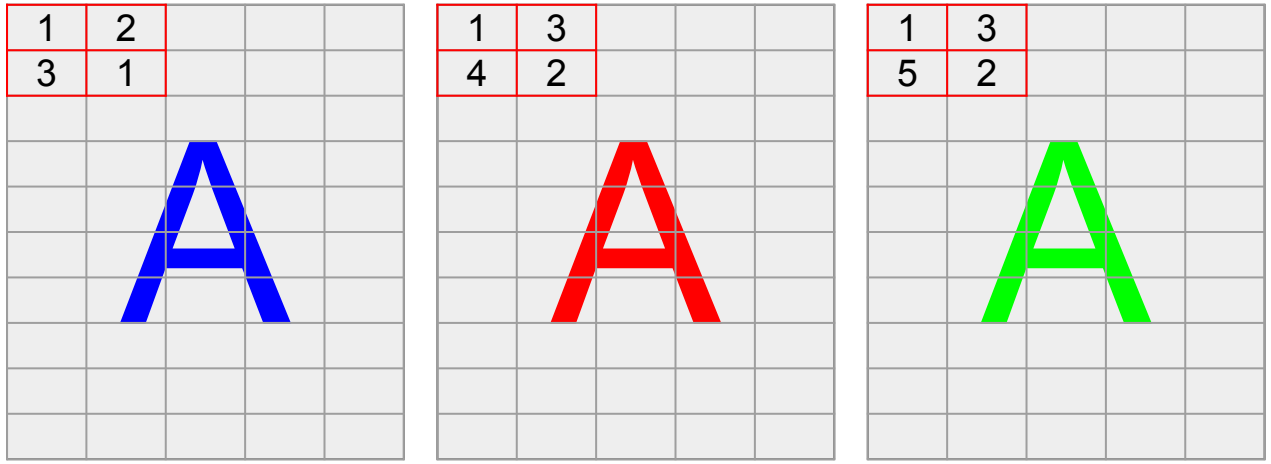


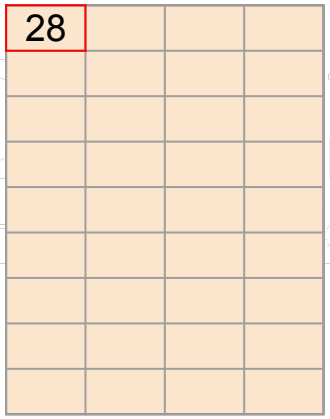
When we “convolve”, we are sliding our filter over each subset of the image.



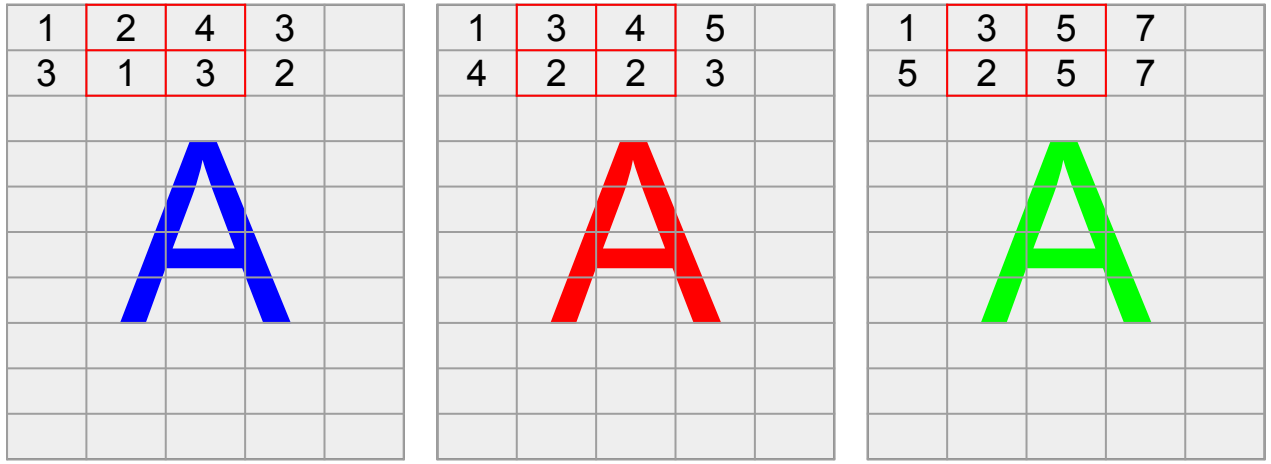

When we “convolve”, we are sliding our filter over each subset of the image.

The filter itself is defined based on weights - i.e., the simplest filter would have weights of “1” for every cell, so this convolution would be the sum of the 12 red cells **(28)**.

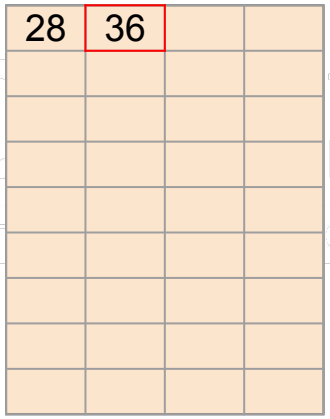


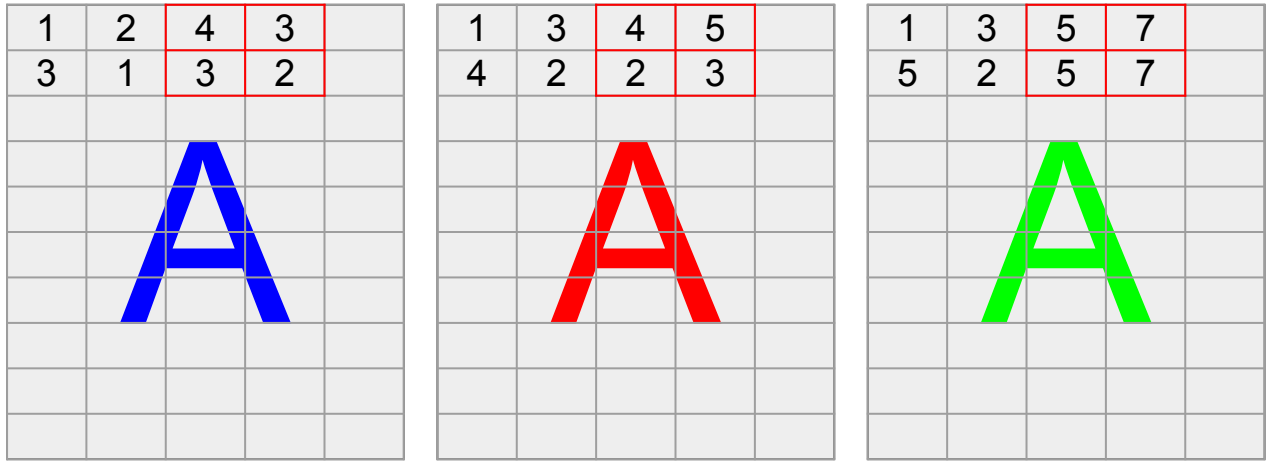




This becomes the first cell in the activation layer.

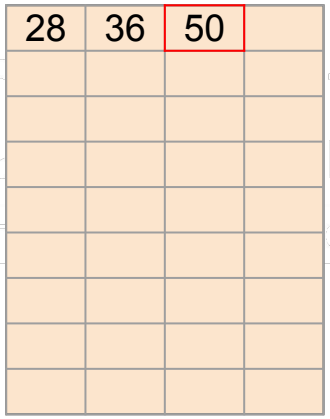


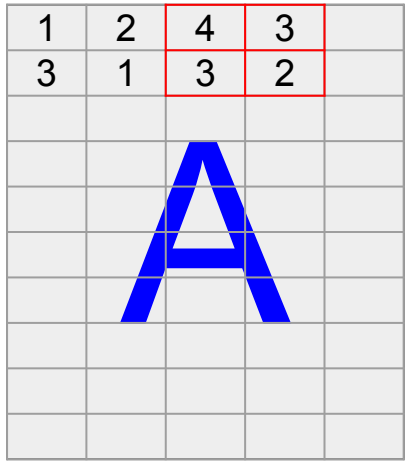

This becomes the **second** cell in the activation layer.

