UFV
Universidade Federal de Viçosa

Aula 06 – Redes Neurais Convolucionais

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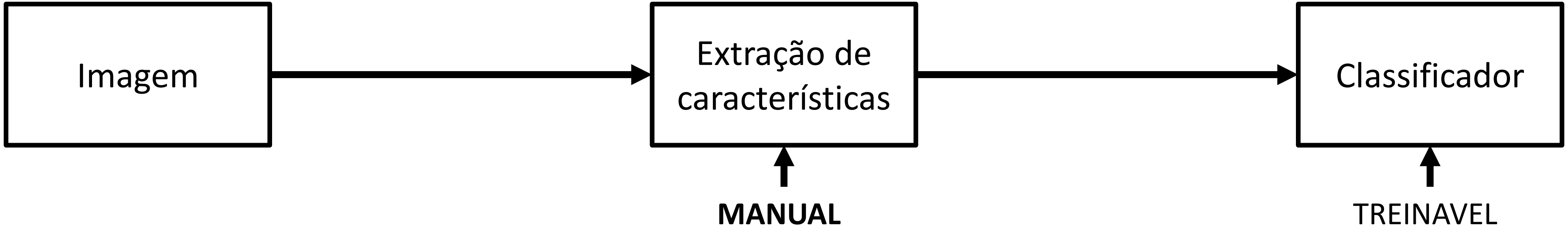
Roteiro

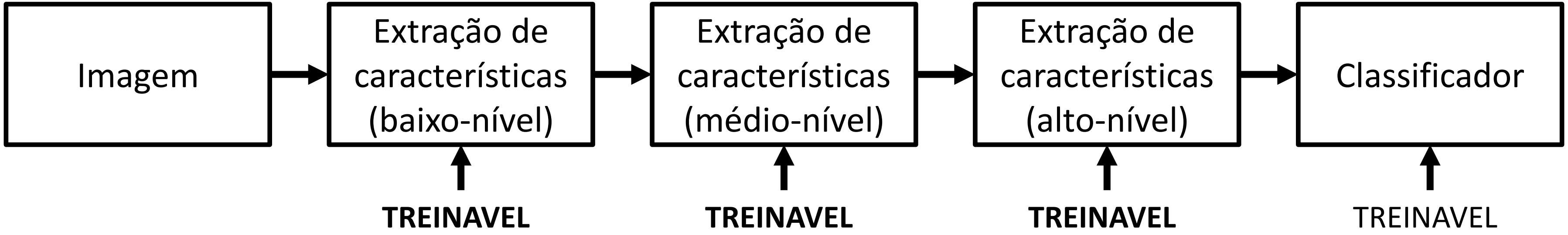
- Pipelines de classificação
- Perceptron de múltiplas camadas (MLP)
- Redes Neurais Convolucionais (CNNs)
- Camada convolucional
- Camada de pooling
- Função de ativação
- Camada completamente conectada
- Camada de saída – softmax
- Função de perda (loss)
- Otimizadores
- Arquiteturas
- Bibliotecas e desenvolvimento
- Conjuntos de imagens

