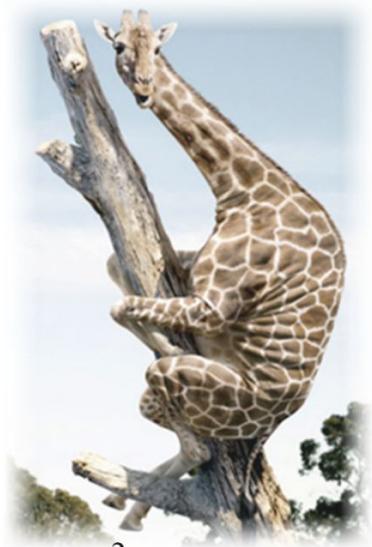

Convolutional Neural Networks

The importance of vision for humans

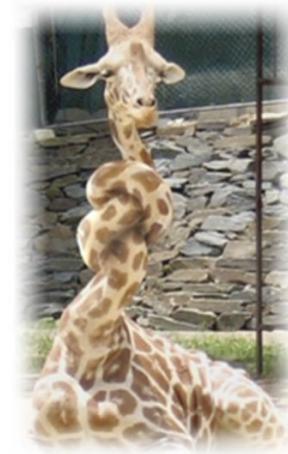
Change Blindness

https://www.youtube.com/watch?time_continue=6&v=Lbvl9e4C39g

Describe a Giraffe

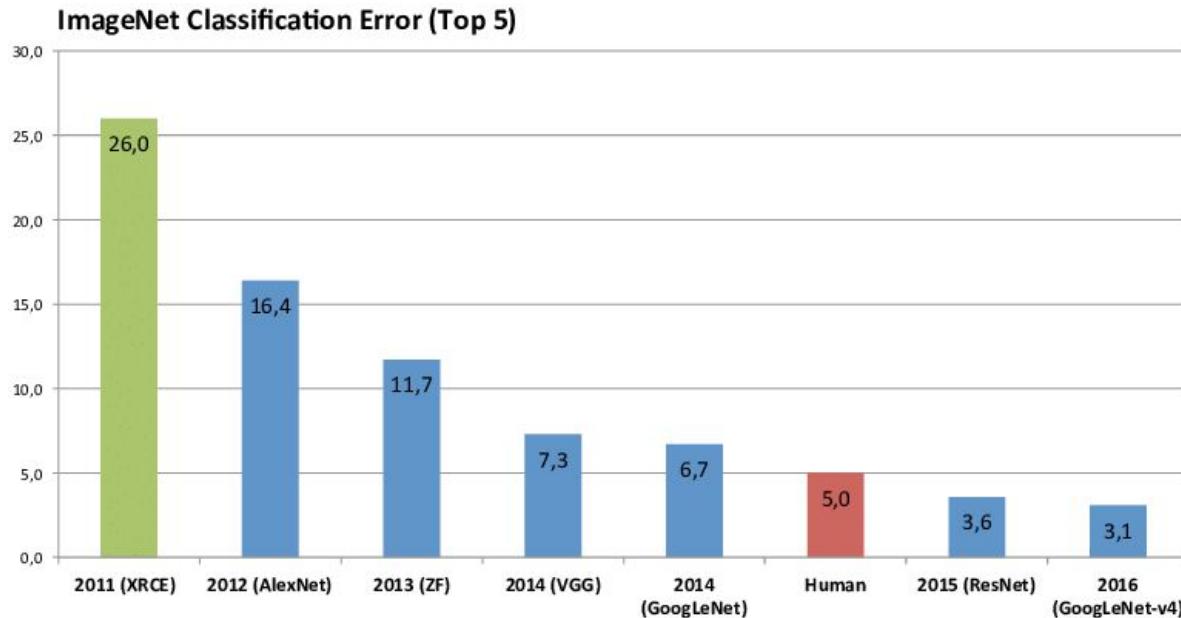


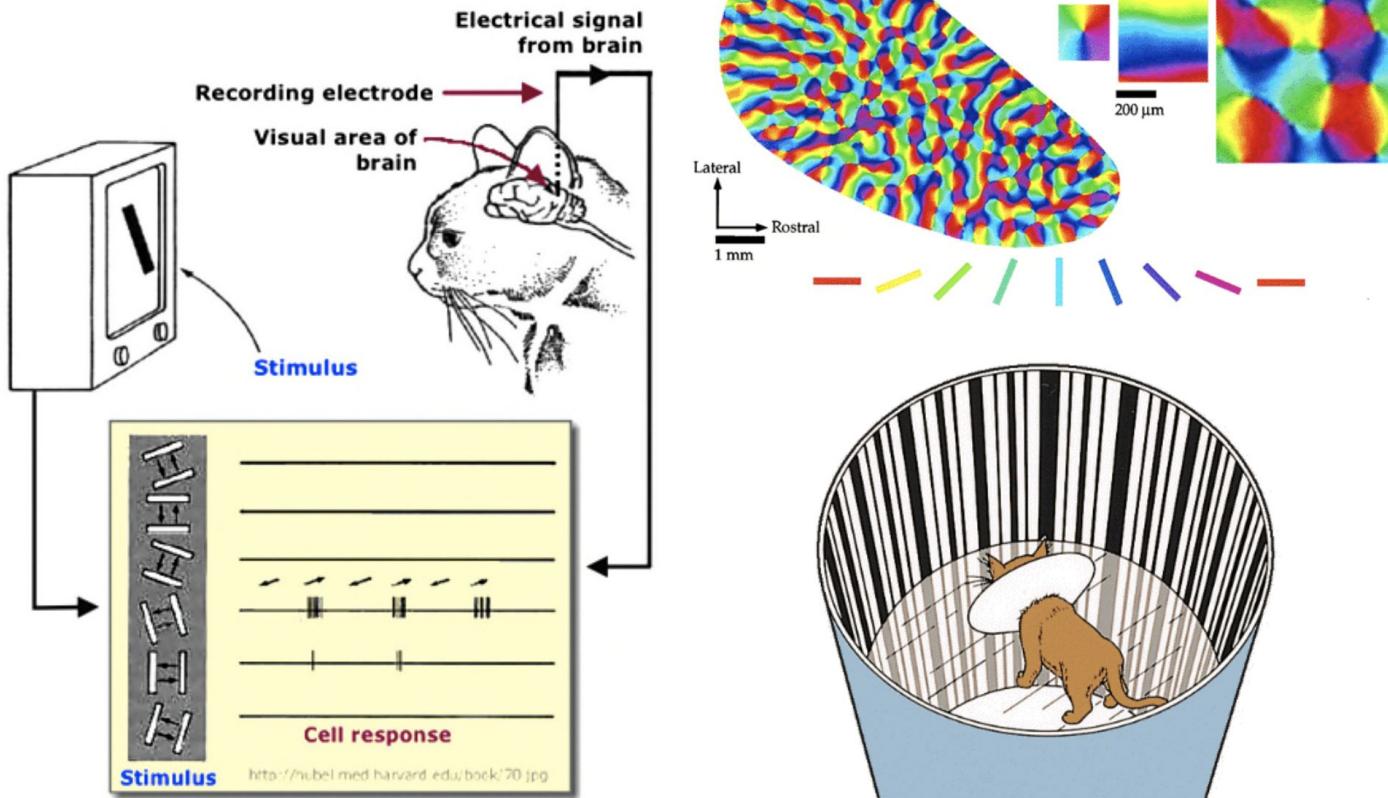
2



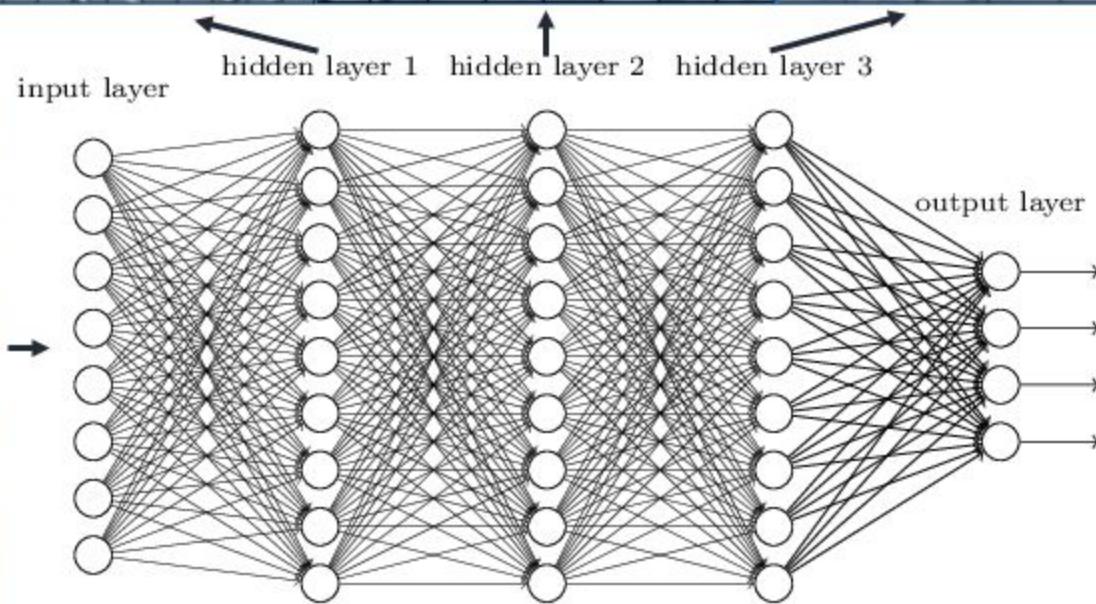
[Thomas Serre 2012]

Imagenet -- Now on Kaggle





Deep neural
networks learn
hierarchical feature
representations



