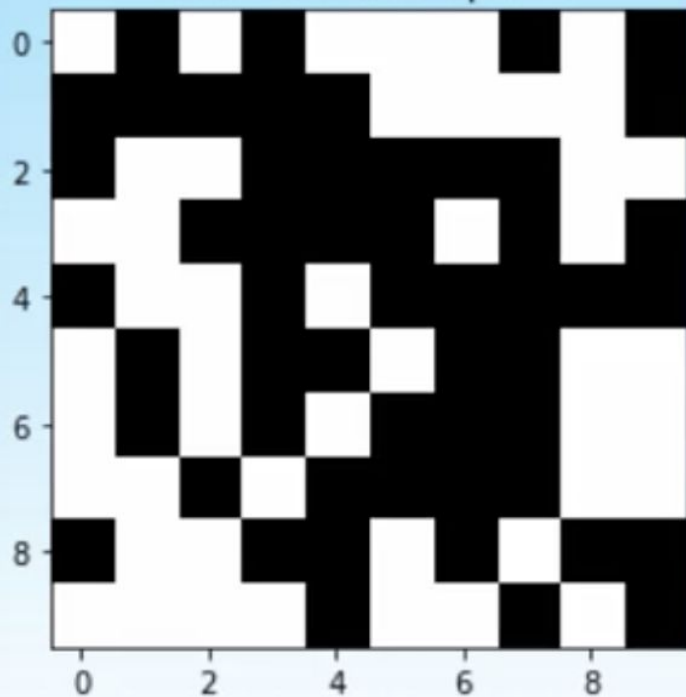


Convolutional Neural Networks



BLACK AND WHITE

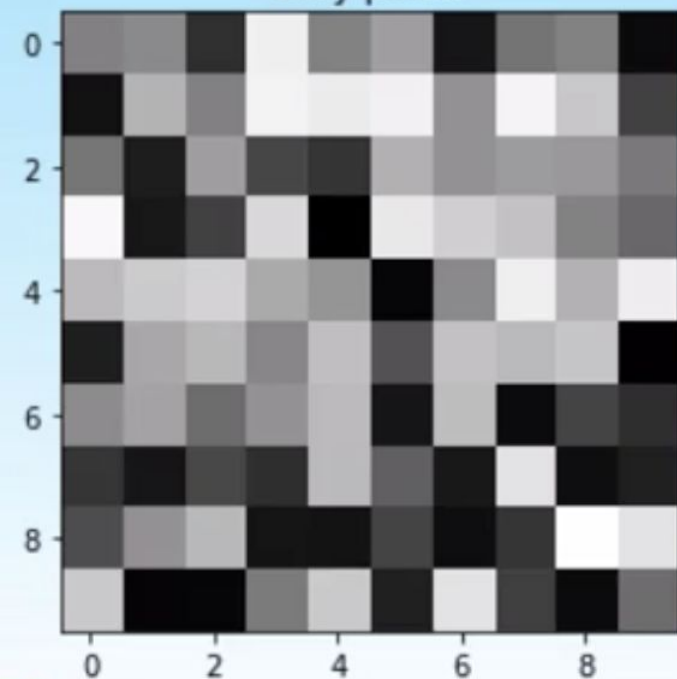
Black and White pixels



```
array([[1, 0, 1, 0, 1, 1, 1, 0, 1, 0],  
       [0, 0, 0, 0, 0, 1, 1, 1, 1, 0],  
       [0, 1, 1, 0, 0, 0, 0, 0, 0, 1],  
       [1, 1, 0, 0, 0, 0, 1, 0, 1, 0],  
       [0, 1, 1, 0, 1, 0, 0, 0, 0, 0],  
       [1, 0, 1, 0, 0, 1, 0, 0, 1, 1],  
       [1, 0, 1, 0, 1, 0, 0, 0, 1, 1],  
       [1, 1, 0, 1, 0, 0, 0, 0, 1, 1],  
       [0, 1, 1, 0, 0, 1, 0, 1, 0, 0],  
       [1, 1, 1, 1, 0, 1, 1, 0, 1, 0]])
```

GRAYSCALE

Grey pixels



```
array([[127, 136, 48, 234, 128, 155, 24, 114, 128, 12],  
       [ 18, 177, 127, 239, 230, 236, 145, 240, 195, 65],  
       [116, 29, 155, 70, 51, 174, 144, 153, 149, 120],  
       [243, 26, 66, 213, 1, 227, 203, 191, 128, 105],  
       [183, 199, 207, 167, 146, 7, 136, 234, 175, 232],  
       [ 31, 166, 180, 133, 187, 82, 192, 182, 194, 2],  
       [139, 161, 108, 144, 183, 23, 185, 12, 67, 47],  
       [ 53, 24, 72, 46, 182, 94, 25, 221, 16, 34],  
       [ 76, 144, 181, 22, 21, 67, 16, 53, 250, 222],  
       [197, 6, 7, 122, 198, 34, 222, 64, 12, 108]])
```