Pipelines de classificação

Pipeline clássico de classificação de imagens

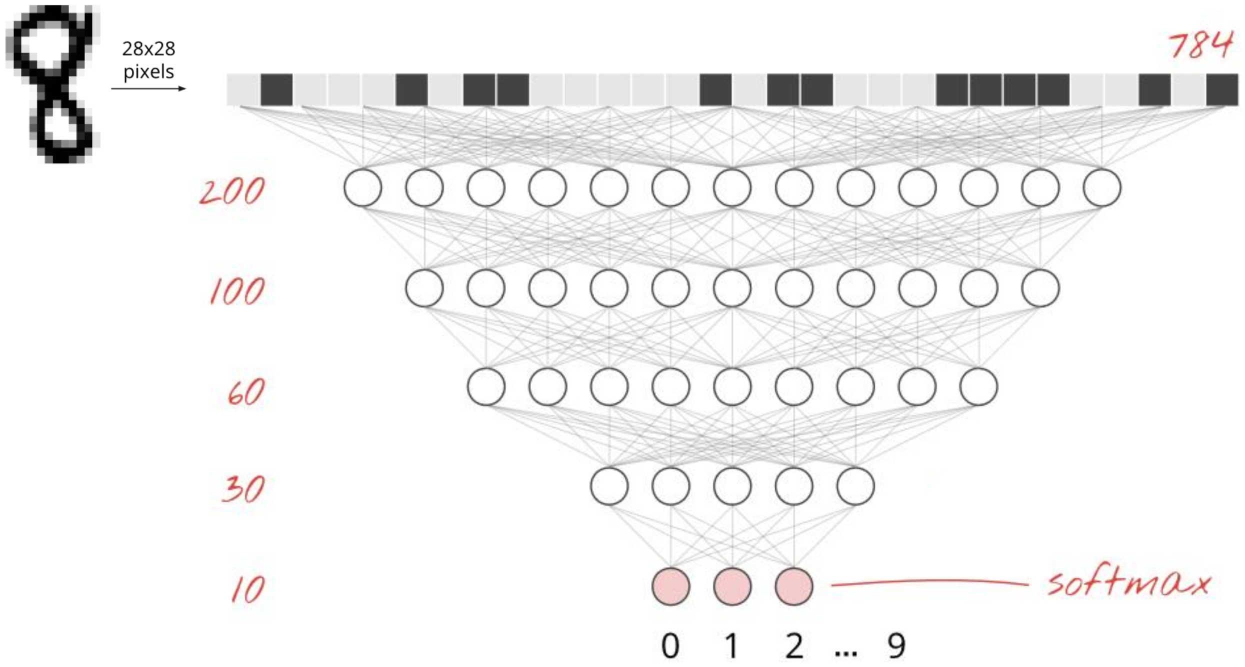


Deep Learning



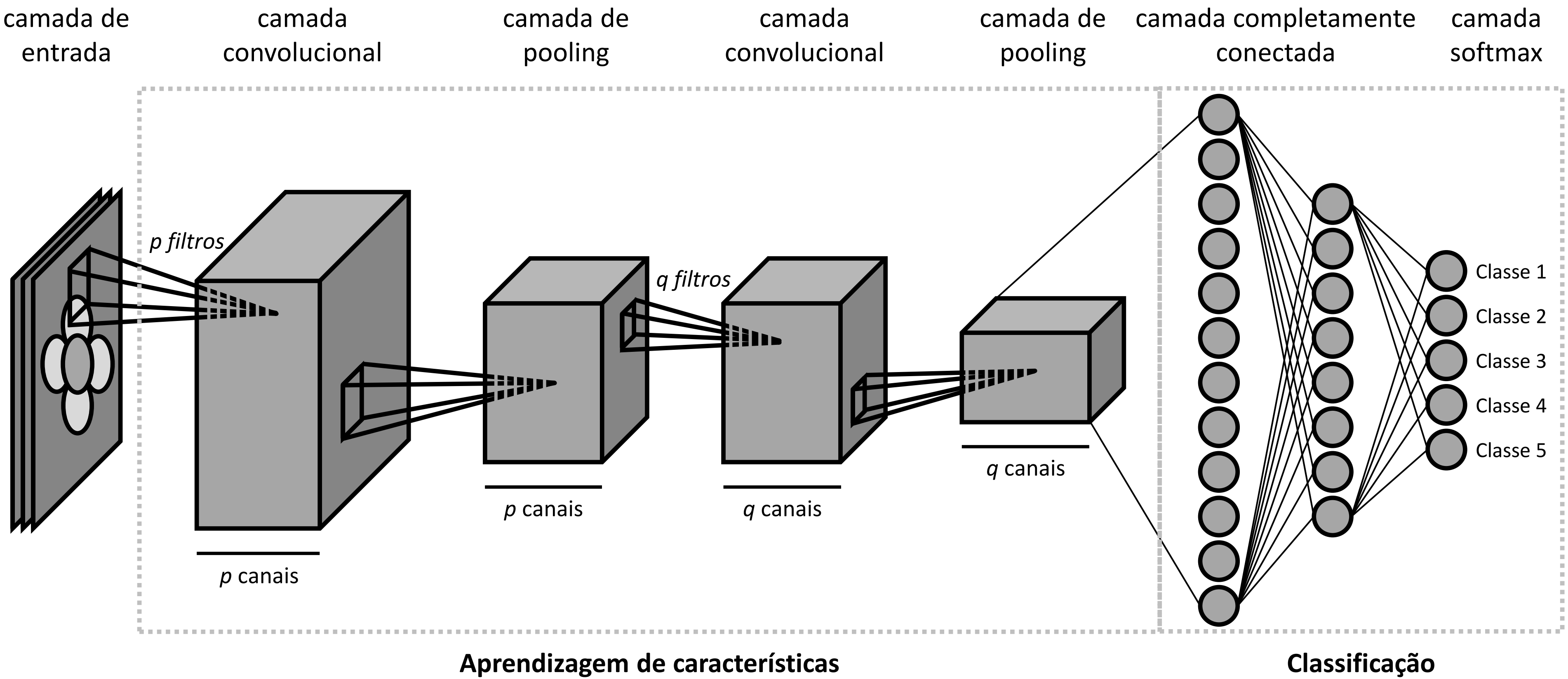
Yann LeCun's Deep Learning Course at CDS - SPRING 2021

Perceptron de múltiplas camadas (MLP)



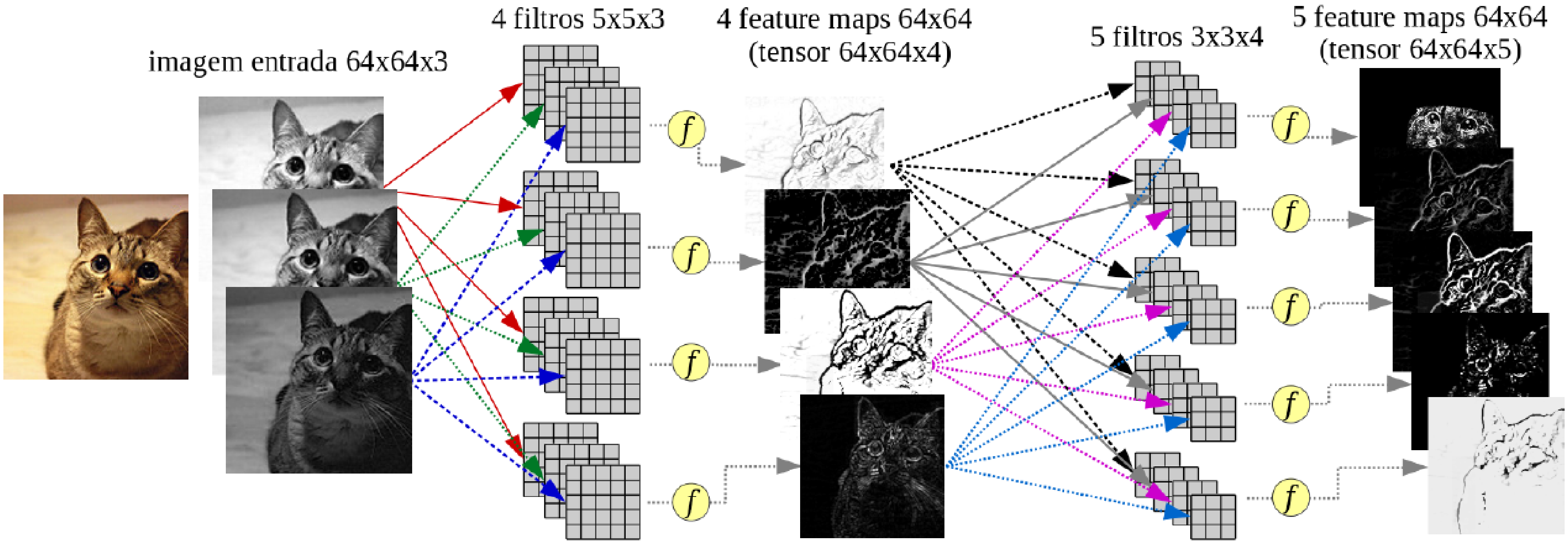
Learn TensorFlow and deep learning, without a Ph.D.

Redes Neurais Convolucionais (CNNs)



CAMADA CONVOLUCIONAL

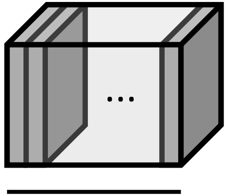
Camada convolucional



Moacir Ponti. [*http://conteudo.icmc.usp.br/pessoas/moacir/p17sibgrapi-tutorial/*](http://conteudo.icmc.usp.br/pessoas/moacir/p17sibgrapi-tutorial/)