Vision API

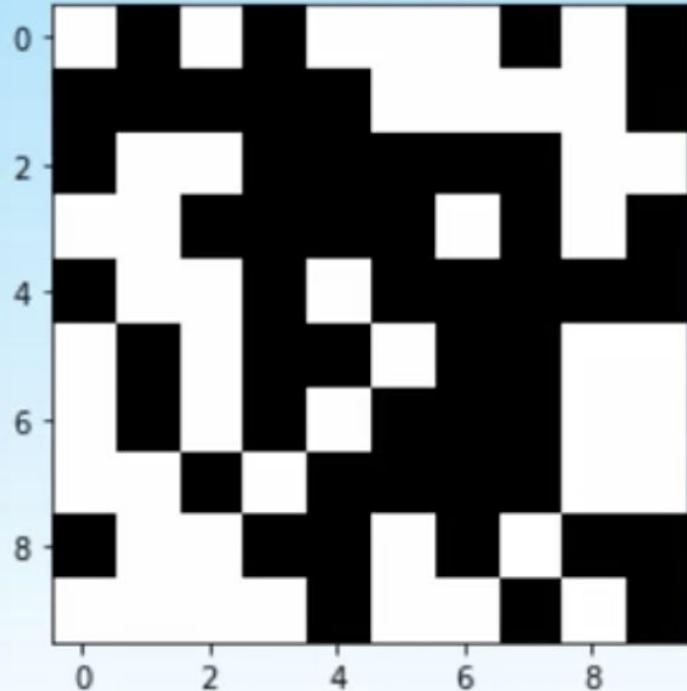
<https://cloud.google.com/vision/>

Topics

- Images in computers
 - Image features
 - Convolution
 - 1 dimension
 - 2 dimensions
 - Convolutional Layer in Neural Networks
 - Strides / Padding / Pooling
 - Building CNNs
-

BLACK AND WHITE

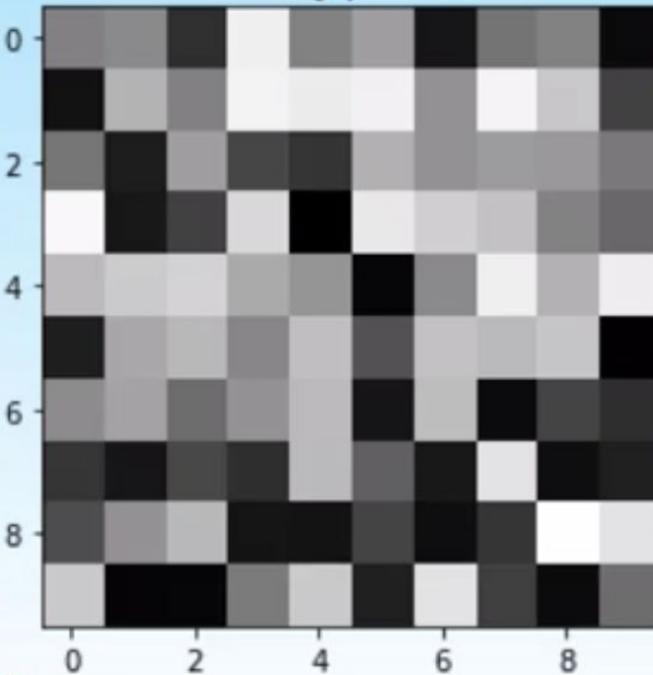
Black and White pixels



```
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, 1, 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]])
```