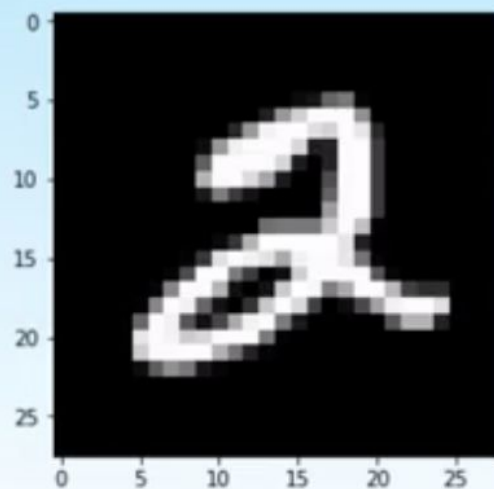
MNIST



5 0 4 1

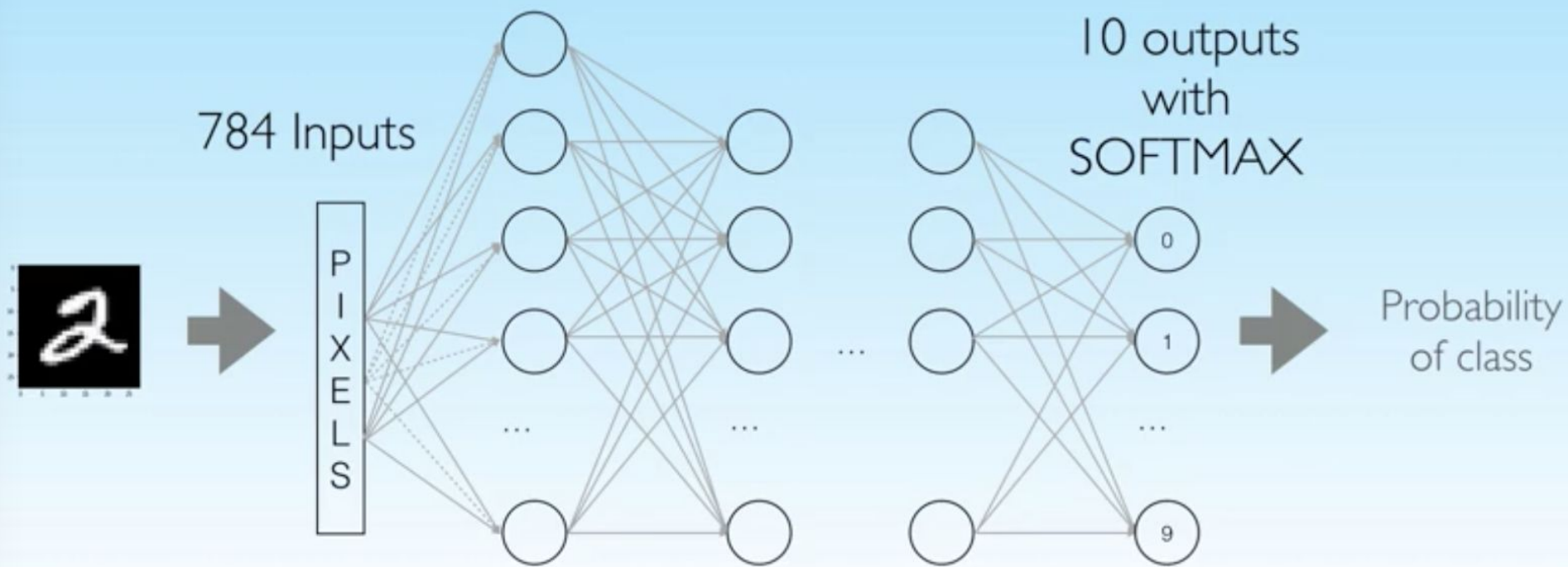
MNIST

.5.5 | 00000000000000000000000000000000 | 1000000.5.5 | 0000000000



28 x 28 image => 784 input pixels array

FULLY CONNECTED



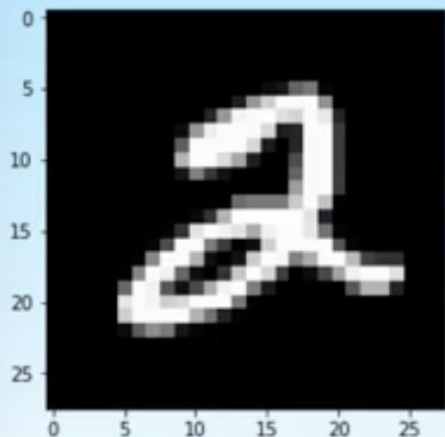


Fully connected NN

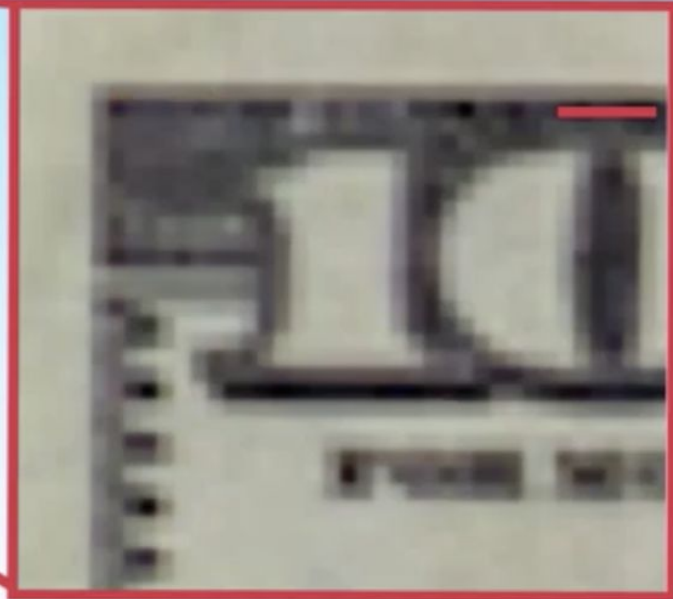
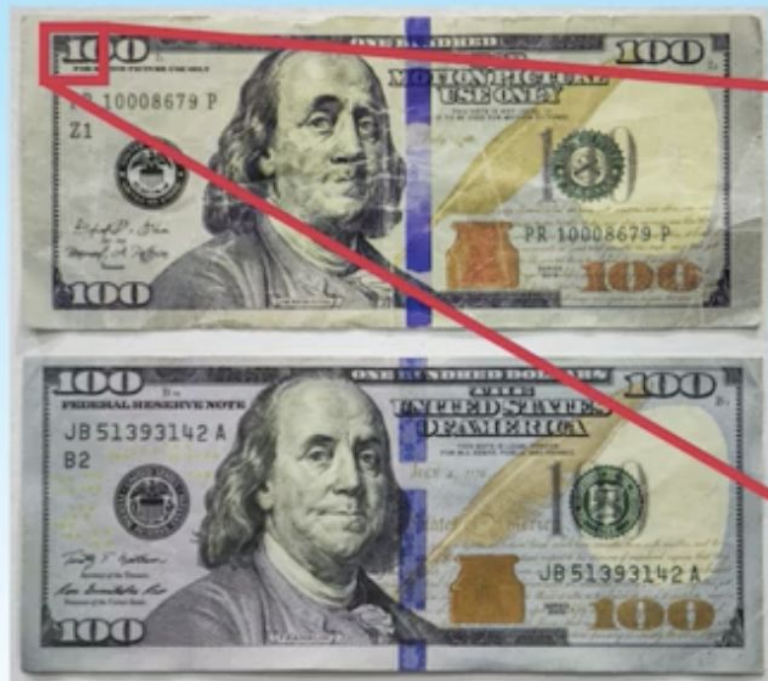
FEATURES

Feature Vector

- Fourier coefficients
- Wavelets
- Histogram of Oriented Gradients (HOG)
- Speeded Up Robust Features (SURF)
- Local Binary Patterns (LBP)
- Color histograms
- ...