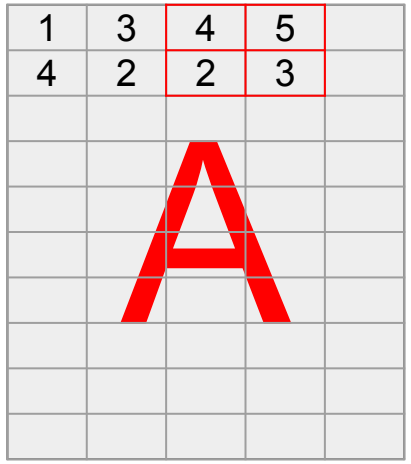


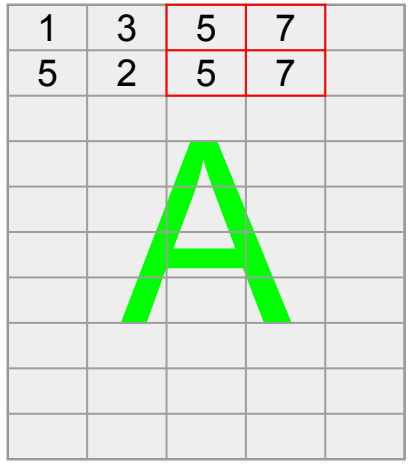



This becomes the **third** cell in the activation layer.



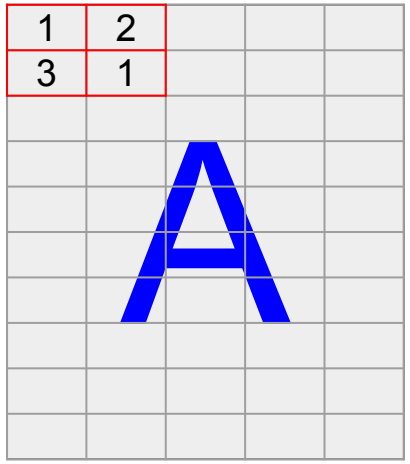


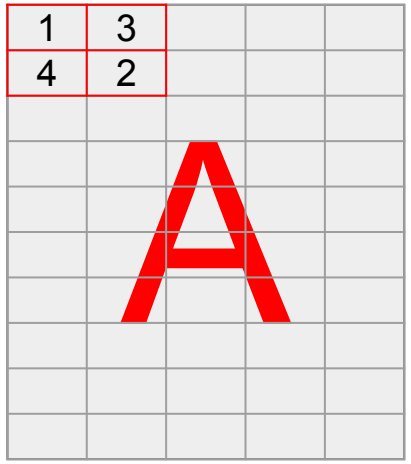



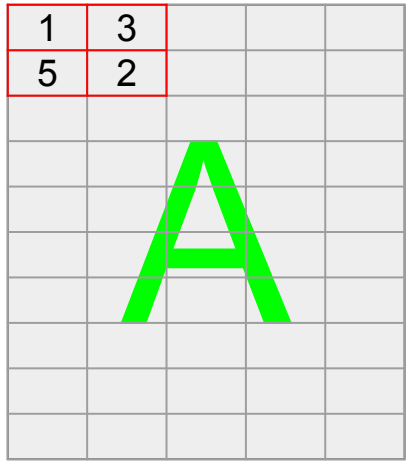



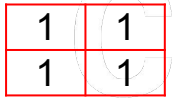

...and so on to define an activation layer.

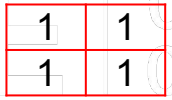
| | | | |
|---|---|---|---|
| 28 | 36 | 50 | 45 |
| 35 | 45 | 15 | 43 |
| 15 | 1 | 65 | 25 |
| 15 | 5 | 38 | 41 |
| 25 | 6 | 78 | 45 |
| 35 | 15 | 15 | 15 |
| 65 | 25 | 35 | 5 |
| 15 | 5 | 68 | 2 |
| 78 | 8 | 97 | 15 |