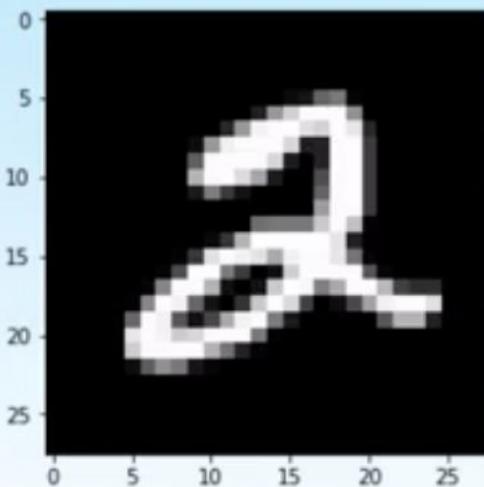
MNIST



5 0 4 |

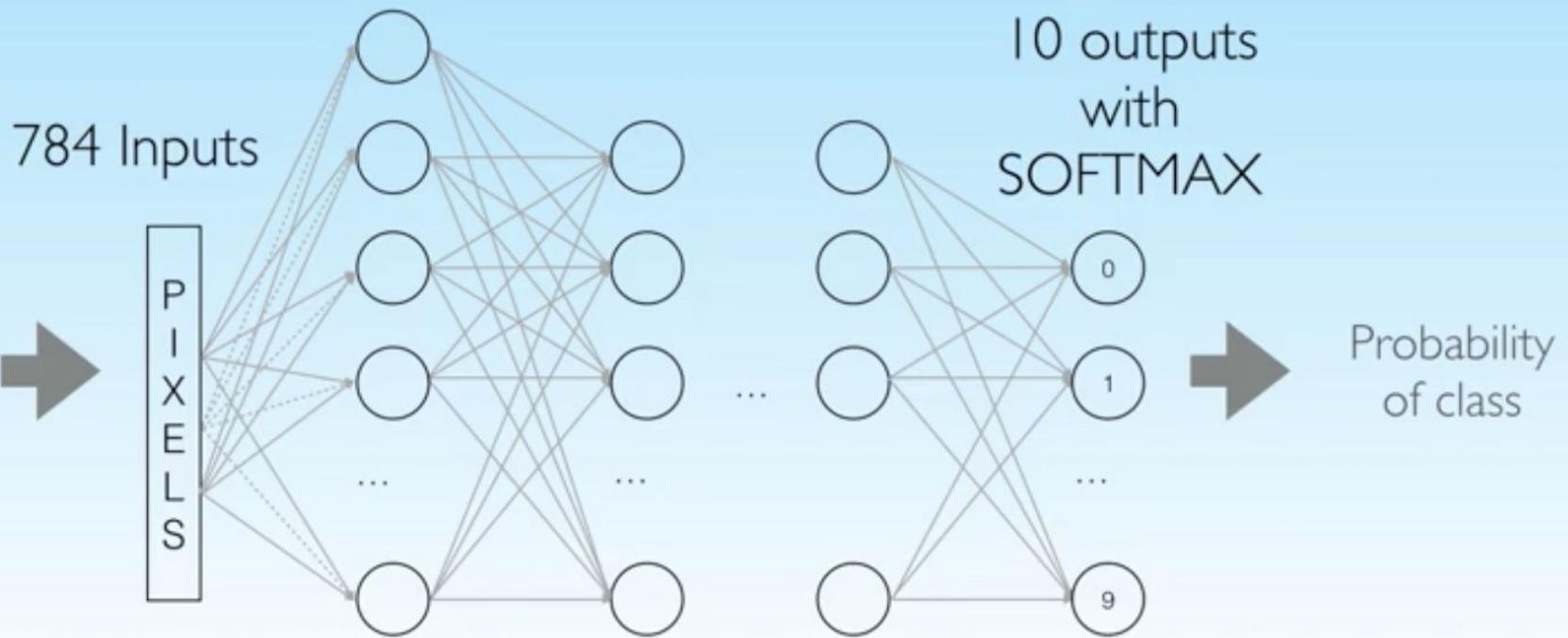
MNIST

.5 .5 | 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 | | 0 0 0 0 0 5 .5 | 0 0 0 0 0 0 0



28 × 28 image => 784 input pixels array

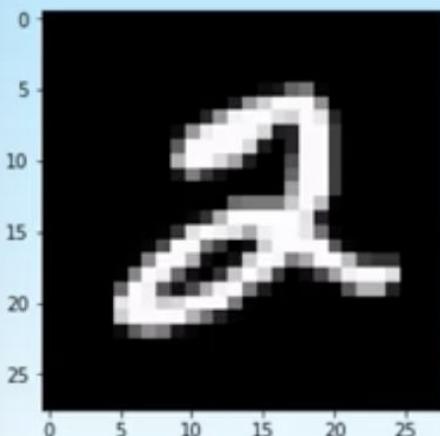
FULLY CONNECTED



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

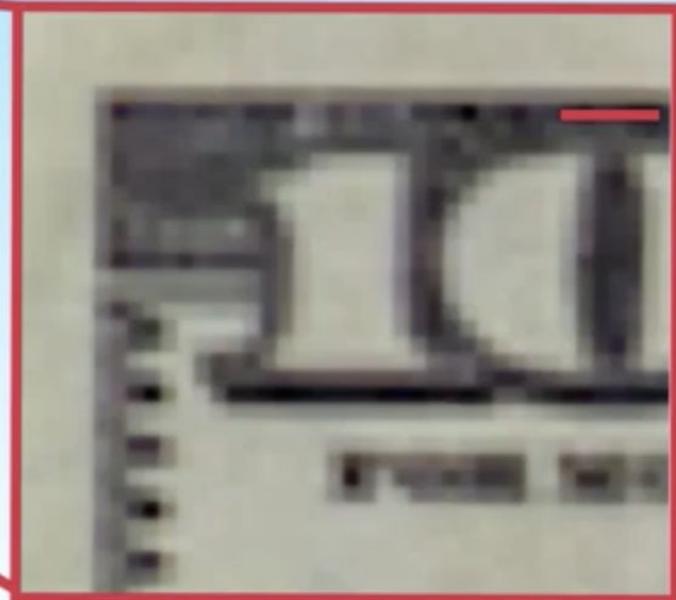
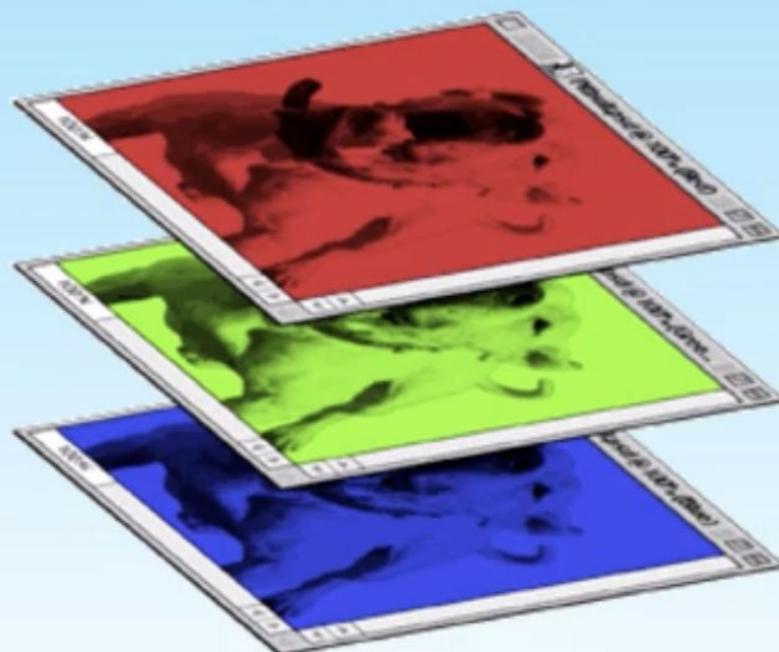