LOCAL PATTERNS





The importance of vision for humans



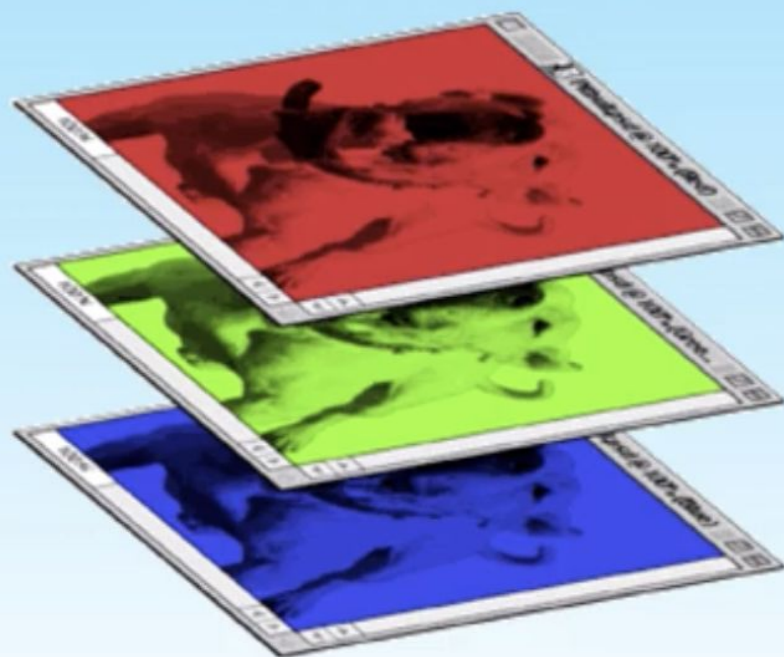
Image to Tensors

TENSORS

| Order | Name | Example | Shape |
|-------|--------|---|-----------|
| 0 | Scalar | 3 | no shape |
| 1 | Vector | [4, 5, 0, 3, 1, 4, 5] | (7,) |
| 2 | Matrix | $\begin{bmatrix} 0 & 1 & 0 \\ 5 & 0 & 2 \end{bmatrix}$ | (2, 3) |
| 3 | Tensor | $\begin{bmatrix} [0, 1, 0, 5], \\ [5, 0, 2, 6], \\ [1, 2, 4, 4], \\ [8, 3, 1, 9] \end{bmatrix}$ | (2, 2, 4) |



COLORED IMAGES



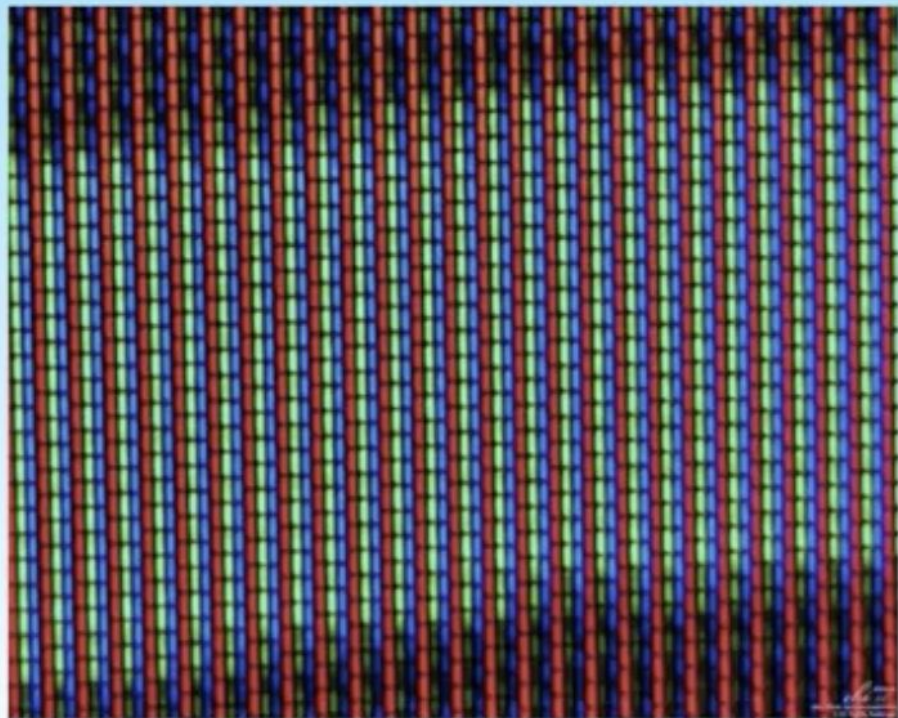
Red Channel

Green Channel

Blue Channel

(C, H, W)

COLORED IMAGES



(C, H, W)

(H, W, C)



Code

Github - [tensor_math.ipynb](#)