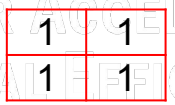


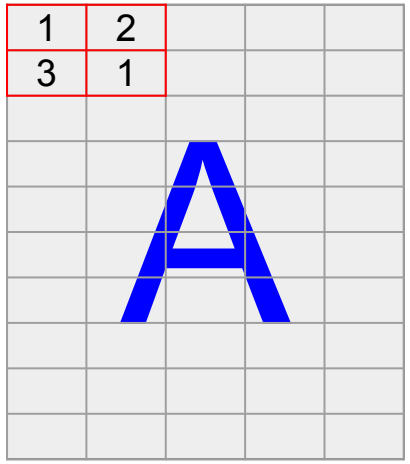



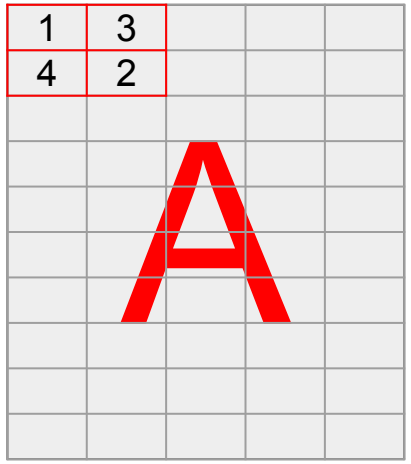



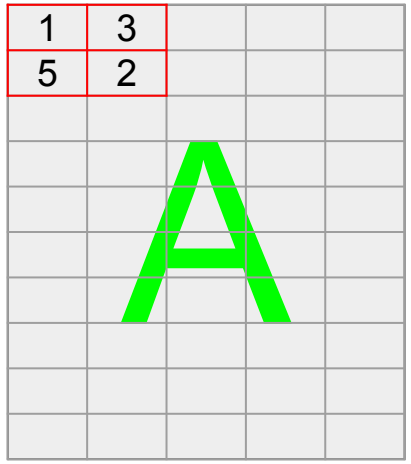





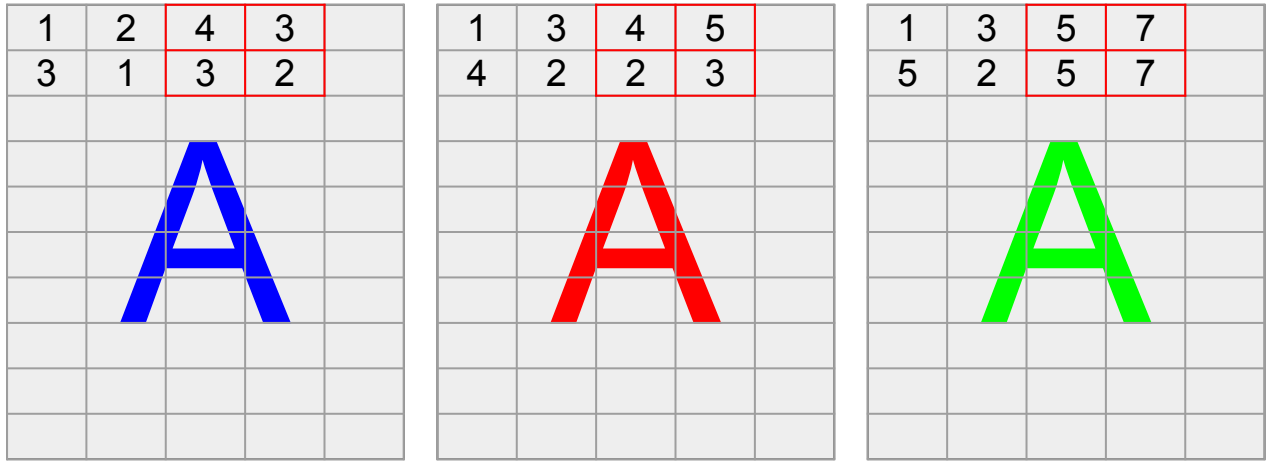



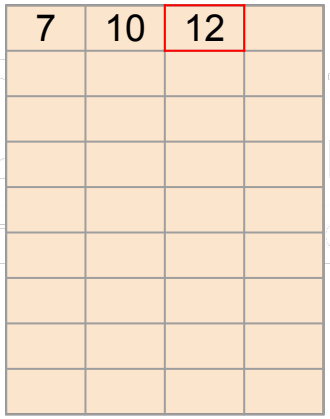

| | |
|---|---|
| 1 | 1 |
| 1 | 1 |

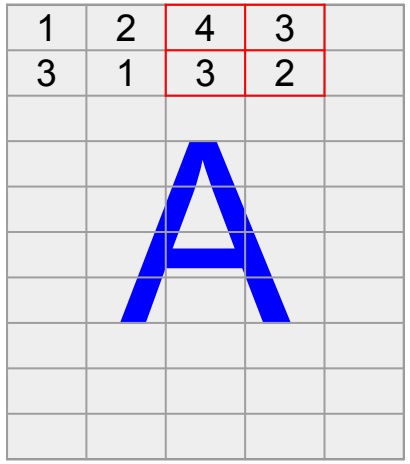
| | |
|---|---|
| 0 | 0 |
| 0 | 0 |

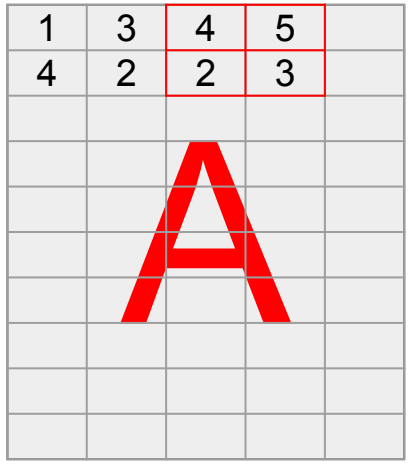
| | |
|---|---|
| 0 | 0 |
| 0 | 0 |

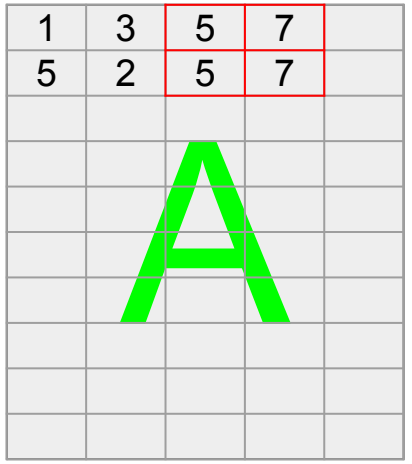



This would make a new activation layer, representing blue colors.