Camada convolucional

M^{l-1}

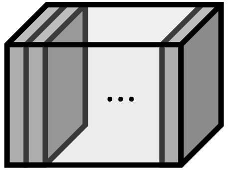


D canais

Camada convolucional

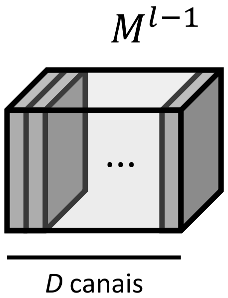
Camada convolucional C^l

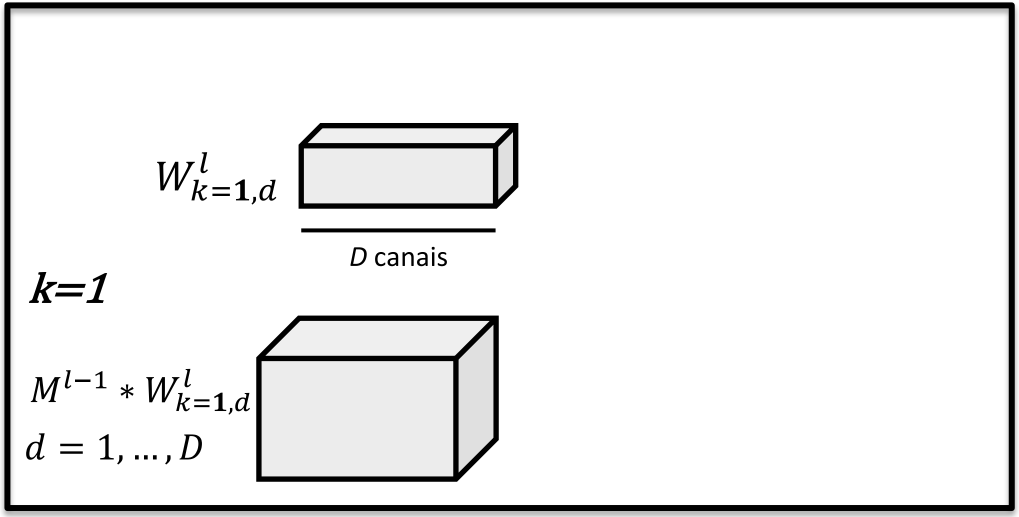
M^{l-1}



k=1