DISCRETE CONVOLUTION



DISCRETE CONVOLUTION





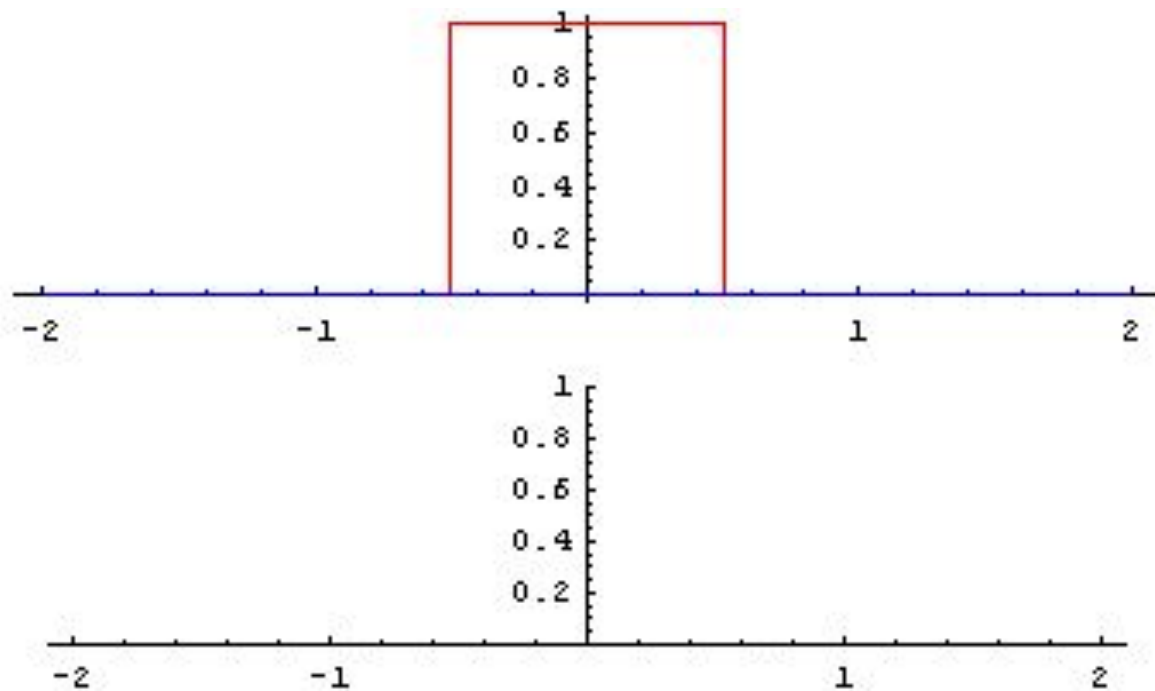
Definition

Convolution of f and g at position n is the sum of products between M and $-M$ of f at $n - m$ and g of m

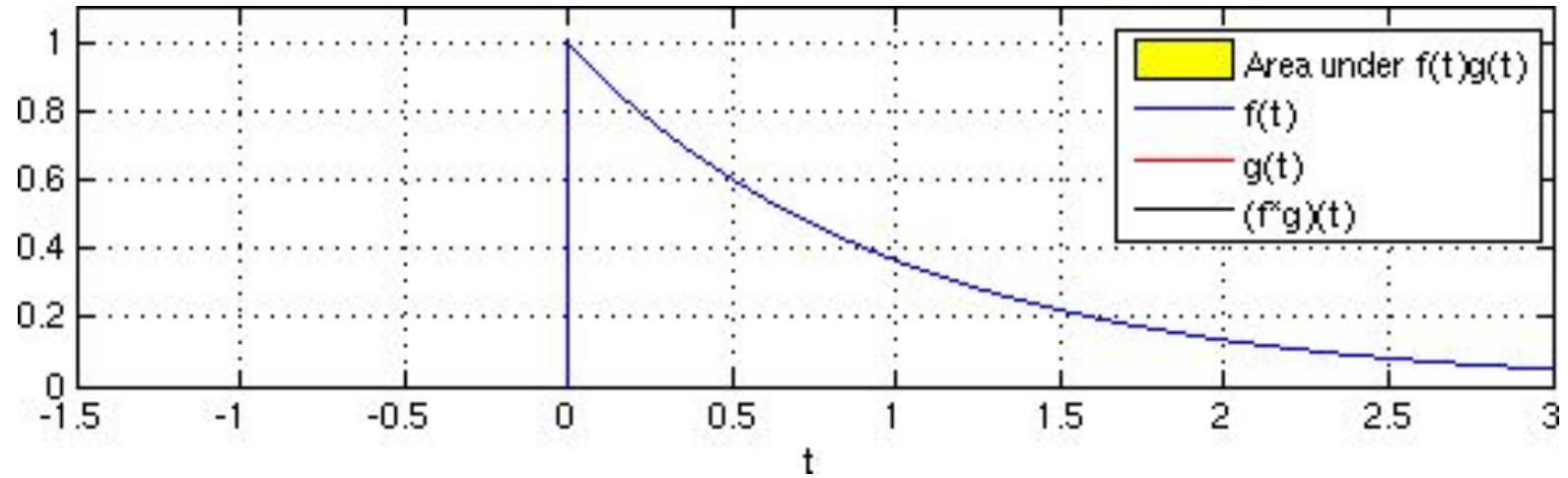
$$(f * g)[n] = \sum_{m=-M}^M f[n - m]g[m]$$



Visualize



Another Example





code

Github - convolutions.ipynb



2 D convolution

2D CONV

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

1

\times

1

$= 1$

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

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

$1+1+1+1+1+1+1+1$

2D CONV

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

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

$$\frac{1+1+1+1+1+1+1+1+1}{9} = 1$$

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

A diagram showing a green square on a grid. The square is labeled with the number 1, indicating the first iteration of a process.