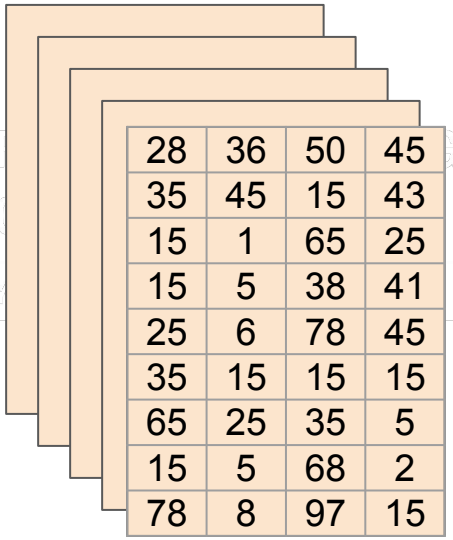


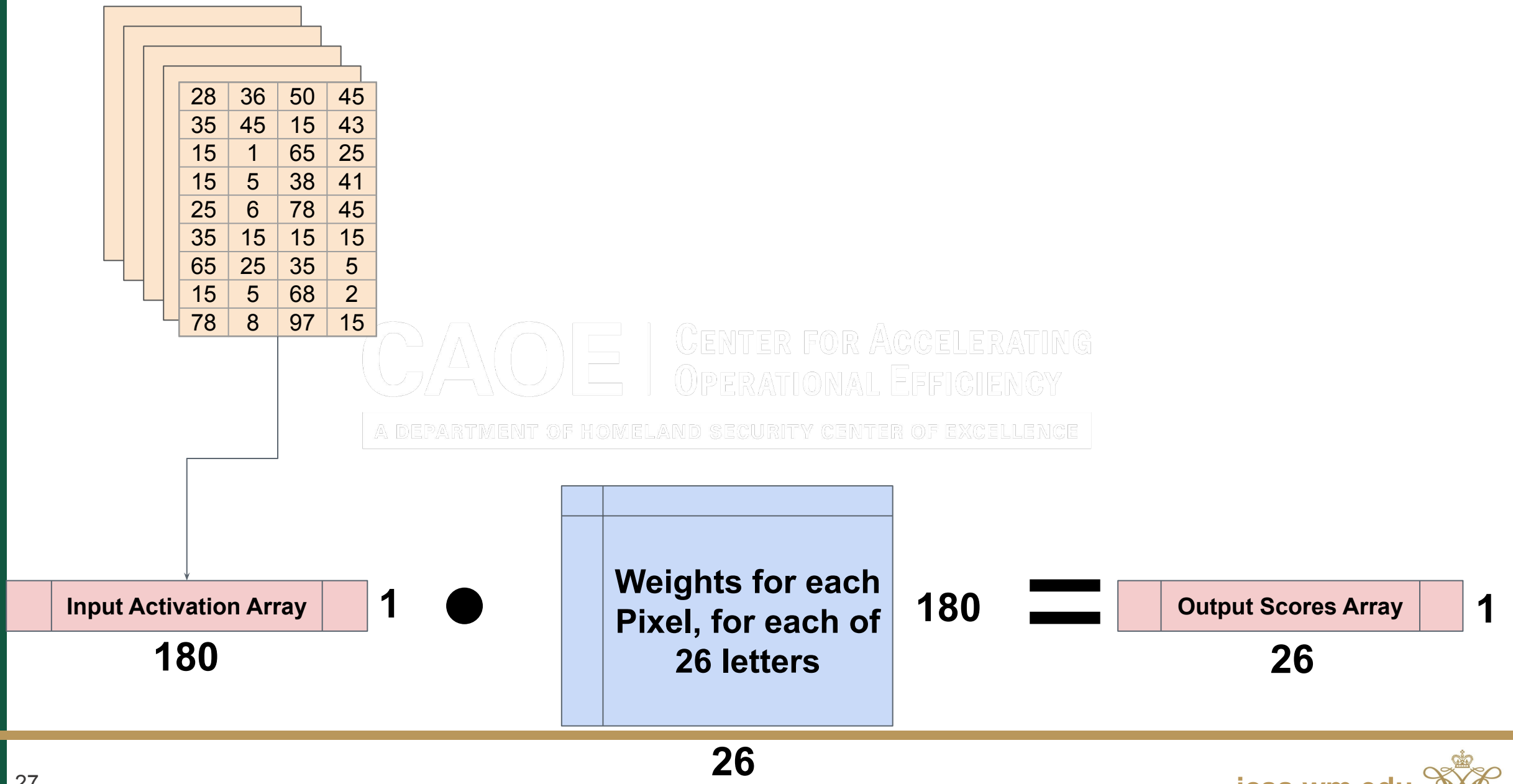


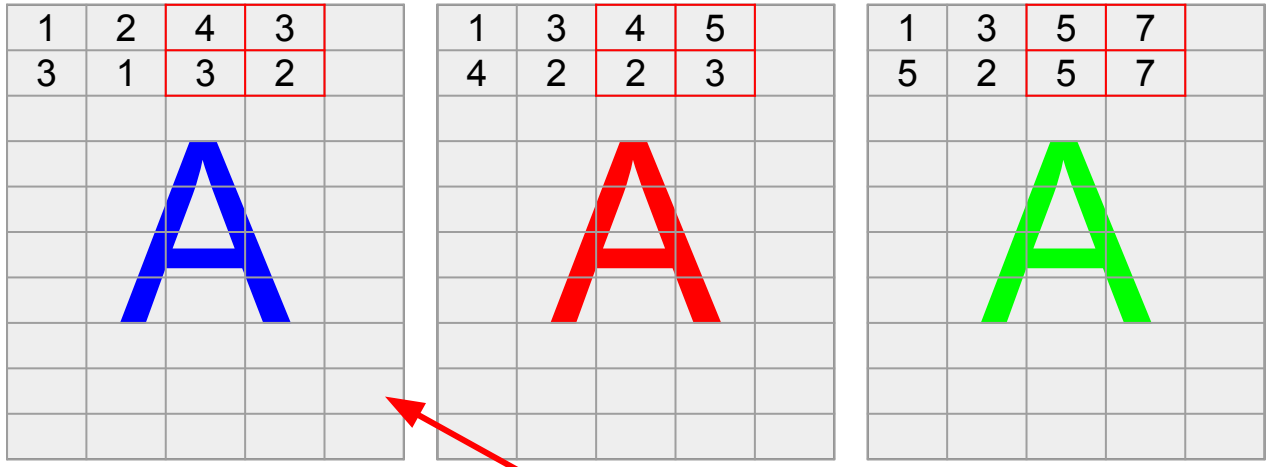




If we apply 5 different filters, we get 5 new activation layers.








These activation layers then become the source images for the next round of the network.

| | | | |
|---|---|---|---|
| 28 | 36 | 50 | 45 |
| 35 | 45 | 15 | 43 |
| 15 | 1 | 65 | 25 |
| 15 | 5 | 38 | 41 |
| 25 | 6 | 78 | 45 |
| 35 | 15 | 15 | 15 |
| 65 | 25 | 35 | 5 |
| 15 | 5 | 68 | 2 |
| 78 | 8 | 97 | 15 |

All Color Filter

| | | | |
|---|---|---|---|
| 28 | 36 | 50 | 45 |
| 35 | 45 | 15 | 43 |
| 15 | 1 | 65 | 25 |
| 15 | 5 | 38 | 41 |
| 25 | 6 | 78 | 45 |
| 35 | 15 | 15 | 15 |
| 65 | 25 | 35 | 5 |
| 15 | 5 | 68 | 2 |
| 78 | 8 | 97 | 15 |

Blue Color Filter

| | | | |
|---|---|---|---|
| 2 | 6 | 50 | 45 |
| 35 | 4 | 15 | 3 |
| 5 | 1 | 5 | 5 |
| 15 | 5 | 38 | 41 |
| 25 | 6 | 78 | 45 |
| 8 | 15 | 4 | 15 |
| 65 | 25 | 35 | 5 |
| 15 | 5 | 3 | 2 |
| 78 | 8 | 97 | 15 |

Red Color Filter

| | | | |
|---|---|---|---|
| 1 | 36 | 50 | 45 |
| 25 | 4 | 15 | 43 |
| 44 | 1 | 65 | 25 |
| 9 | 5 | 0 | 41 |
| 25 | 6 | 6 | 4 |
| 75 | 10 | 15 | 15 |
| 65 | 25 | 35 | 5 |
| 15 | 5 | 68 | 20 |
| 78 | 8 | 97 | 15 |

Green Color Filter

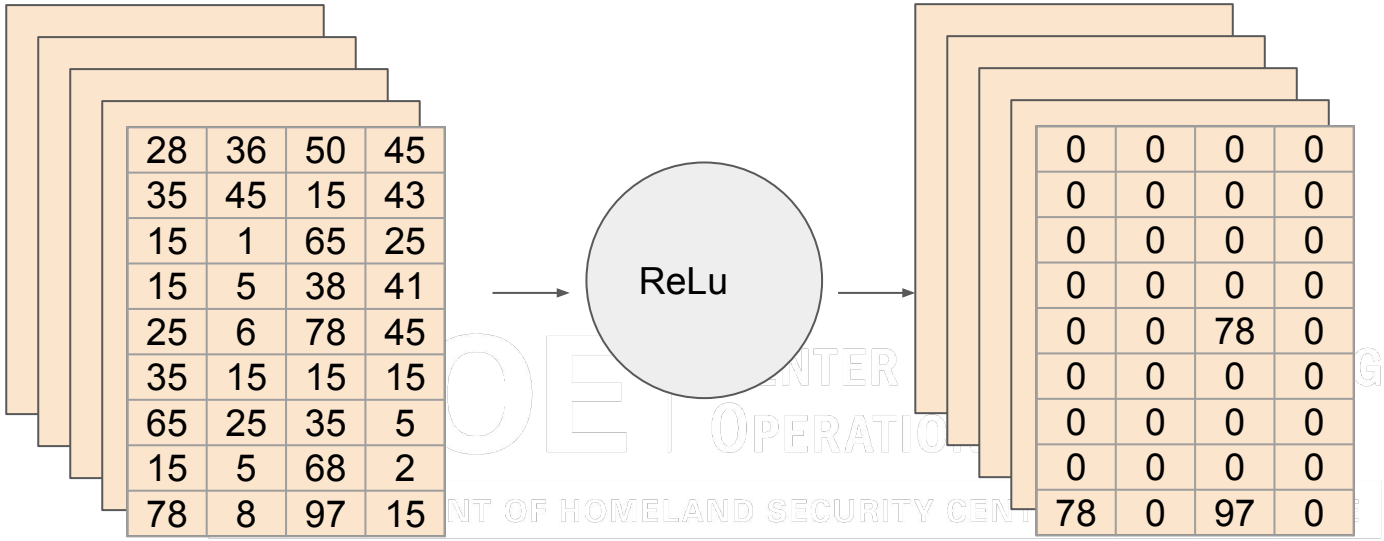
| | | | |
|---|---|---|---|
| 3 | 16 | 0 | 45 |
| 7 | 6 | 1 | 4 |
| 85 | 8 | 5 | 25 |
| 95 | 5 | 8 | 41 |
| 12 | 6 | 8 | 45 |
| 45 | 15 | 15 | 15 |
| 35 | 25 | 35 | 5 |
| 85 | 5 | 8 | 2 |
| 78 | 8 | 97 | 15 |

Green + Blue

| | | | |
|---|---|---|---|
| 28 | 36 | 50 | 45 |
| 35 | 45 | 15 | 43 |
| 15 | 1 | 65 | 25 |
| 15 | 5 | 38 | 41 |
| 25 | 6 | 78 | 45 |
| 35 | 15 | 15 | 15 |
| 65 | 25 | 35 | 5 |
| 15 | 5 | 68 | 2 |
| 78 | 8 | 97 | 15 |

These activation layers - after passing through the neurons - then become the source images for the next round of the network.

| | | |
|---|---|---|
| 433 | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |
| | | |


28 36 50 45
35 45 15 43
15 1 65 25
15 5 38 41
25 6 78 45
35 15 15 15
65 25 35 5
15 5 68 2
78 8 97 15
ReLu
0 0 0 0
0 0 0 0
0 0 0 0
0 0 0 0
0 0 78 0
0 0 0 0
0 0 0 0
0 0 0 0
78 0 97 0