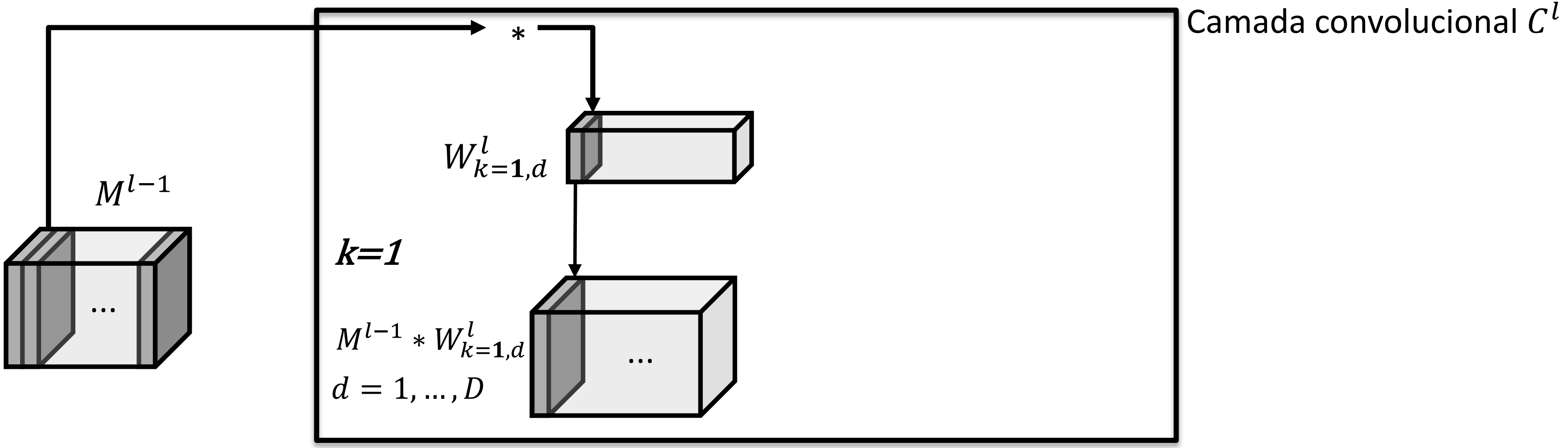
Camada convolucional



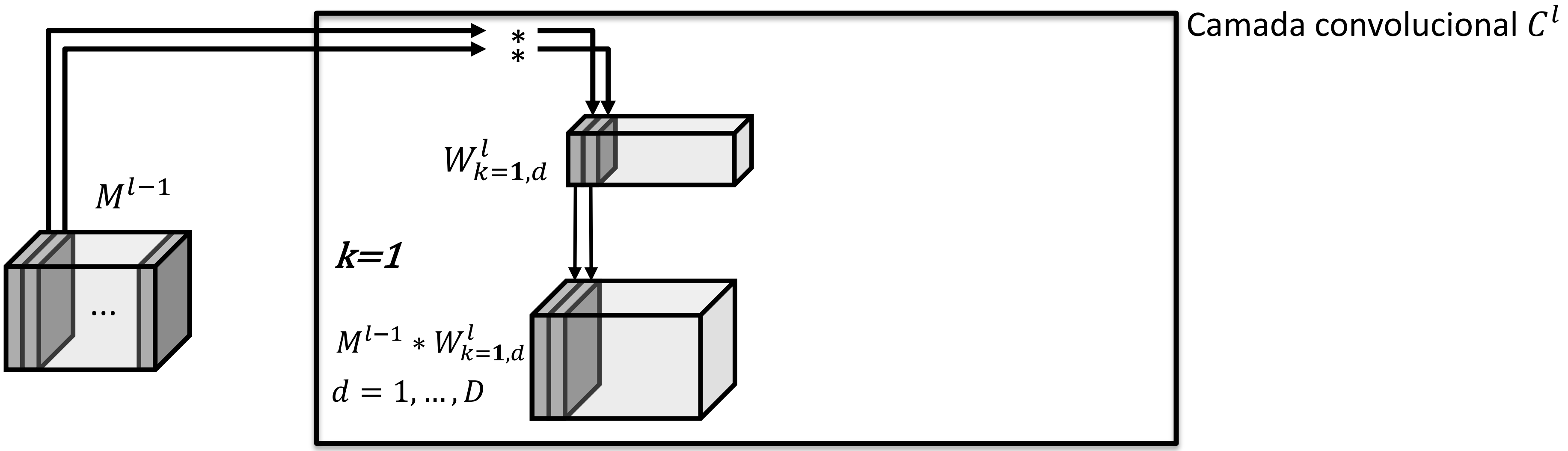


Camada convolucional C^l

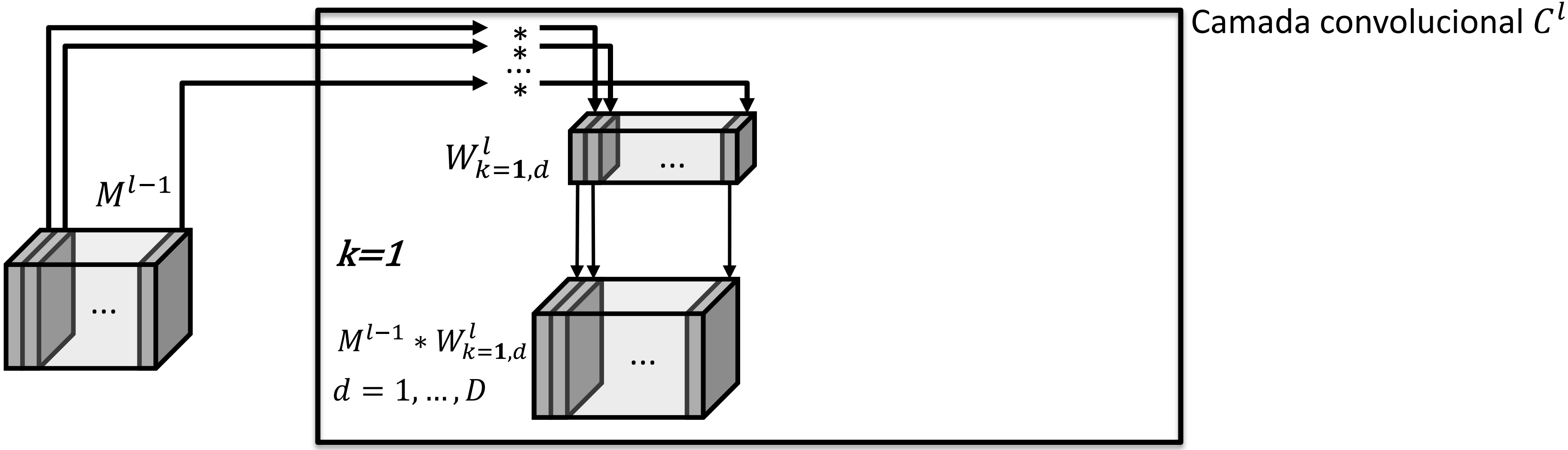
Camada convolucional



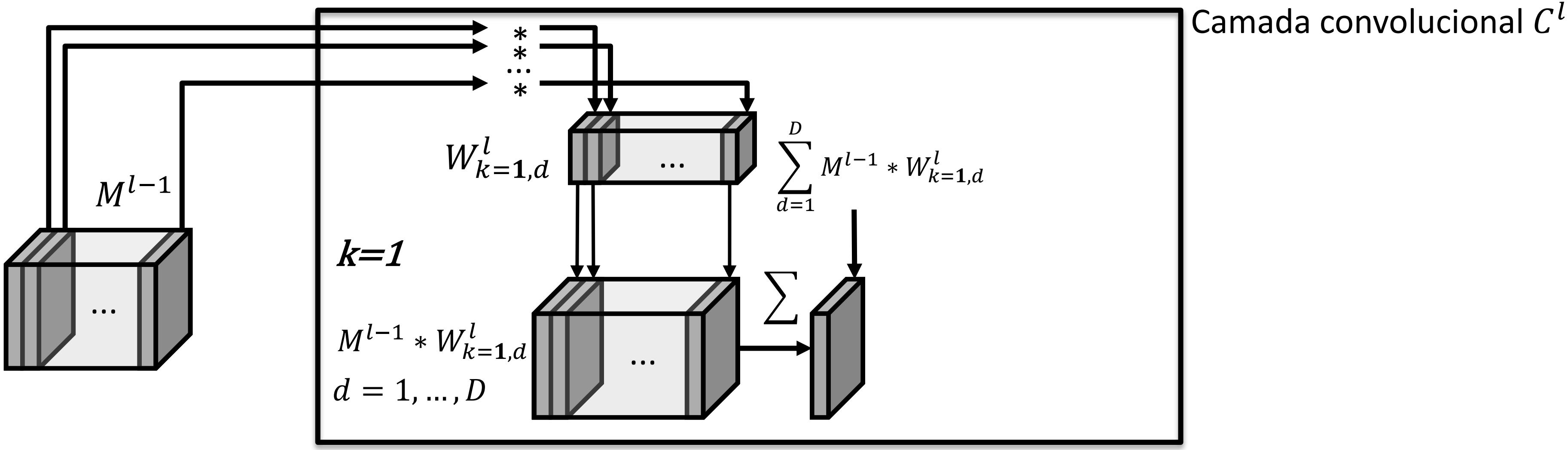
Camada convolucional