Image to Tensors

TENSORS

| Order | Name | Example | Shape |
|-------|--------|-----------------------------------------------------------------------|-----------|
| 0 | Scalar | 3 | no shape |
| 1 | Vector | [4, 5, 0, 3, 1, 4, 5] | (7,) |
| 2 | Matrix | [[0, 1, 0], [5, 0, 2]] | (2, 3) |
| 3 | Tensor | [[[0, 1, 0, 5], [5, 0, 2, 6]], [[1, 2, 4, 4], [8, 3, 1, 9]]] | (2, 2, 4) |

COLORED IMAGES



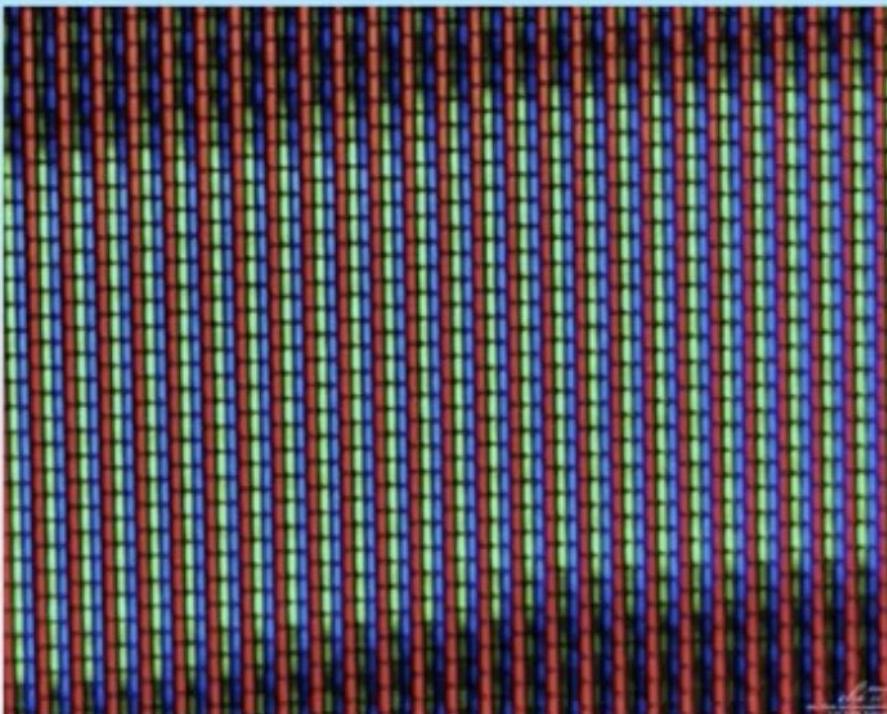
Red Channel

Green Channel

Blue Channel

(C, H, W)

COLORED IMAGES



(C, H, W)

(H, W, C)

Convolution

DISCRETE CONVOLUTION

g

-1 1

X X

f

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

+

n=0

DISCRETE CONVOLUTION

g

| | |
|----|---|
| -1 | 1 |
| X | X |

f

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

十

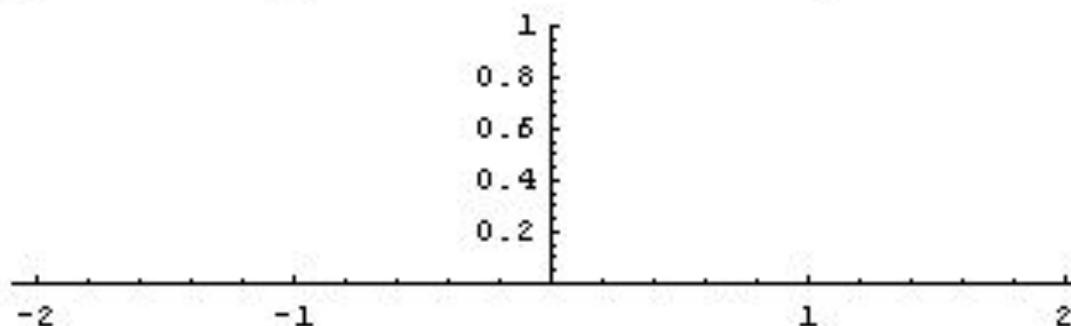
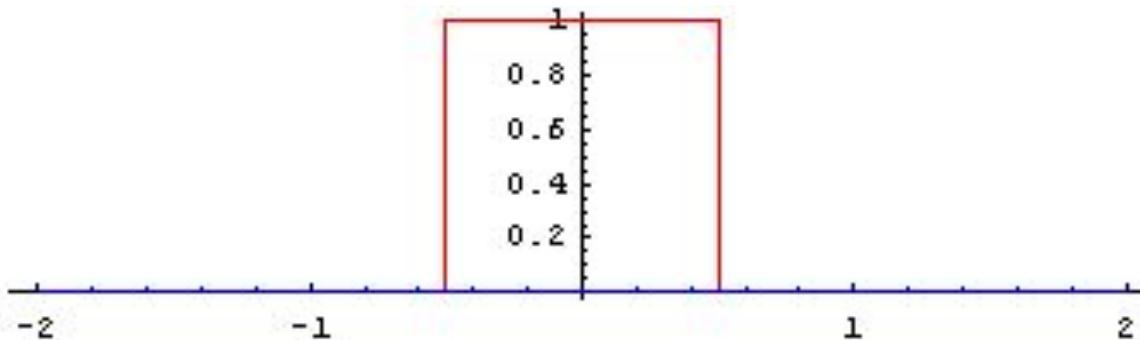
n=8