# Pooling

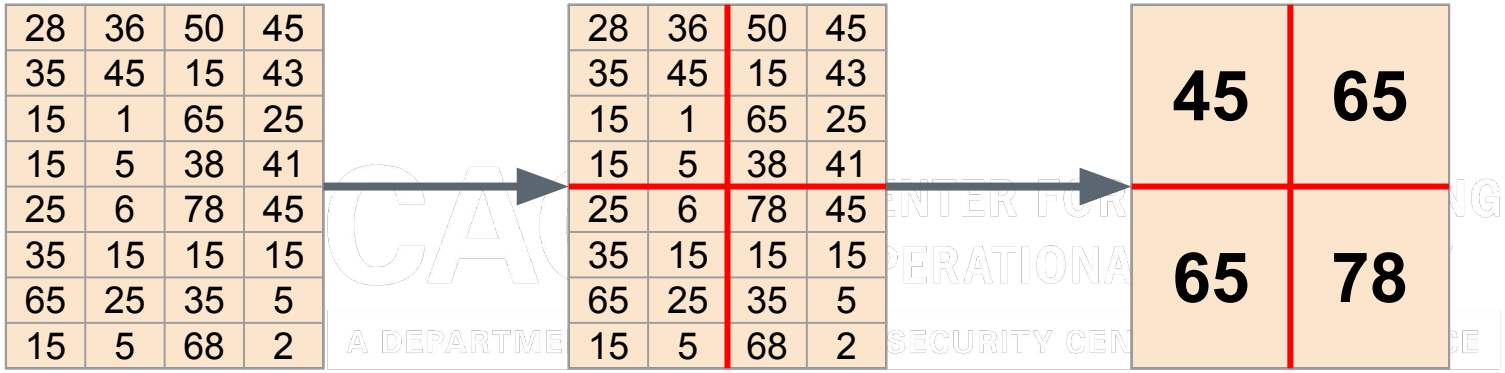
| | | | |
|---|---|---|---|
| 28 | 36 | 50 | 45 |
| 35 | 45 | 15 | 43 |
| 15 | 1 | 65 | 25 |
| 15 | 5 | 38 | 41 |
| 25 | 6 | 78 | 45 |
| 35 | 15 | 15 | 15 |
| 65 | 25 | 35 | 5 |
| 15 | 5 | 68 | 2 |

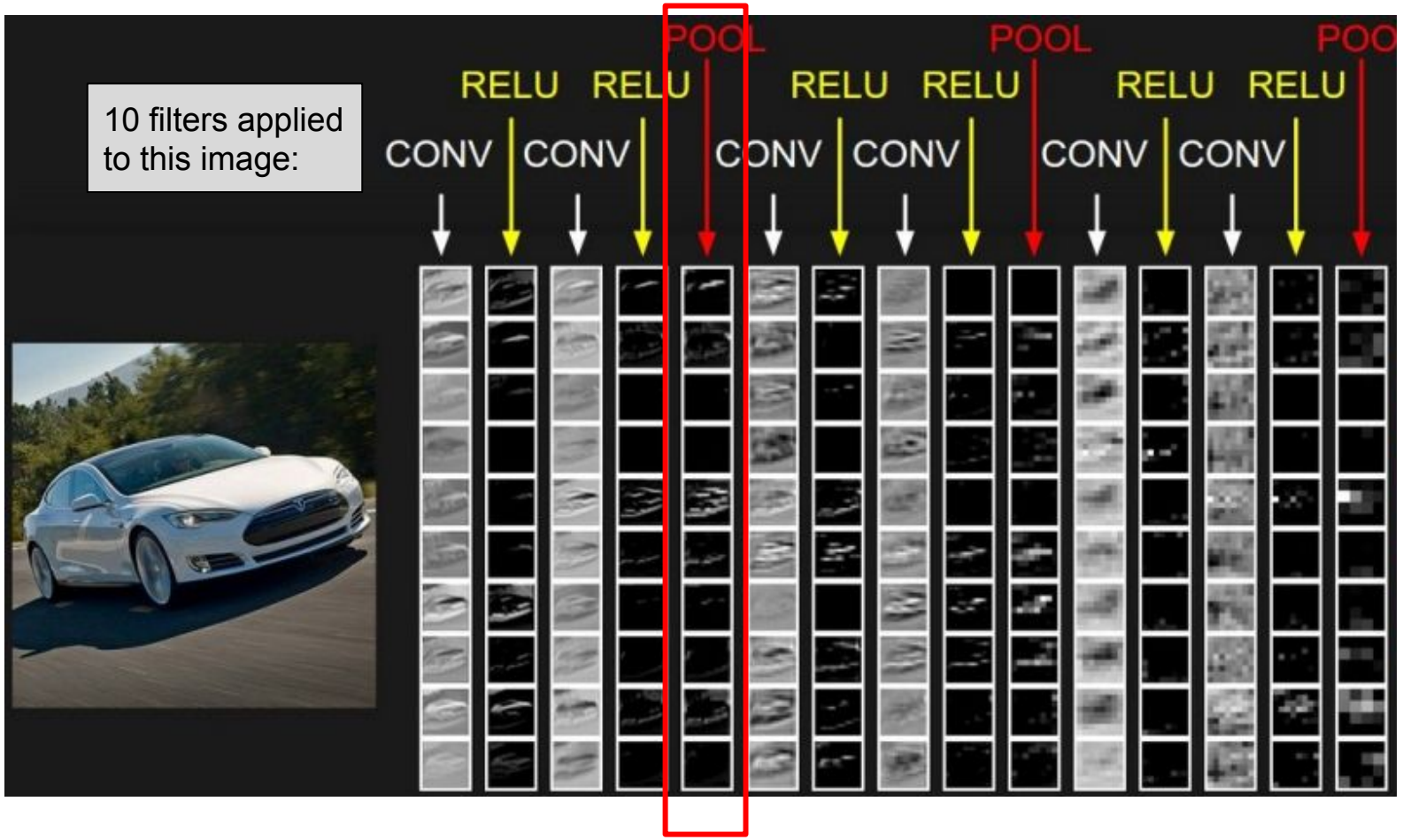
# Pooling

| | | | |
|---|---|---|---|
| 28 | 36 | 50 | 45 |
| 35 | 45 | 15 | 43 |
| 15 | 1 | 65 | 25 |
| 15 | 5 | 38 | 41 |
| 25 | 6 | 78 | 45 |
| 35 | 15 | 15 | 15 |
| 65 | 25 | 35 | 5 |
| 15 | 5 | 68 | 2 |