2 D CONV

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

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

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



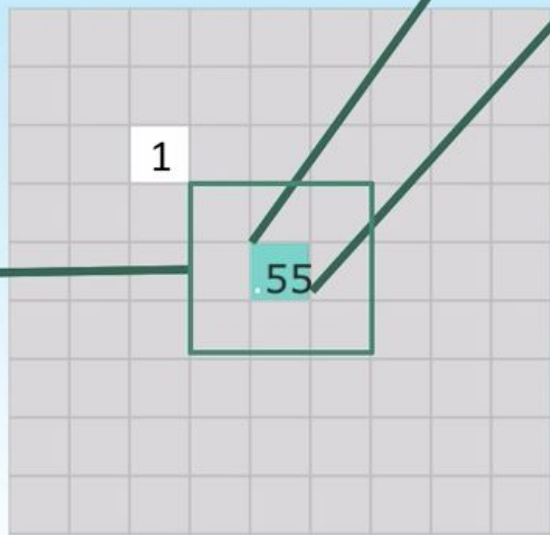
2D CONV

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

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

$$\frac{1+1-1+1+1+1-1+1+1}{9} = 0.55$$

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



2 D CONV

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

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



| | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|
| 0.77 | -0.11 | 0.11 | 0.33 | 0.55 | -0.11 | 0.33 |
| -0.11 | 1.00 | -0.11 | 0.33 | -0.11 | 0.11 | -0.11 |
| 0.11 | -0.11 | 1.00 | -0.33 | 0.11 | -0.11 | 0.55 |
| 0.33 | 0.33 | -0.33 | 0.55 | -0.33 | 0.33 | 0.33 |
| 0.55 | -0.11 | 0.11 | -0.33 | 1.00 | -0.11 | 0.11 |
| -0.11 | 0.11 | -0.11 | 0.33 | -0.11 | 1.00 | -0.11 |
| 0.33 | -0.11 | 0.55 | 0.33 | 0.11 | -0.11 | 0.77 |





Code

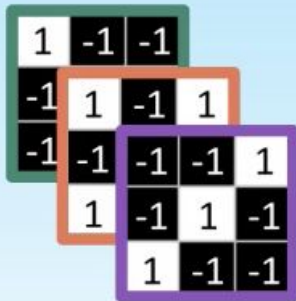
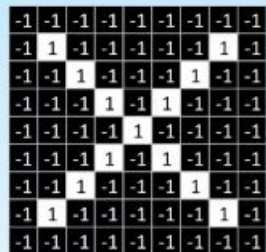
convolutions2d.ipynb



CNNs

- Convolutional Layer
- Convolution of tensors
- Strides and Padding

CONVOLUTION LAYER



Number of Filters



Output Channels



INPUT TENSOR

Input: order 4 tensor

(N, H, W, C)

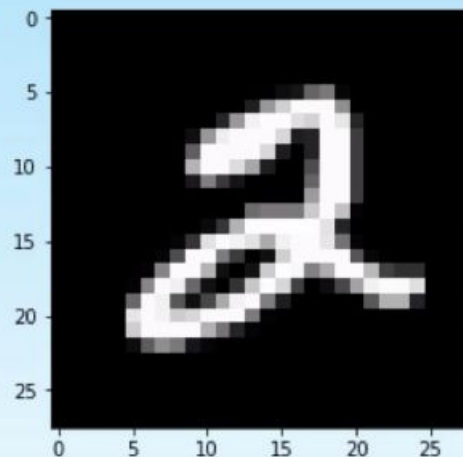
N: Number of images

H: Height of image

W: Width of image

C: Number of color channels

MNIST training set



(60000, 28, 28, 1)



CONV LAYER TENSOR

Example

CONV: order 4 tensor

(H_f, W_f, C_i, C_o)

H_f : Height of filter patch

W_f : Width of filter patch

C_i : Channels in input

C_o : Channels in output (# filters)

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

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

$(3, 3, 1, 2)$

CONV LAYER

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



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



| | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|
| 0.77 | -0.11 | 0.11 | 0.33 | 0.55 | -0.11 | 0.33 |
| -0.11 | 0.33 | -0.55 | 0.11 | -0.11 | 0.11 | -0.55 |
| 0.11 | -0.55 | 0.55 | -0.55 | 0.33 | -0.55 | 0.55 |
| 0.33 | 0.11 | -0.55 | 0.55 | -0.77 | 0.55 | -0.55 |
| 0.55 | -0.11 | 0.33 | -0.77 | 1.00 | -0.77 | 0.33 |
| -0.11 | 0.11 | -0.55 | 0.55 | -0.77 | 0.55 | -0.55 |
| 0.33 | -0.55 | 0.55 | -0.55 | 0.33 | -0.55 | 0.55 |
| 0.33 | -0.55 | 0.11 | -0.11 | 0.11 | -0.55 | 0.33 |

Examples, H, W, inp channels

(-, 9, 9, 1)

(3, 3, 1, 2)

examples, H, W, out channels

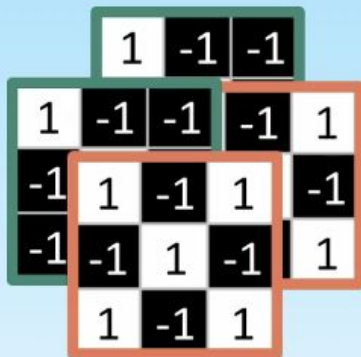
(-, 7, 7, 2)

H, W, inp channels , # filters, out channels



Since output is order 4, we can keep going

| | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|
| 0.77 | -0.11 | 0.11 | 0.33 | 0.55 | -0.11 | 0.33 | |
| -0.11 | 0.33 | -0.55 | 0.11 | -0.11 | 0.11 | -0.55 | 0.33 |
| 0.11 | -0.55 | 0.55 | -0.55 | 0.33 | -0.55 | 0.55 | -0.55 |
| 0.33 | 0.11 | -0.55 | 0.55 | -0.77 | 0.55 | -0.55 | 0.11 |
| 0.55 | -0.11 | 0.33 | -0.77 | 1.00 | -0.77 | 0.33 | -0.11 |
| -0.11 | 0.11 | -0.55 | 0.55 | -0.77 | 0.55 | -0.55 | 0.11 |
| 0.33 | -0.55 | 0.55 | -0.55 | 0.33 | -0.55 | 0.55 | -0.55 |
| | 0.33 | -0.55 | 0.11 | -0.11 | 0.11 | -0.55 | 0.33 |



| | | | | | |
|-------|-------|-------|-------|-------|-------|
| 1.00 | -0.11 | 0.33 | -0.11 | 0.11 | |
| -0.11 | 0.55 | -0.55 | 0.33 | -0.55 | 0.55 |
| 0.33 | -0.55 | 0.55 | -0.77 | 0.55 | -0.55 |
| -0.11 | 0.33 | -0.77 | 1.00 | -0.77 | 0.33 |
| 0.11 | -0.55 | 0.55 | -0.77 | 0.55 | -0.55 |
| | 0.55 | -0.55 | 0.33 | -0.55 | 0.55 |