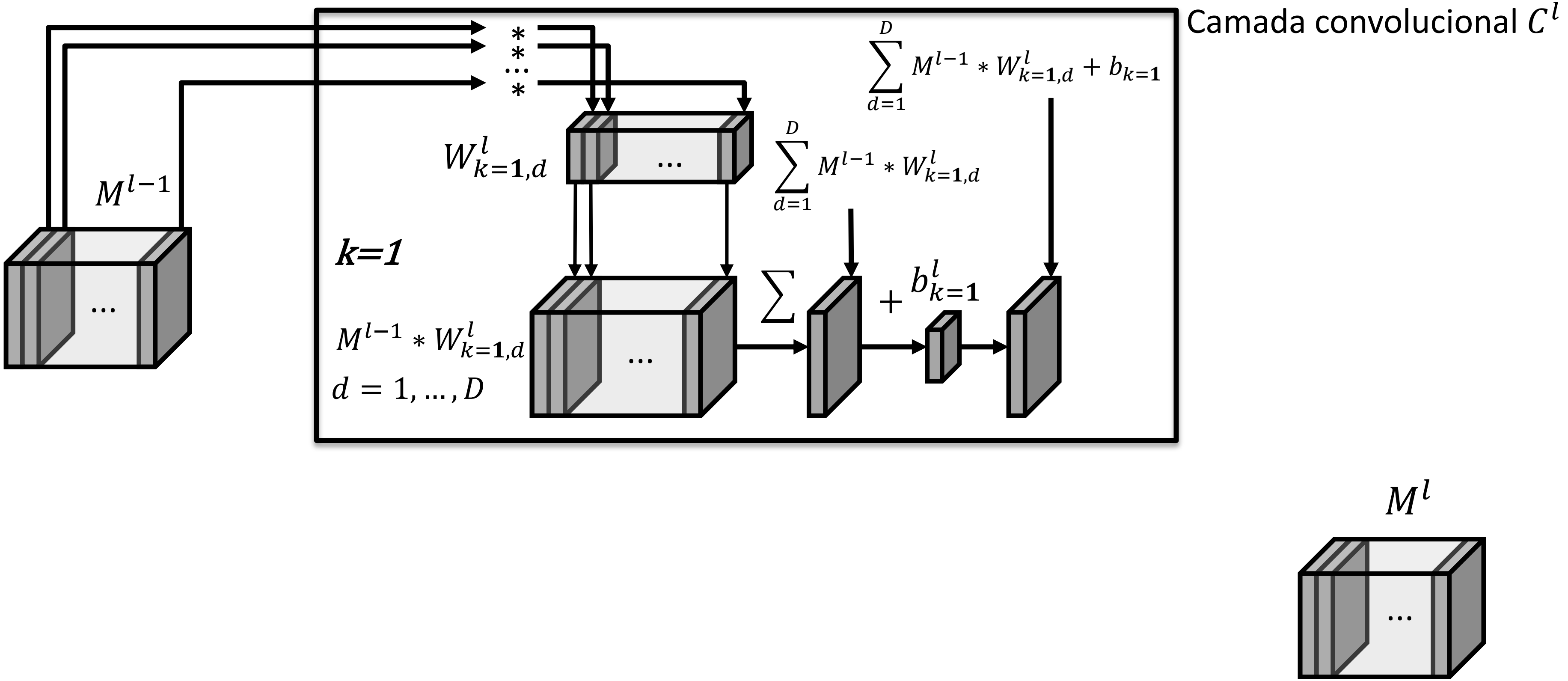
Camada convolucional



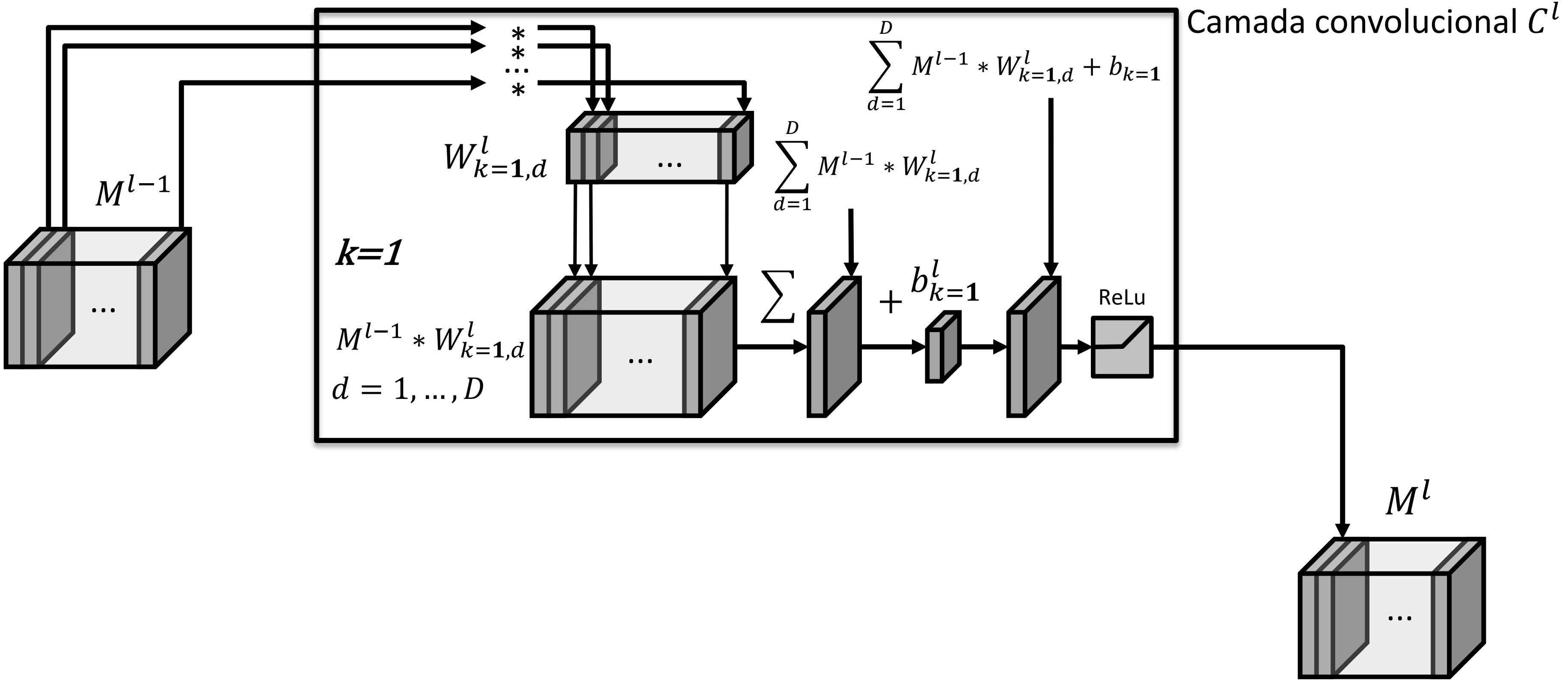
Camada convolucional



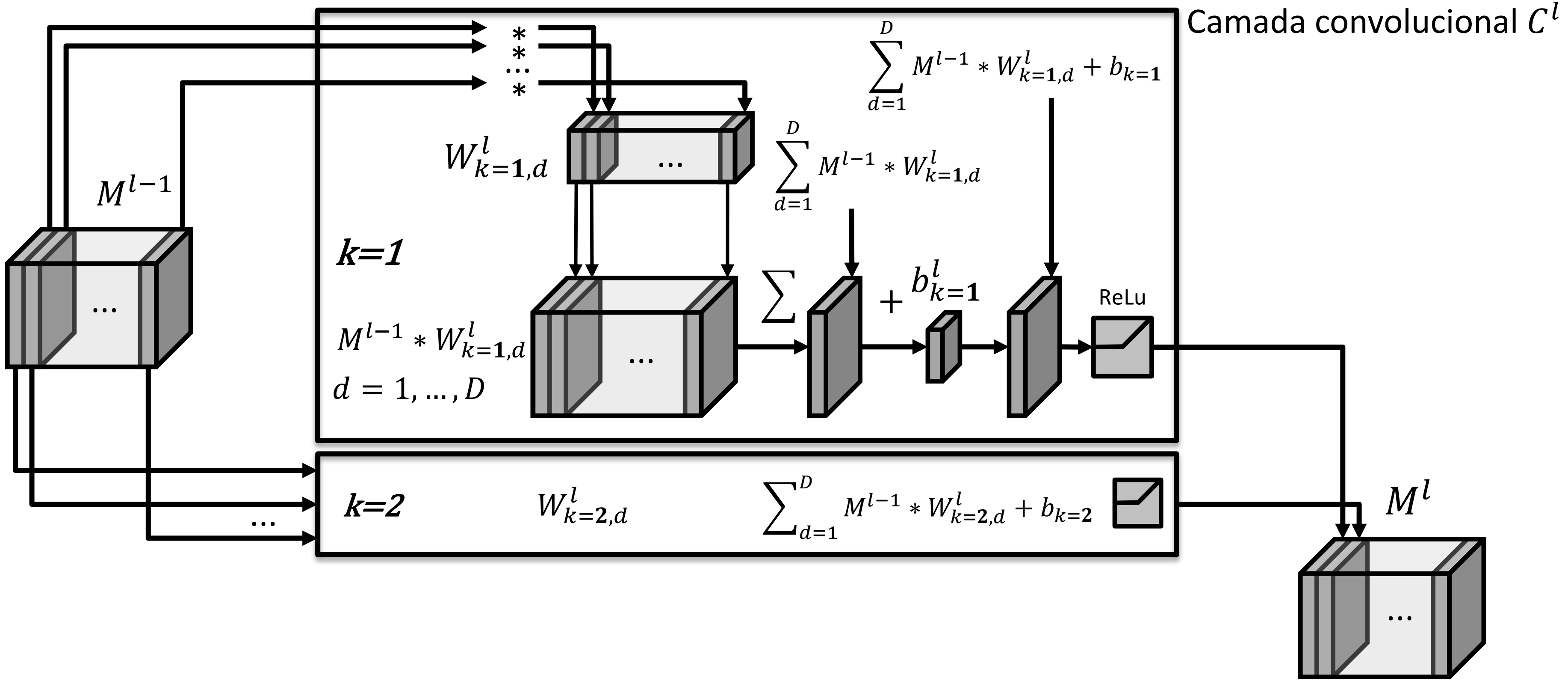
Camada convolucional



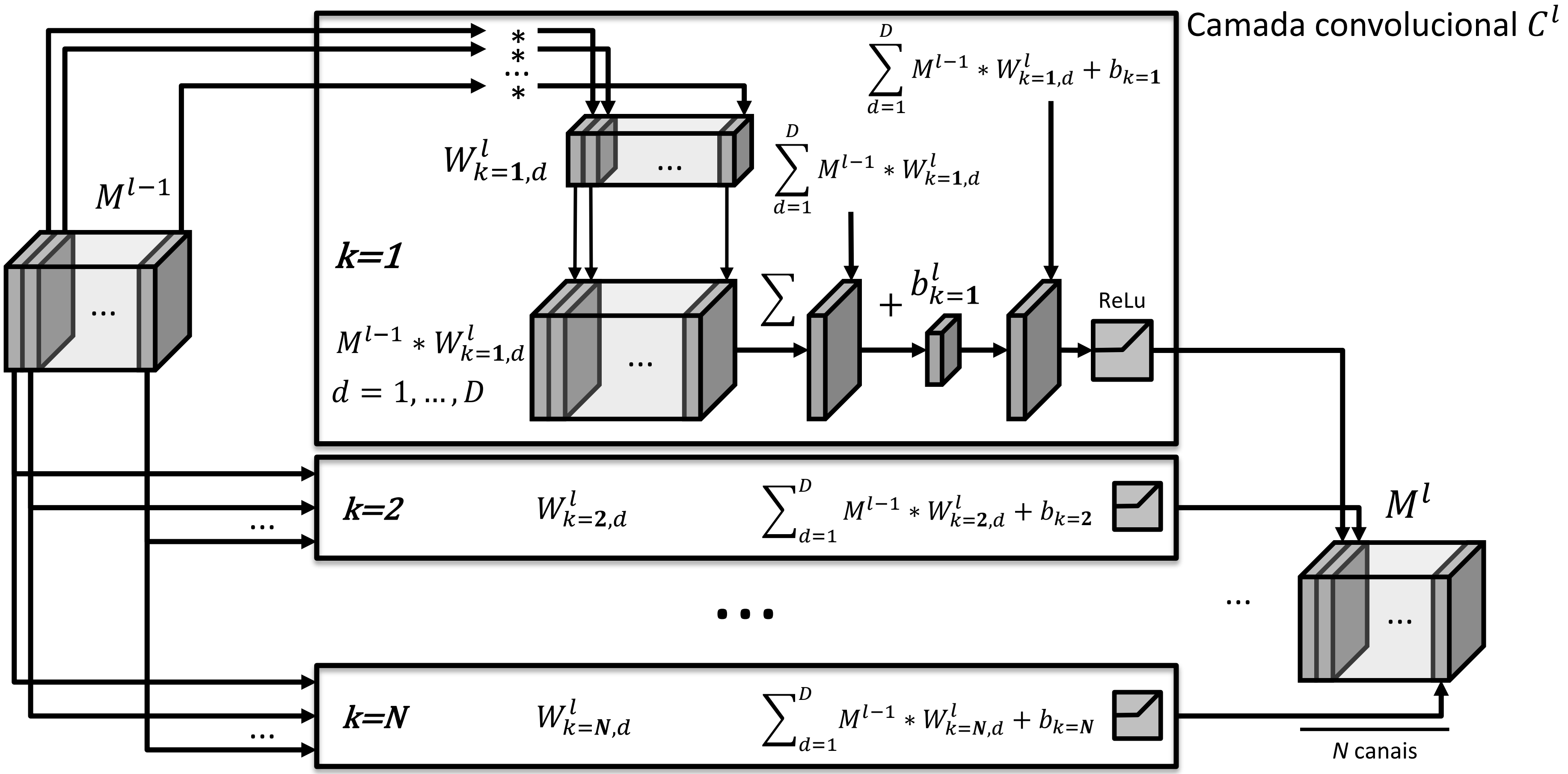
Camada convolucional



Camada convolucional



Camada convolucional



Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

x[:,:,1] * w0[:,:,1]

b0

1

x[:,:,2] * w0[:,:,2]

---

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

x[:,:,1] * w1[:,:,1]