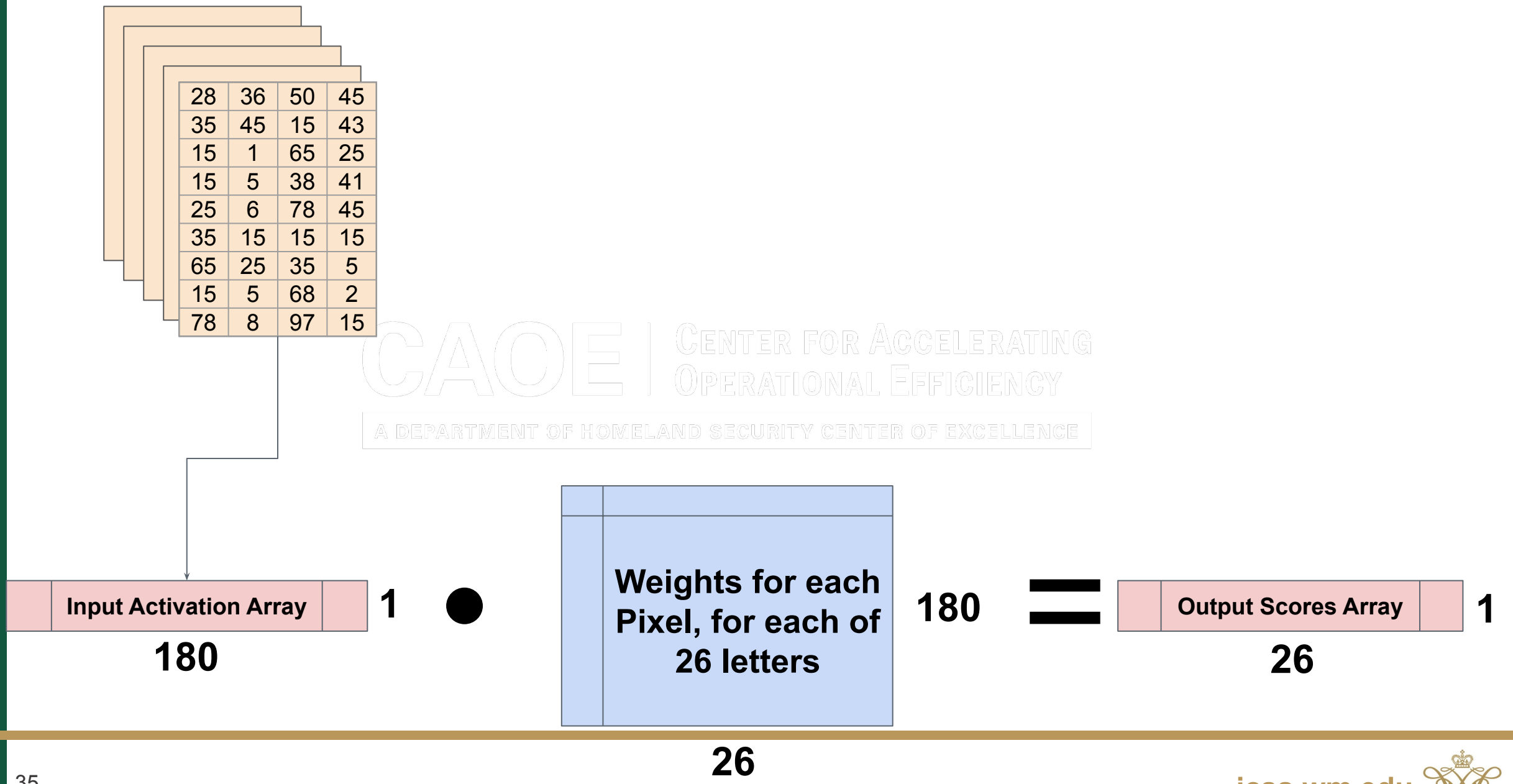
| | | | |
|---|---|---|---|
| 28 | 36 | 50 | 45 |
| 35 | 45 | 15 | 43 |
| 15 | 1 | 65 | 25 |
| 15 | 5 | 38 | 41 |
| 25 | 6 | 78 | 45 |
| 35 | 15 | 15 | 15 |
| 65 | 25 | 35 | 5 |
| 15 | 5 | 68 | 2 |

# Pooling

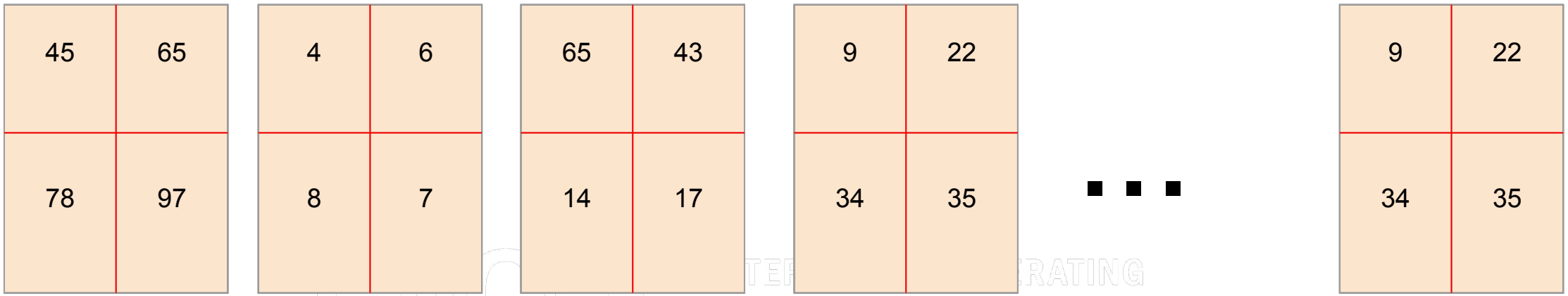

28 36 50 45
35 45 15 43
15 1 65 25
15 5 38 41
25 6 78 45
35 15 15 15
65 25 35 5
15 5 68 2
45 65
65 78