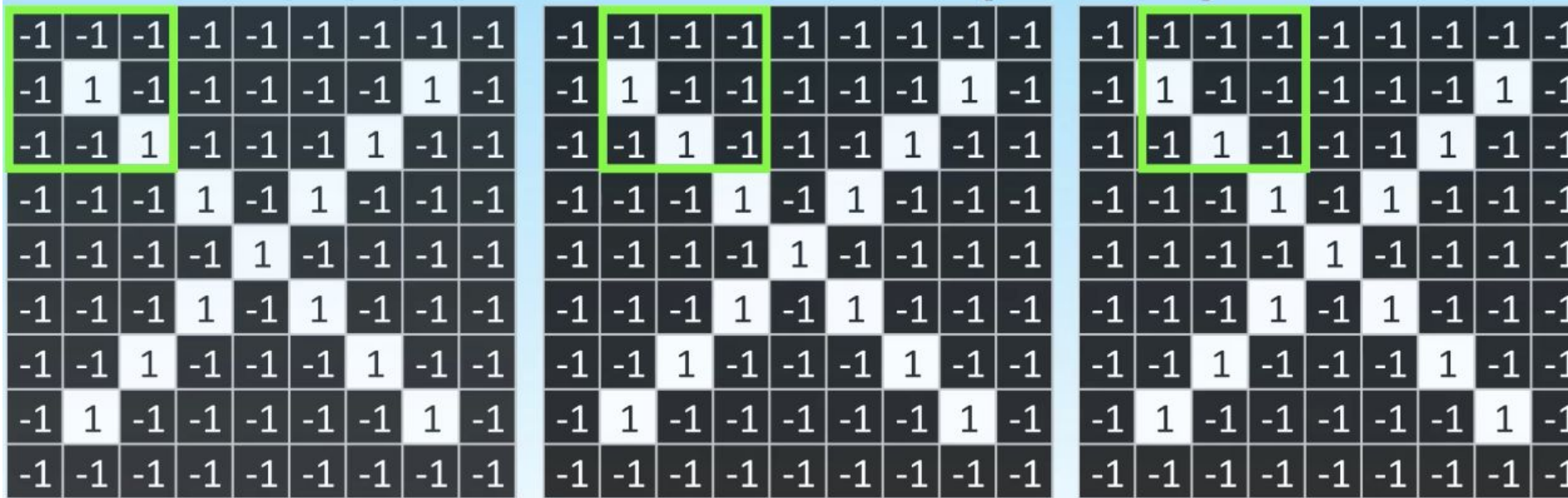
Match channels

(-, 7, 7, **2**)

(3, 3, **2**, 2)

(-, 5, 5, 2)

STRIDES: (1, 1)



Output image => 7 x 7



STRIDES: (2, 2)



Output image \Rightarrow 4 x 4



STRIDES: (3, 3)

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

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

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

Output image => 3 x 3



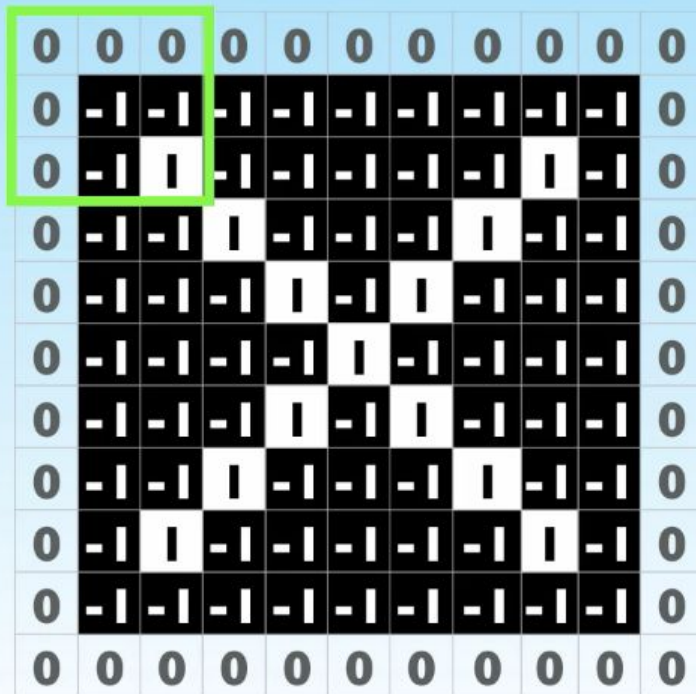
STRIDES: (3, 1)

[illegible]

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

[illegible]

PADDING



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

- Valid
- Same

Output image => 9 x 9



Code

convolutional_layer.ipynb

MAX POOLING

| | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|
| 0.77 | -0.11 | 0.11 | 0.33 | 0.55 | -0.11 | 0.33 |
| -0.11 | 1.00 | -0.11 | 0.33 | -0.11 | 0.11 | -0.11 |
| 0.11 | -0.11 | 1.00 | -0.33 | 0.11 | -0.11 | 0.55 |
| 0.33 | 0.33 | -0.33 | 0.55 | -0.33 | 0.33 | 0.33 |
| 0.55 | -0.11 | 0.11 | -0.33 | 1.00 | -0.11 | 0.11 |
| -0.11 | 0.11 | -0.11 | 0.33 | -0.11 | 1.00 | -0.11 |
| 0.33 | -0.11 | 0.55 | 0.33 | 0.11 | -0.11 | 0.77 |

maximum

| | | | |
|------|--|--|--|
| 1.00 | | | |
| | | | |
| | | | |
| | | | |

MAX POOLING

| | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|
| 0.77 | -0.11 | 0.11 | 0.33 | 0.55 | -0.11 | 0.33 |
| -0.11 | 1.00 | -0.11 | 0.33 | -0.11 | 0.11 | -0.11 |
| 0.11 | -0.11 | 1.00 | -0.33 | 0.11 | -0.11 | 0.55 |
| 0.33 | 0.33 | -0.33 | 0.55 | -0.33 | 0.33 | 0.33 |
| 0.55 | -0.11 | 0.11 | -0.33 | 1.00 | -0.11 | 0.11 |
| -0.11 | 0.11 | -0.11 | 0.33 | -0.11 | 1.00 | -0.11 |
| 0.33 | -0.11 | 0.55 | 0.33 | 0.11 | -0.11 | 0.77 |



| | | | |
|------|------|------|------|
| 1.00 | 0.33 | 0.55 | 0.33 |
| 0.33 | 1.00 | 0.33 | 0.55 |
| 0.55 | 0.33 | 1.00 | 0.11 |
| 0.33 | 0.55 | 0.11 | 0.77 |