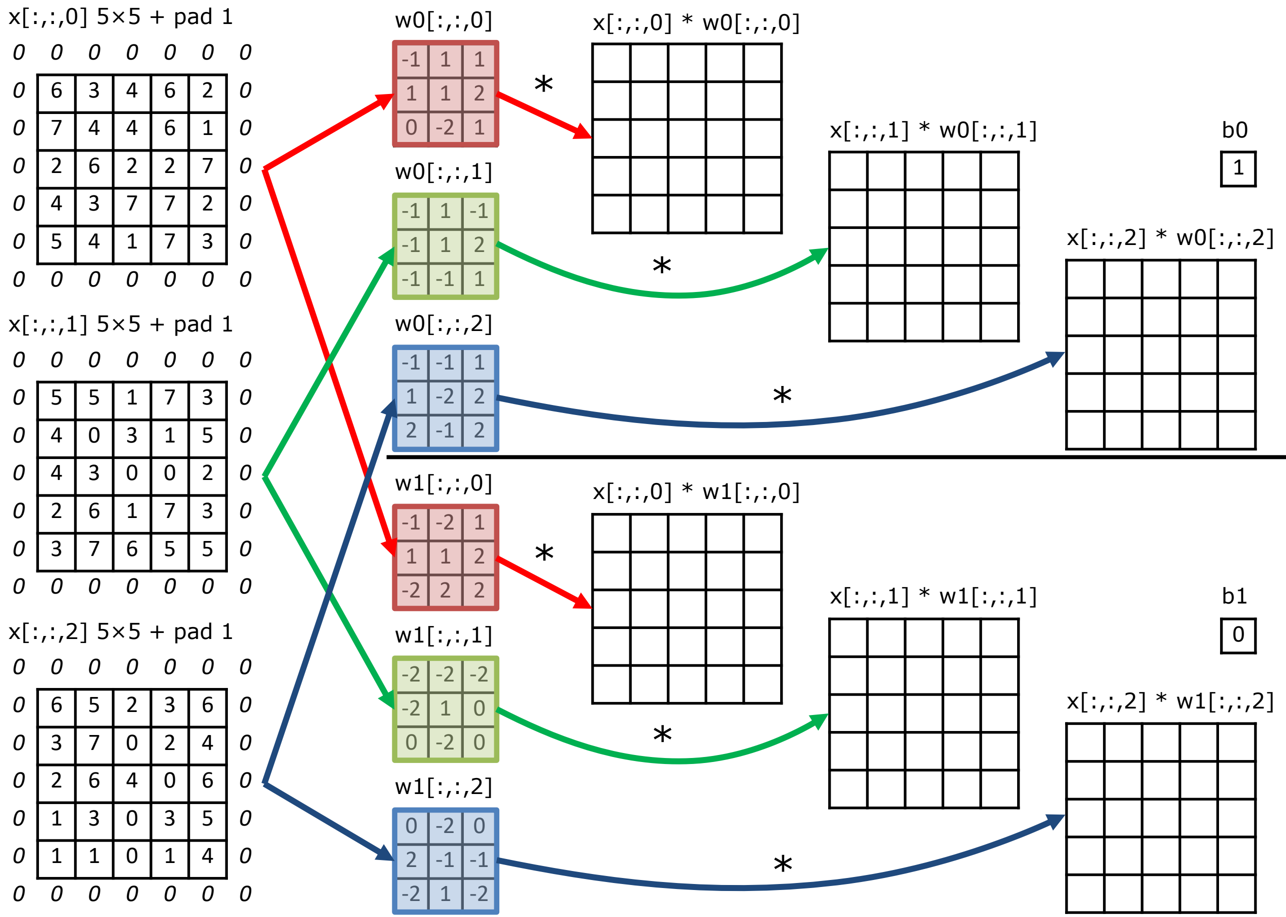
b1

0

x[:,:,2] * w1[:,:,2]

https://cs231n.github.io/convolutional-networks/

Camada convolucional



$$x * w = \sum_{s=-a}^{a} \sum_{t=-b}^{b} w(s,t)x(i-s,j-t)$$

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

x[:,:,1] * w0[:,:,1]

x[:,:,2] * w0[:,:,2]

b0

1

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

x[:,:,1] * w1[:,:,1]

x[:,:,2] * w1[:,:,2]

b1

0

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12				

x[:,:,1] * w0[:,:,1]

4				

b0

1

x[:,:,2] * w0[:,:,2]

-17				

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9				

x[:,:,1] * w1[:,:,1]

-13				

b1

0

x[:,:,2] * w1[:,:,2]

-2				

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26			

x[:,:,1] * w0[:,:,1]

4	7			

b0

1

x[:,:,2] * w0[:,:,2]

-17	0			

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14			

x[:,:,1] * w1[:,:,1]

-13	-11			

b1

0

x[:,:,2] * w1[:,:,2]

-2	-21			

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18		

x[:,:,1] * w0[:,:,1]

4	7	6		

x[:,:,2] * w0[:,:,2]

-17	0	14		

b0

1

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6		

x[:,:,1] * w1[:,:,1]

-13	-11	-21		

x[:,:,2] * w1[:,:,2]

-2	-21	-1		

b1

0

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	

x[:,:,1] * w0[:,:,1]

4	7	6	-1	

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	

b0

1

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	

b1

0

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	21

x[:,:,1] * w0[:,:,1]

4	7	6	-1	12

b0

1

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	-8

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	18

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	-9

b1

0

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	-17

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	21
-5				

x[:,:,1] * w0[:,:,1]

4	7	6	-1	12
-5				

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	-8
-3				

b0

1

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	18
7				

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	-9
-20				

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	-17
3				

b1

0

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	21
12				

x[:,:,1] * w0[:,:,1]

4	7	6	-1	12
4				

b0

1

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	-8
-17				

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	18
7				

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	-9
-20				

b1

0

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	-17
3				

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	21
-5	28	19	4	24
-5	11	15	17	24
4	16	20	26	14
1	16	5	5	20

x[:,:,1] * w0[:,:,1]

4	7	6	-1	12
-5	3	-4	-9	13
-7	15	-10	-2	-6
-15	8	3	-2	15
-12	2	13	3	19

b0

1

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	-8
-3	-5	32	11	-10
9	-7	22	12	-14
9	2	17	14	-13
4	-1	15	9	-5

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	18
7	20	20	22	17
3	17	2	22	28
-15	26	27	1	35
11	15	22	36	35

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	-9
-20	-30	-7	-27	-5
-26	-15	-34	-28	-28
-38	-34	-49	-31	-21
-15	-17	-6	-19	-1

b1

0

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	-17
3	-33	-25	-7	-18
-3	-5	-28	-4	-16
-7	-12	-5	-15	-10
-4	-1	-11	0	-6

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	21
-5	28	19	4	24
-5	11	15	17	24
4	16	20	26	14
1	16	5	5	20

x[:,:,1] * w0[:,:,1]

4	7	6	-1	12
-5	3	-4	-9	13
-7	15	-10	-2	-6
-15	8	3	-2	15
-12	2	13	3	19

b0

1

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	-8
-3	-5	32	11	-10
9	-7	22	12	-14
9	2	17	14	-13
4	-1	15	9	-5

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	18
7	20	20	22	17
3	17	2	22	28
-15	26	27	1	35
11	15	22	36	35

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	-9
-20	-30	-7	-27	-5
-26	-15	-34	-28	-28
-38	-34	-49	-31	-21
-15	-17	-6	-19	-1

b1

0

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	-17
3	-33	-25	-7	-18
-3	-5	-28	-4	-16
-7	-12	-5	-15	-10
-4	-1	-11	0	-6

Camada convolucional

UFV
Universidade Federal de Viçosa

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	21
-5	28	19	4	24
-5	11	15	17	24
4	16	20	26	14
1	16	5	5	20

x[:,:,1] * w0[:,:,1]

4	7	6	-1	12
-5	3	-4	-9	13
-7	15	-10	-2	-6
-15	8	3	-2	15
-12	2	13	3	19

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	-8
-3	-5	32	11	-10
9	-7	22	12	-14
9	2	17	14	-13
4	-1	15	9	-5

b0

1

Σ

v[:,:,0]