Definition

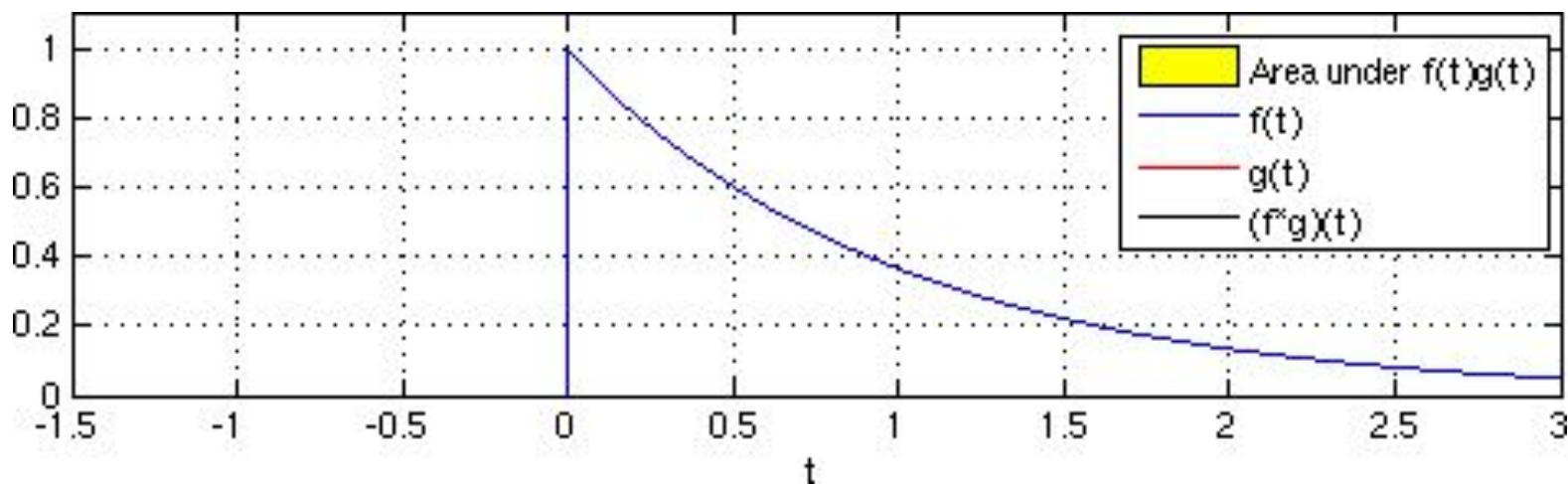
Convolution of f and g at position n is the sum of products between M and $-M$ of f at $n - m$ and g of m

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

Visualize



Another Example

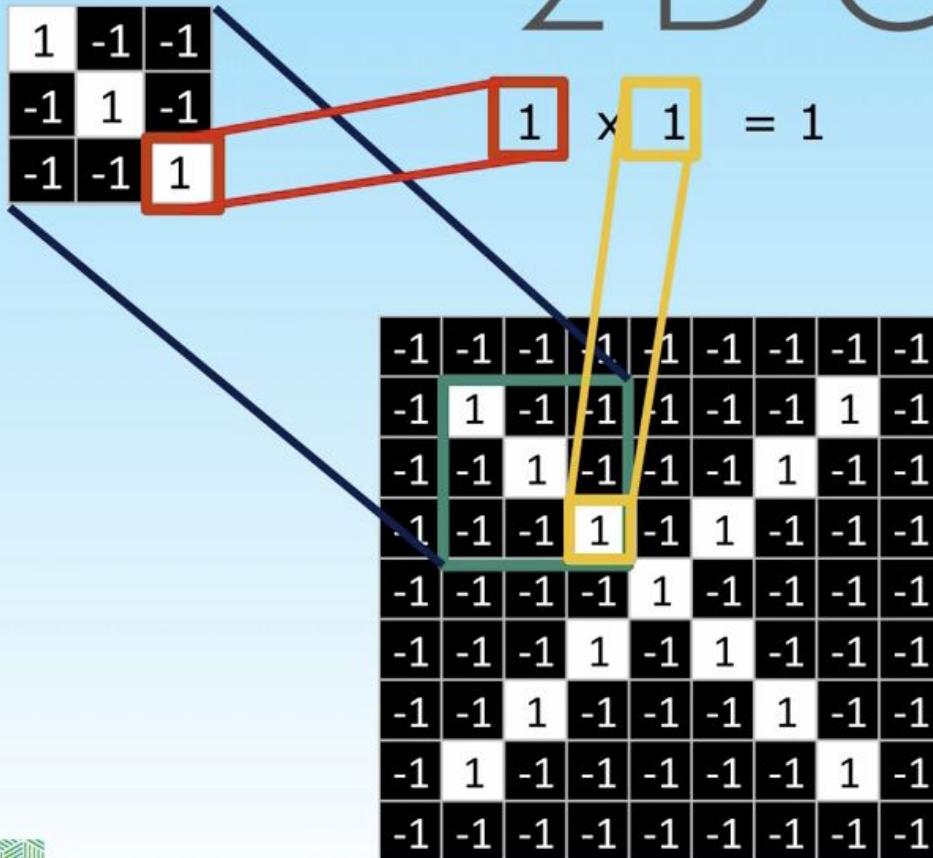


code

https://github.com/nrkfeller/YCBS_notes/blob/master/C4_Convolutions_1D.ipynb

2 D convolution

2 D CONV



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

$$1+1+1+1+1+1+1+1 = 8$$

2D CONV

$$\begin{bmatrix} 1 & -1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{bmatrix}$$

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

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

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



2D CONV

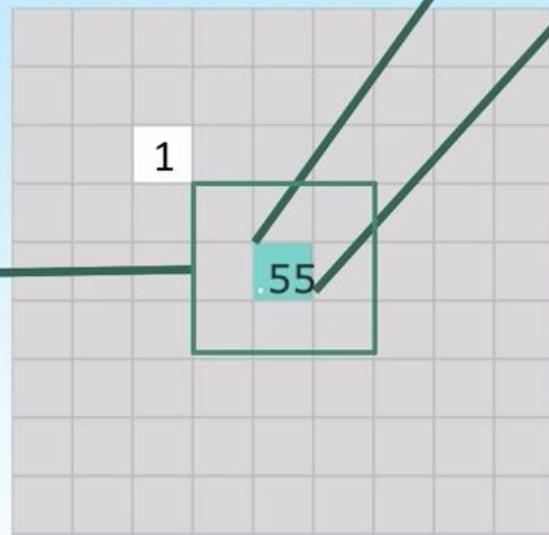
$$\begin{bmatrix} 1 & -1 & -1 \\ -1 & 1 & -1 \\ -1 & -1 & 1 \end{bmatrix}$$

$$\begin{bmatrix} 1 & 1 & -1 \\ 1 & 1 & 1 \\ -1 & 1 & 1 \end{bmatrix}$$

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

A 9x9 input grid with values ranging from -1 to 1. A 3x3 kernel is highlighted in green, centered at position (5, 5). The kernel values are 1, -1, 1, -1, 1, -1, 1, -1, 1.