POOLING LAYER

| | | | | | | | | | |
|-------|-------|-------|-------|-------|-------|-------|-------|-------|--|
| 0.77 | -0.11 | 0.11 | 0.33 | 0.55 | -0.11 | 0.33 | | | |
| -0.11 | 0.33 | -0.55 | 0.11 | -0.11 | 0.11 | -0.55 | 0.33 | | |
| 0.11 | -0.55 | 0.33 | -0.11 | 0.55 | 0.33 | 0.11 | -0.11 | 0.77 | |
| 0.33 | 0.11 | -0.11 | 0.11 | -0.11 | 0.33 | -0.11 | 1.00 | -0.11 | |
| 0.55 | -0.11 | 0.55 | -0.11 | 0.11 | -0.33 | 1.00 | -0.11 | 0.11 | |
| -0.11 | 0.11 | 0.33 | 0.33 | -0.33 | 0.55 | -0.33 | 0.33 | 0.33 | |
| 0.33 | -0.55 | 0.11 | -0.11 | 1.00 | -0.33 | 0.11 | -0.11 | 0.55 | |
| | 0.33 | -0.11 | 1.00 | -0.11 | 0.33 | -0.11 | 0.11 | -0.11 | |
| | | 0.77 | -0.11 | 0.11 | 0.33 | 0.55 | -0.11 | 0.33 | |



| | | | | | | | | | |
|------|------|------|------|------|------|--|--|--|--|
| 1.00 | 0.33 | 0.55 | 0.33 | | | | | | |
| 0.33 | 0.55 | 0.33 | 0.55 | 0.33 | | | | | |
| 0.55 | 0.33 | 0.33 | 0.55 | 1.00 | 0.77 | | | | |
| 0.33 | 0.55 | 0.55 | 0.55 | 1.00 | 0.33 | | | | |
| | 0.33 | 1.00 | 1.00 | 0.11 | 0.55 | | | | |
| | | 0.77 | 0.33 | 0.55 | 0.33 | | | | |

(-, 7, 7, 3)

Operates on H and W

(-, 4, 4, 3)



Code

Pooling_layer.ipynb



CNN Finally!