Fe-Fei Li, Andrej Karpathy, Justin Johnson



# Fully Connected Layer



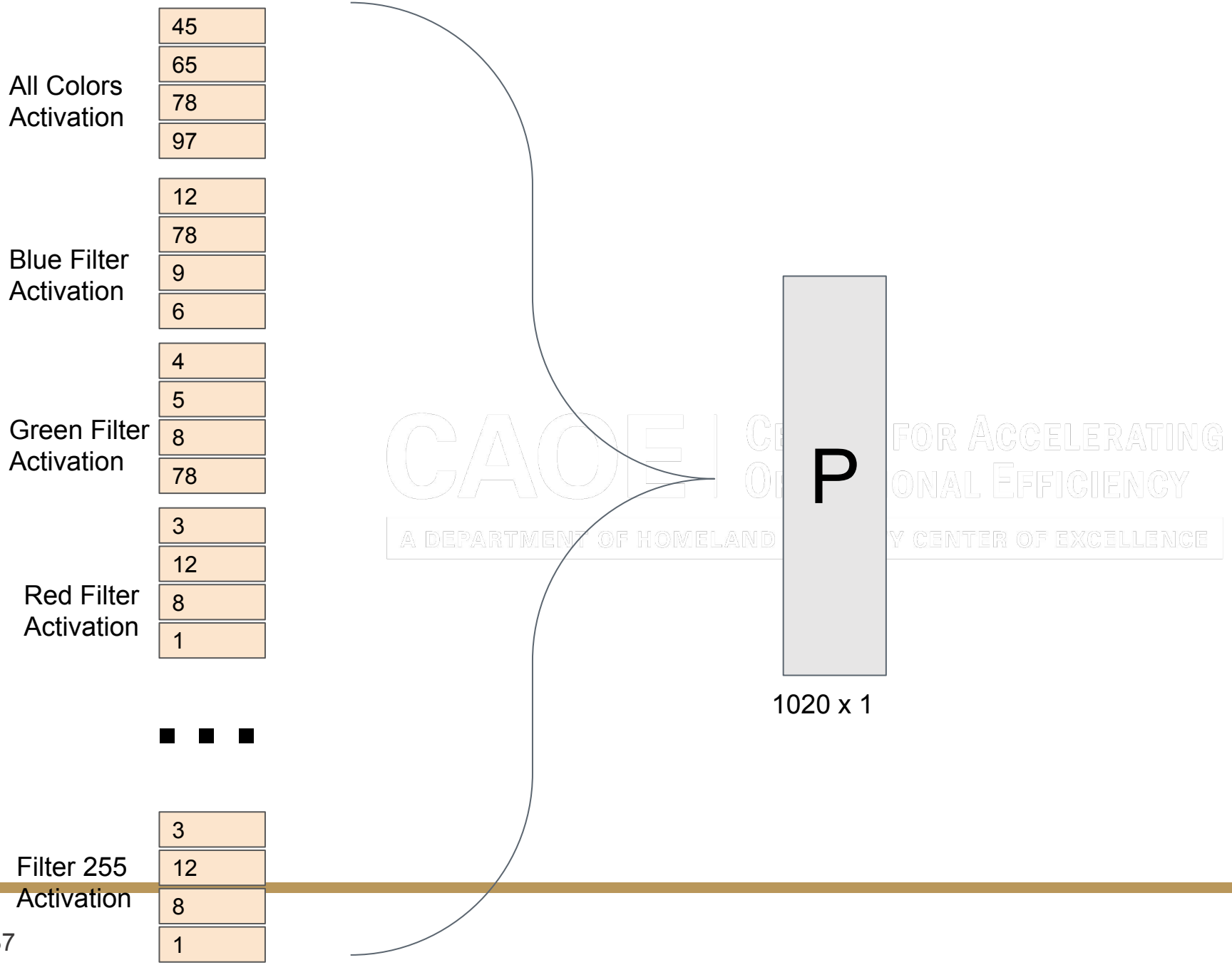

All Colors Activation

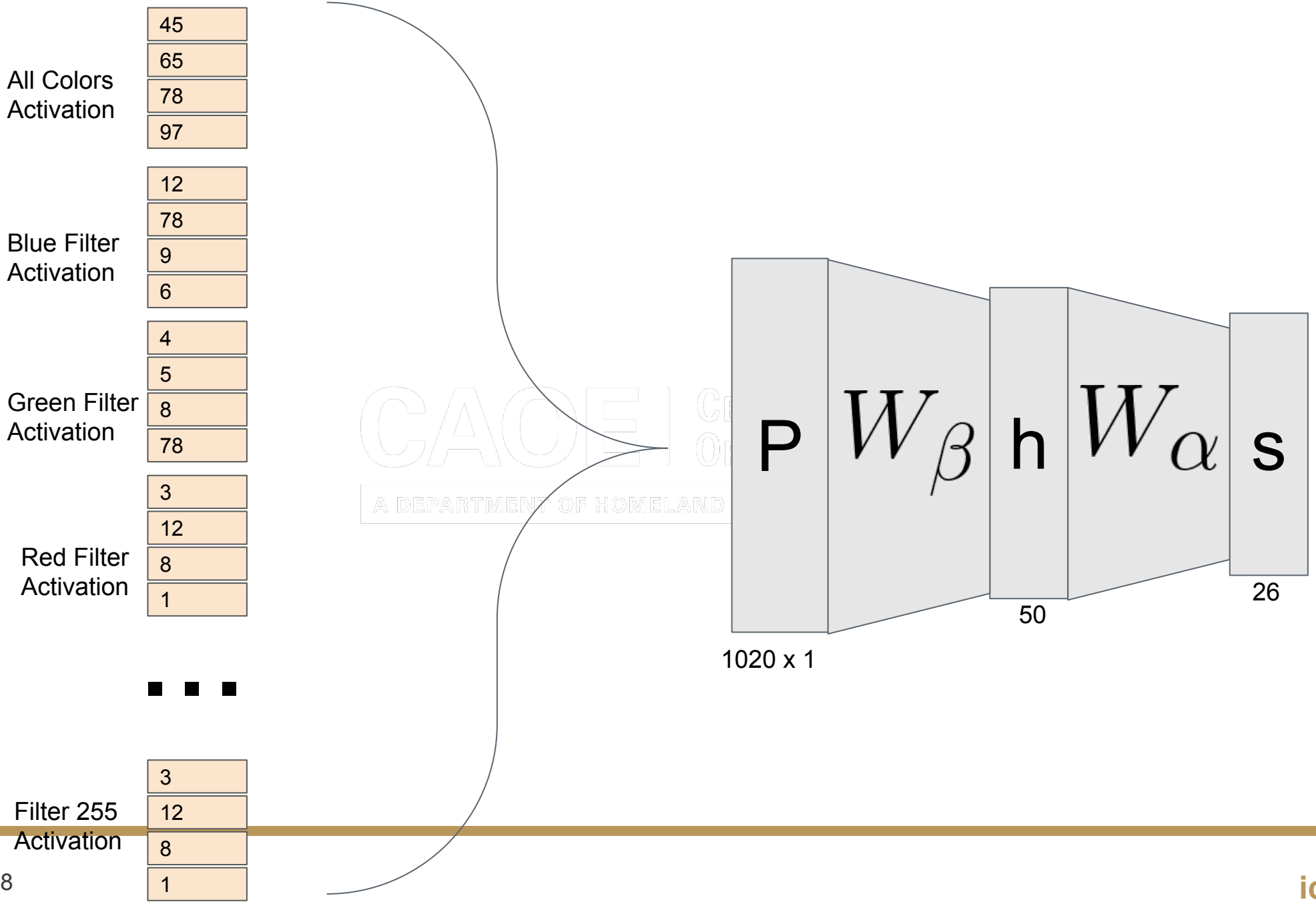
Blue Filter Activation

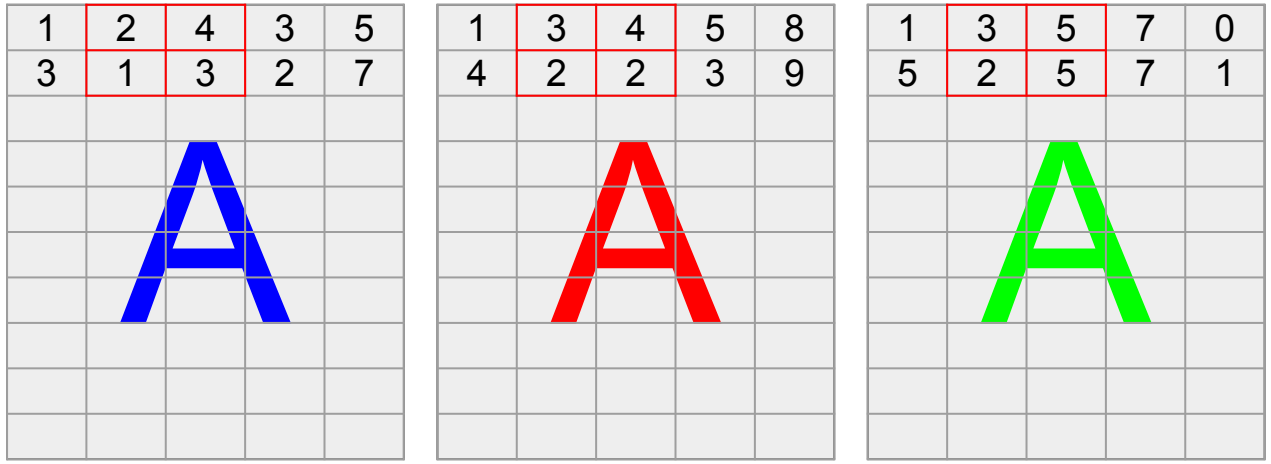
Green Filter Activation

Red Filter Activation

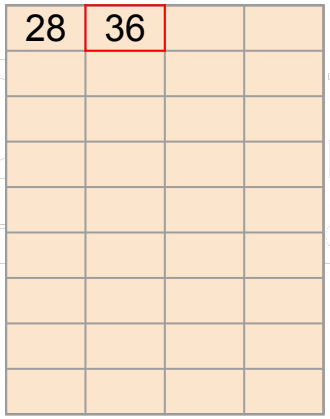
Filter 255 Activation

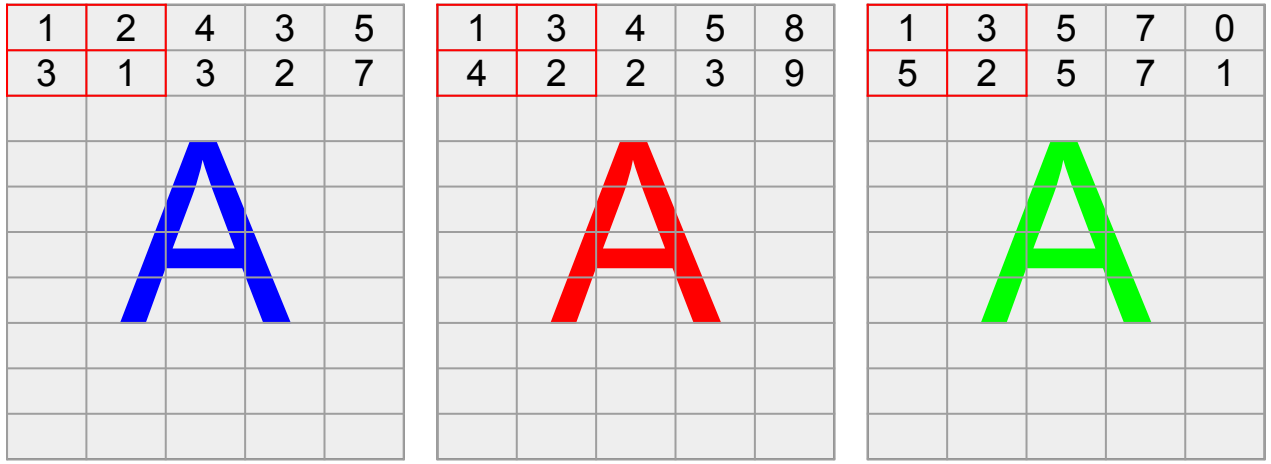




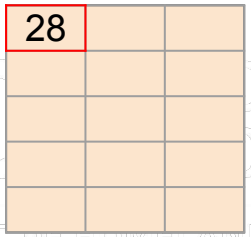


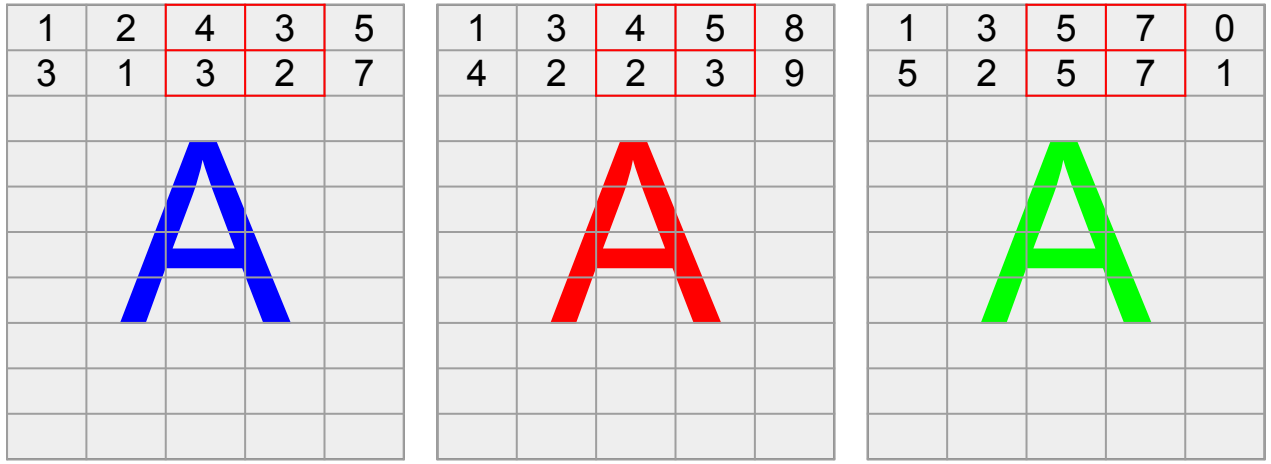

This example is an example where stride = 1 (i.e., we always shift one cell during our convolutions).



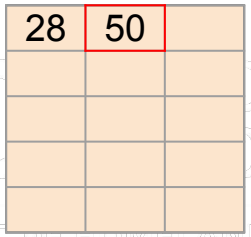


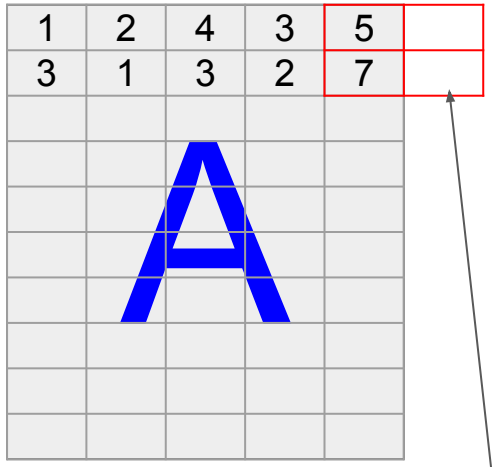

Stride = 2 behaves like this.

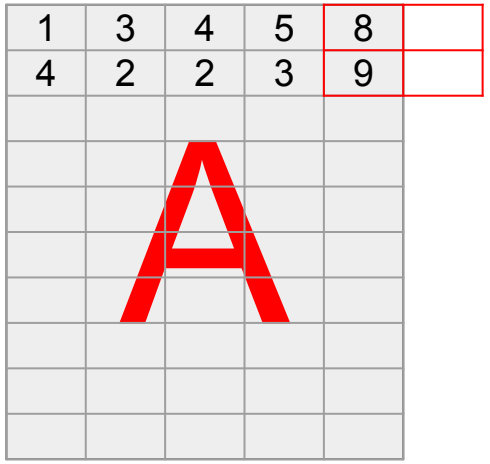


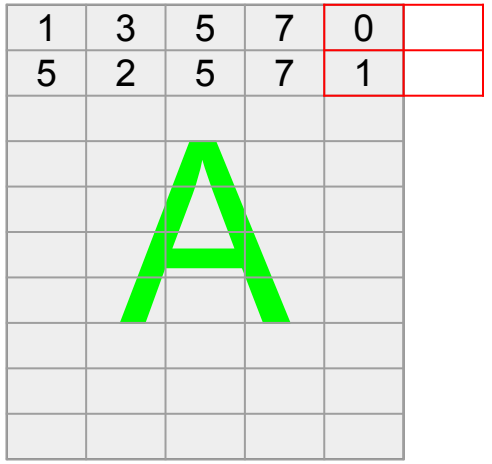


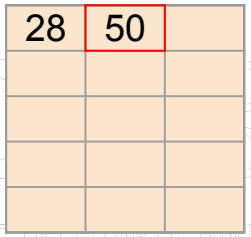

Stride = 2 behaves like this.





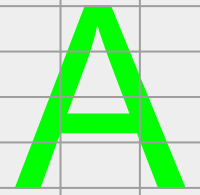




In stride=2, the box 3 runs out of space - there are no values.

| 1 | 2 | 4 | 3 | 5 | 0 |
|---|---|---|---|---|---|
| 3 | 1 | 3 | 2 | 7 | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |

| 1 | 3 | 4 | 5 | 8 | 0 |
|---|---|---|---|---|---|
| 4 | 2 | 2 | 3 | 9 | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |

| 1 | 3 | 5 | 7 | 0 | 0 |
|---|---|---|---|---|---|
| 5 | 2 | 5 | 7 | 1 | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |
| | | | | | 0 |



Zero padding is frequently used to ensure strides fit within the images, given the filter size.

| 28 | 50 | 30 |
|---|---|---|
| | | |
| | | |
| | | |
| | | |

# Summary

Convolutional Layers

- Input Image with a Width, Height and Depth (Colors)
- Four Choices (Hyperparameters)
  - Number of Filters
  - Filter Dimensions
  - Stride
  - Zero Padding
- Generally strung together interspersed with computational (i.e., reLu) and pooling layers.