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

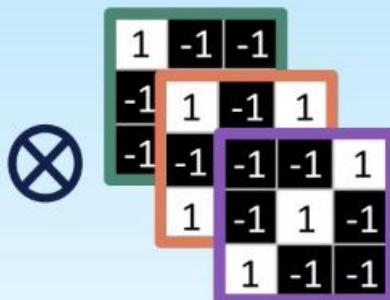
https://github.com/nrkfeller/YCBS_notes/blob/master/C4_Convolutions_2D.ipynb

CNNs

- Convolutional Layer
- Convolution of tensors
- Strides and Padding

CONVOLUTION 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 |



Number of Filters

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



Output Channels

INPUT TENSOR

MNIST training set

Input: order 4 tensor

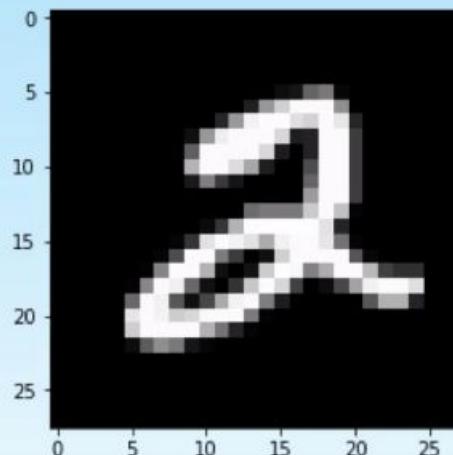
(N, H, W, C)

N: Number of images

H: Height of image

W: Width of image

C: Number of color channels



(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 |

(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 |



| | | | |
|----|----|----|----|
| 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 | 0.33 |
| 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 | |

Examples, H, W, inp channels

examples, H, W, out channels

(3, 3, 1, 2)

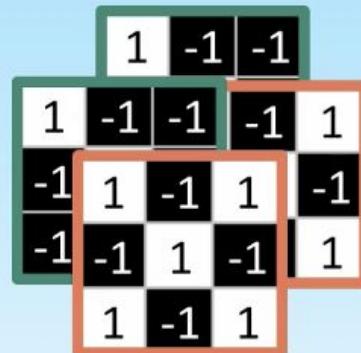
(-, 7, 7, 2)

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 |
| 0.11 | -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 |



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

Match channels

(-, 7, 7, 2)

(3, 3, 2, 2)

(-, 5, 5, 2)

STRIDES: (1, 1)

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

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

| | | | | | | | | |
|----|----|----|----|----|----|----|----|----|
| -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| -1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| -1 | -1 | 1 | -1 | -1 | -1 | 1 | -1 | -1 |
| -1 | -1 | -1 | 1 | -1 | 1 | -1 | -1 | -1 |
| -1 | -1 | -1 | -1 | 1 | -1 | -1 | -1 | -1 |
| -1 | -1 | -1 | 1 | -1 | 1 | -1 | -1 | -1 |
| -1 | -1 | 1 | -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 => 7 x 7

STRIDES: (2, 2)

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

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

| | | | | | | | | | |
|----|----|----|----|----|----|----|----|----|----|
| -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| -1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| -1 | -1 | 1 | -1 | -1 | -1 | -1 | -1 | -1 | -1 |
| -1 | -1 | -1 | 1 | -1 | -1 | 1 | -1 | -1 | -1 |
| -1 | -1 | -1 | -1 | 1 | -1 | 1 | -1 | -1 | -1 |
| -1 | -1 | -1 | -1 | -1 | 1 | -1 | -1 | -1 | -1 |
| -1 | -1 | -1 | -1 | -1 | -1 | 1 | -1 | -1 | -1 |
| -1 | -1 | -1 | 1 | -1 | -1 | 1 | -1 | -1 | -1 |
| -1 | -1 | 1 | -1 | -1 | -1 | -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 => 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 |
| -1 | -1 | 1 | -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)

PADDING

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

- Valid
- Same

Output image => 9 x 9

Code

https://github.com/nrkfeller/YCBS_notes/blob/master/C4_Convolutions_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 | -0.11 |
| 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 | | |
| 0.55 | 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

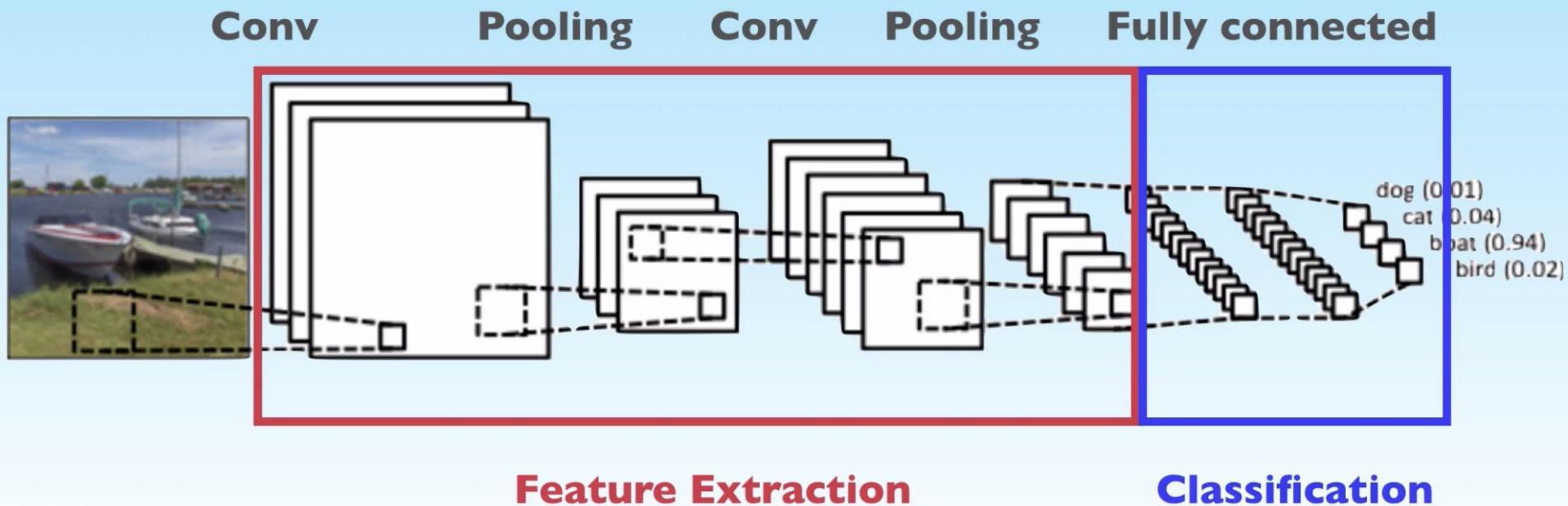
(-, 4, 4, 3)