STACKING LAYERS

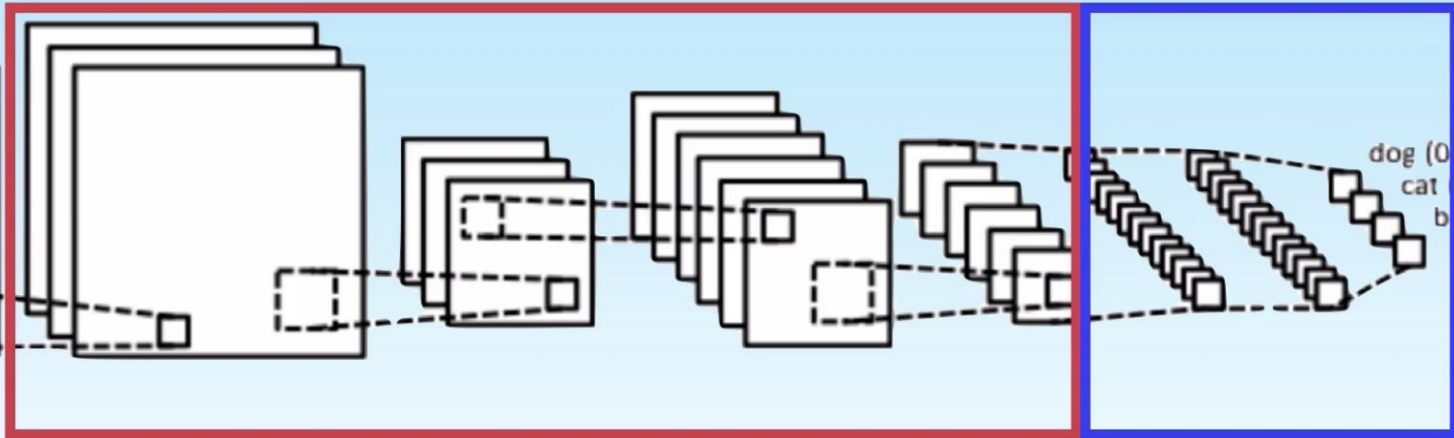
Conv

Pooling

Conv

Pooling

Fully connected

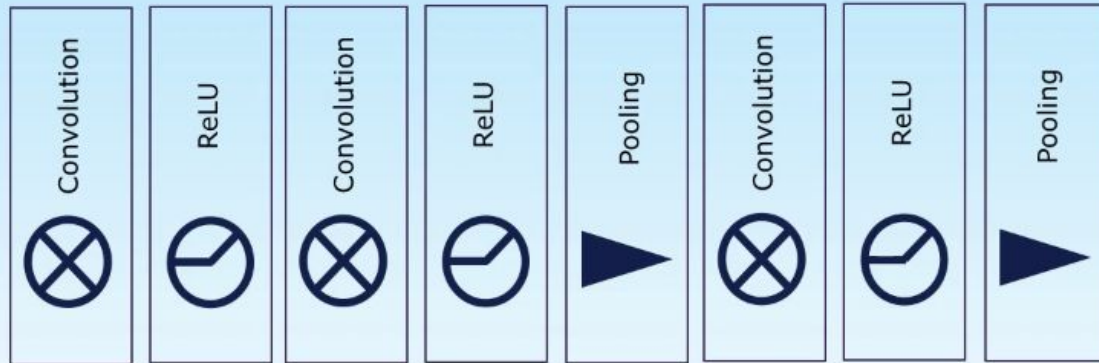


Feature Extraction

Classification

FEATURE EXTRACTION

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

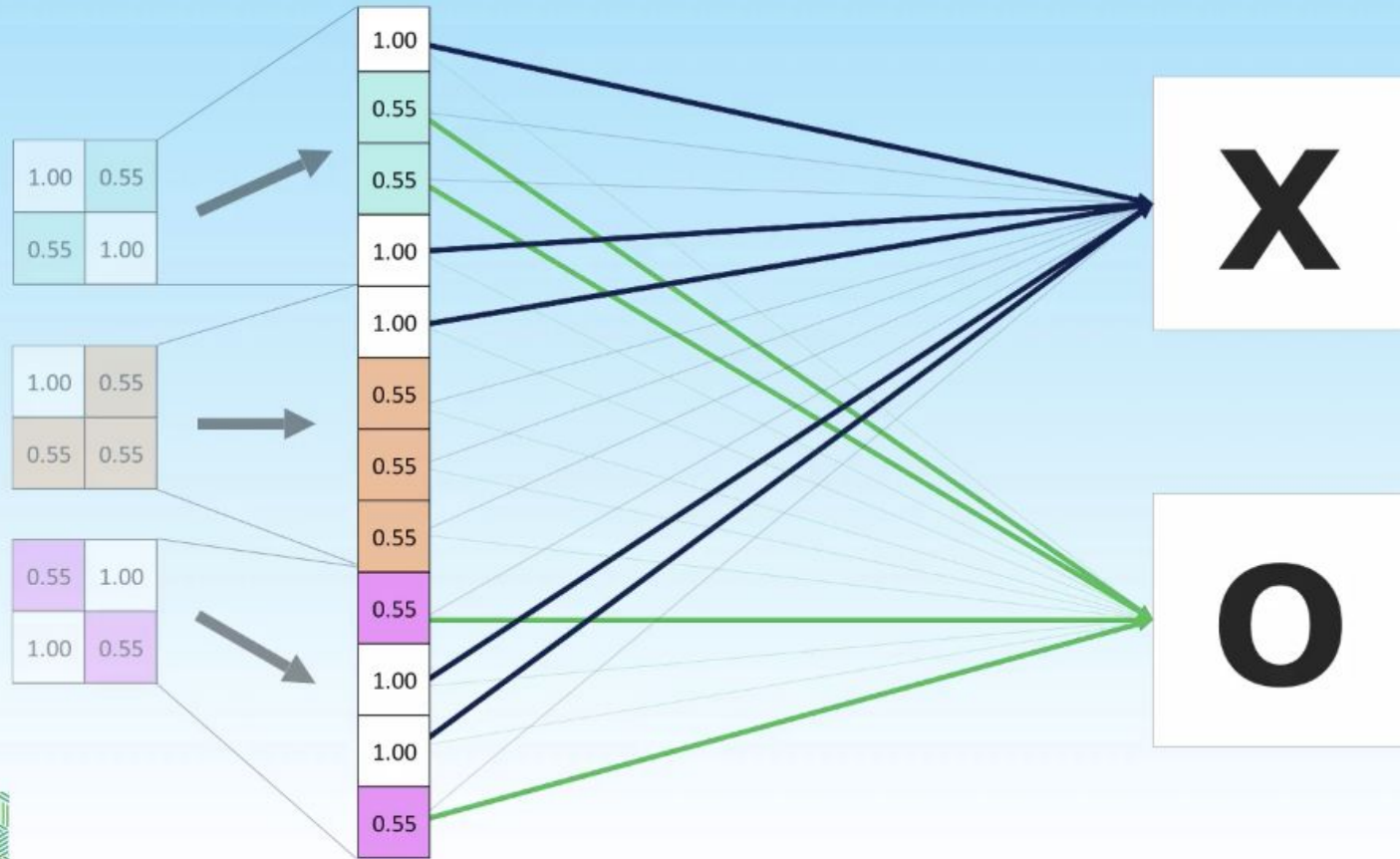


| | |
|------|------|
| 1.00 | 0.55 |
| 0.55 | 1.00 |

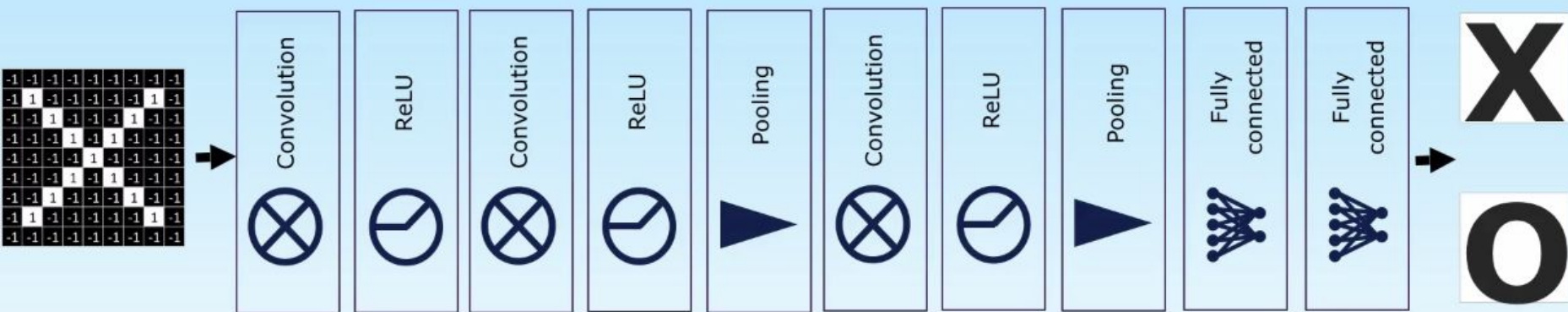
| | |
|------|------|
| 1.00 | 0.55 |
| 0.55 | 0.55 |

| | |
|------|------|
| 0.55 | 1.00 |
| 1.00 | 0.55 |

FULLY CONNECTED LAYER



ALL TOGETHER





Code

CNN.ipynb