Code

https://github.com/nrkfeller/YCBS_notes/blob/master/C4_Convolutions_Pooling_Layer.ipynb

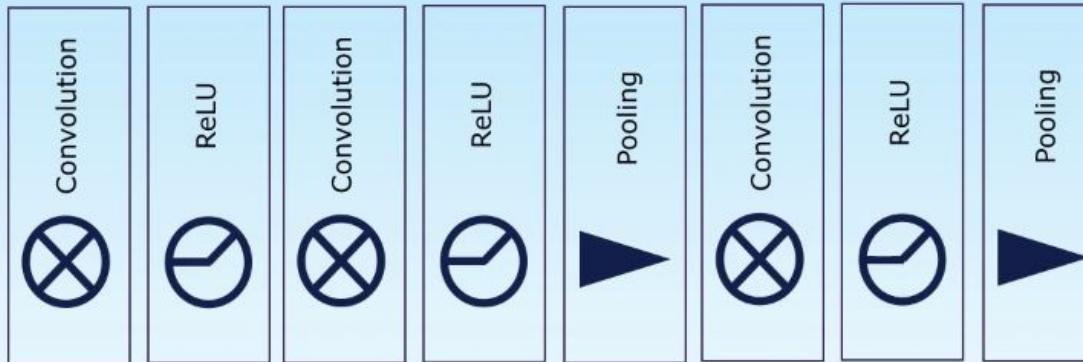
CNN Finally!

STACKING LAYERS



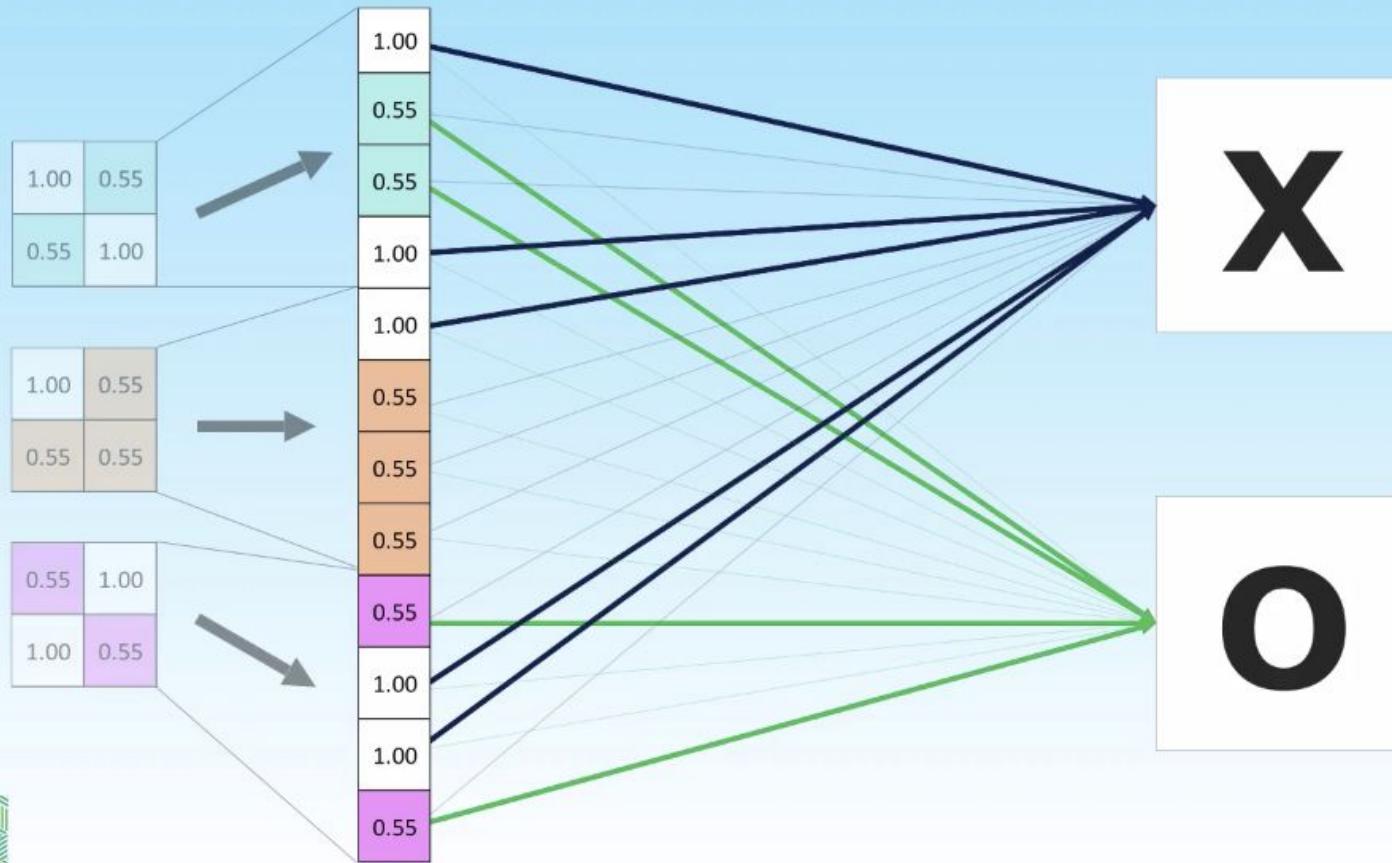
FEATURE EXTRACTION

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

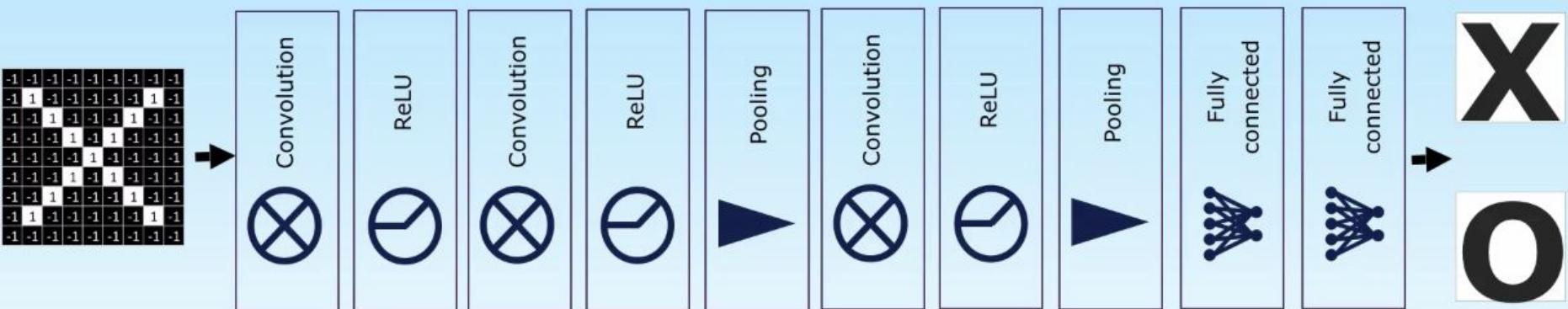


| | |
|------|------|
| 1.00 | 0.55 |
| 0.55 | 1.00 |
| 1.00 | 0.55 |
| 0.55 | 0.55 |
| 0.55 | 1.00 |
| 1.00 | 0.55 |

FULLY CONNECTED LAYER



ALL TOGETHER



FULLY CONNECTED

- Input data: image $10 \times 10 \Rightarrow \mathbf{100}$ numbers
- First layer: **32** nodes $\Rightarrow \mathbf{100}$ weights each
- $\Rightarrow \mathbf{3200}$ weights!

CONVOLUTIONAL

- Input data: image $10 \times 10 \Rightarrow 100$ numbers
 - First layer: **32** conv, kernel **3×3** \Rightarrow 9 weights each
 - $\Rightarrow 32 \times 9 = \mathbf{288}$ weights!
-

Code

https://github.com/nrkfeller/YCBS_notes/blob/master/C4_Convolutional_Neural_Network.ipynb

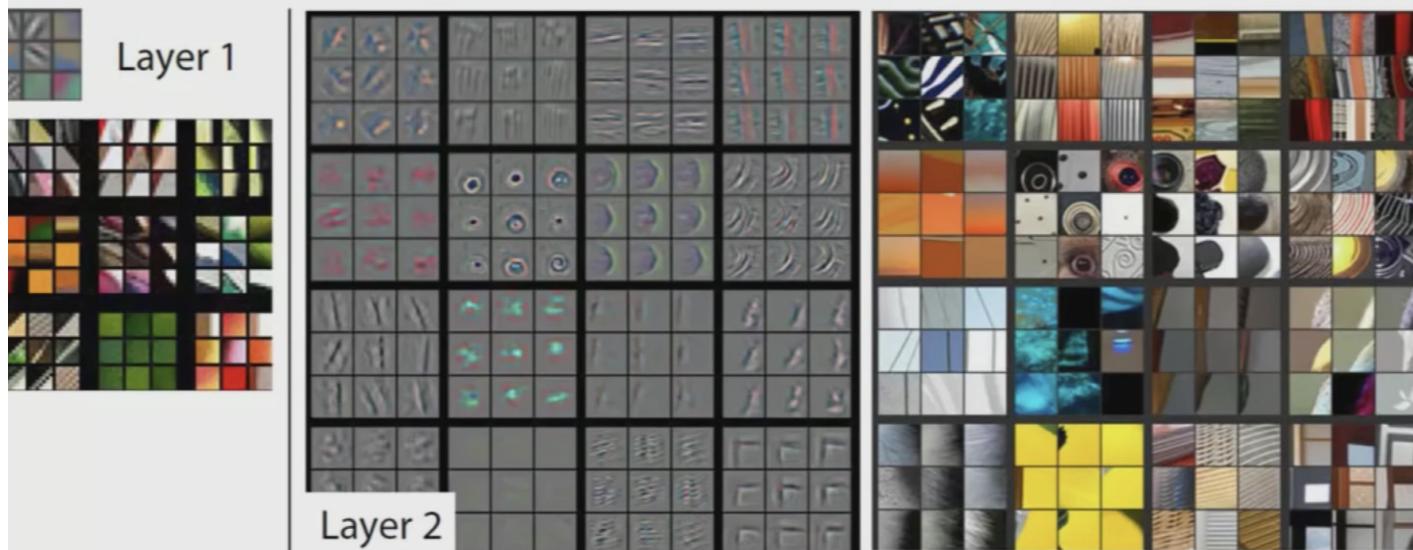
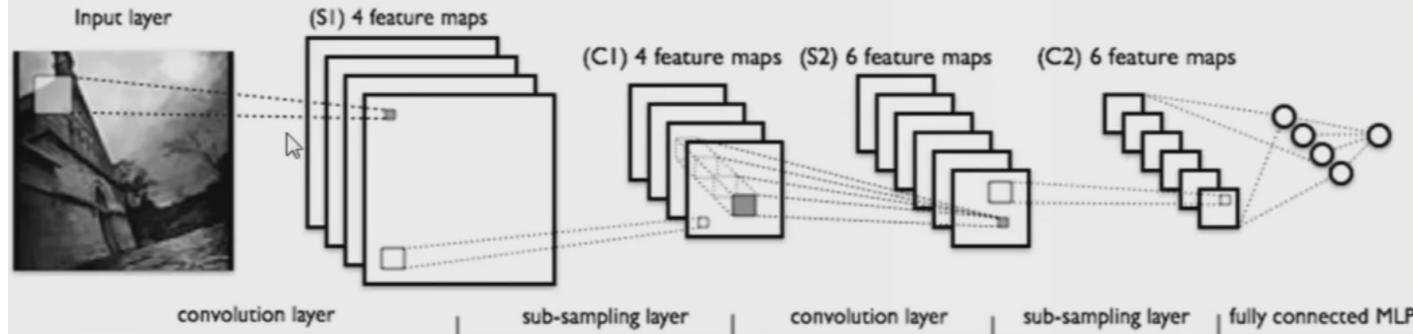
OTHER USES

- SPECTROGRAMS
 - TEXT (Y= WORDS IN DICTIONARY, X= POSITION IN SENTENCE)
 - WHEREVER THERE ARE LOCAL PATTERNS TO EXPLOIT
 - Leveraging feature vectors from pretrained models
-

Topics

- Images in computers
 - Image features
 - Image tensors
 - Convolution
 - 1 dimension
 - 2 dimensions
 - Convolutional Layer in Neural Networks
 - Strides / Padding / Pooling
 - Building CNNs
-

Convolutional networks



Exercise

https://github.com/nrkfeller/YCBS_notes/blob/master/C4_Exercise.ipynb