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	18
7	20	20	22	17
3	17	2	22	28
-15	26	27	1	35
11	15	22	36	35

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	-9
-20	-30	-7	-27	-5
-26	-15	-34	-28	-28
-38	-34	-49	-31	-21
-15	-17	-6	-19	-1

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	-17
3	-33	-25	-7	-18
-3	-5	-28	-4	-16
-7	-12	-5	-15	-10
-4	-1	-11	0	-6

b1

0

Σ

v[:,:,1]

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	21
-5	28	19	4	24
-5	11	15	17	24
4	16	20	26	14
1	16	5	5	20

x[:,:,1] * w0[:,:,1]

4	7	6	-1	12
-5	3	-4	-9	13
-7	15	-10	-2	-6
-15	8	3	-2	15
-12	2	13	3	19

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	-8
-3	-5	32	11	-10
9	-7	22	12	-14
9	2	17	14	-13
4	-1	15	9	-5

b0

1

$\sum$

v[:,:,0]

0	34	39	23	35
-12	27	48	7	28
-2	20	28	48	5
-1	27	41	39	17
-6	15	34	18	35

---

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	18
7	20	20	22	17
3	17	2	22	28
-15	26	27	1	35
11	15	22	36	35

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	-9
-20	-30	-7	-27	-5
-26	-15	-34	-28	-28
-38	-34	-49	-31	-21
-15	-17	-6	-19	-1

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	-17
3	-33	-25	-7	-18
-3	-5	-28	-4	-16
-7	-12	-5	-15	-10
-4	-1	-11	0	-6

b1

0

$\sum$

v[:,:,1]

-24	-18	-16	-7	-8
-10	-43	-12	-12	-6
-26	-3	-60	-10	-16
-60	-20	-27	-45	4
-8	-3	5	17	28

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	21
-5	28	19	4	24
-5	11	15	17	24
4	16	20	26	14
1	16	5	5	20

x[:,:,1] * w0[:,:,1]

4	7	6	-1	12
-5	3	-4	-9	13
-7	15	-10	-2	-6
-15	8	3	-2	15
-12	2	13	3	19

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	-8
-3	-5	32	11	-10
9	-7	22	12	-14
9	2	17	14	-13
4	-1	15	9	-5

b0

1

∑

v[:,:,0]

0	34	39	23	35
-12	27	48	7	28
-2	20	28	48	5
-1	27	41	39	17
-6	15	34	18	35

f

ReLu

y[:,:,0]

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	18
7	20	20	22	17
3	17	2	22	28
-15	26	27	1	35
11	15	22	36	35

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	-9
-20	-30	-7	-27	-5
-26	-15	-34	-28	-28
-38	-34	-49	-31	-21
-15	-17	-6	-19	-1

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	-17
3	-33	-25	-7	-18
-3	-5	-28	-4	-16
-7	-12	-5	-15	-10
-4	-1	-11	0	-6

b1

0

∑

v[:,:,1]

-24	-18	-16	-7	-8
-10	-43	-12	-12	-6
-26	-3	-60	-10	-16
-60	-20	-27	-45	4
-8	-3	5	17	28

f

ReLu

y[:,:,1]

Camada convolucional

x[:,:,0] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	3	4	6	2	0
0	7	4	4	6	1	0
0	2	6	2	2	7	0
0	4	3	7	7	2	0
0	5	4	1	7	3	0
0	0	0	0	0	0	0

x[:,:,1] 5×5 + pad 1

0	0	0	0	0	0	0
0	5	5	1	7	3	0
0	4	0	3	1	5	0
0	4	3	0	0	2	0
0	2	6	1	7	3	0
0	3	7	6	5	5	0
0	0	0	0	0	0	0

x[:,:,2] 5×5 + pad 1

0	0	0	0	0	0	0
0	6	5	2	3	6	0
0	3	7	0	2	4	0
0	2	6	4	0	6	0
0	1	3	0	3	5	0
0	1	1	0	1	4	0
0	0	0	0	0	0	0

w0[:,:,0]

-1	1	1
1	1	2
0	-2	1

w0[:,:,1]

-1	1	-1
-1	1	2
-1	-1	1

w0[:,:,2]

-1	-1	1
1	-2	2
2	-1	2

x[:,:,0] * w0[:,:,0]

12	26	18	25	21
-5	28	19	4	24
-5	11	15	17	24
4	16	20	26	14
1	16	5	5	20

x[:,:,1] * w0[:,:,1]

4	7	6	-1	12
-5	3	-4	-9	13
-7	15	-10	-2	-6
-15	8	3	-2	15
-12	2	13	3	19

x[:,:,2] * w0[:,:,2]

-17	0	14	-2	-8
-3	-5	32	11	-10
9	-7	22	12	-14
9	2	17	14	-13
4	-1	15	9	-5

b0

1

$\sum$

v[:,:,0]

0	34	39	23	35
-12	27	48	7	28
-2	20	28	48	5
-1	27	41	39	17
-6	15	34	18	35

f

ReLu

y[:,:,0]

0	34	39	23	35
0	27	48	7	28
0	20	28	48	5
0	27	41	39	17
0	15	34	18	35

w1[:,:,0]

-1	-2	1
1	1	2
-2	2	2

w1[:,:,1]

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

w1[:,:,2]

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

x[:,:,0] * w1[:,:,0]

-9	14	6	7	18
7	20	20	22	17
3	17	2	22	28
-15	26	27	1	35
11	15	22	36	35

x[:,:,1] * w1[:,:,1]

-13	-11	-21	-17	-9
-20	-30	-7	-27	-5
-26	-15	-34	-28	-28
-38	-34	-49	-31	-21
-15	-17	-6	-19	-1

x[:,:,2] * w1[:,:,2]

-2	-21	-1	3	-17
3	-33	-25	-7	-18
-3	-5	-28	-4	-16
-7	-12	-5	-15	-10
-4	-1	-11	0	-6

b1

0

$\sum$

v[:,:,1]

-24	-18	-16	-7	-8
-10	-43	-12	-12	-6
-26	-3	-60	-10	-16
-60	-20	-27	-45	4
-8	-3	5	17	28

f

ReLu

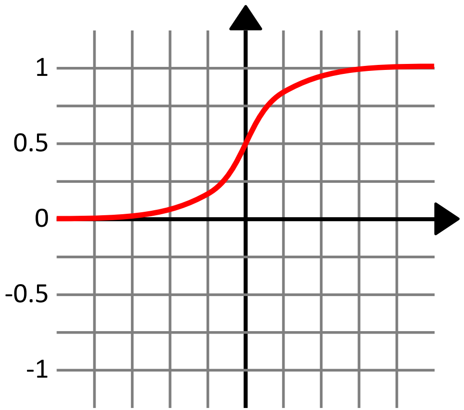
y[:,:,1]

0	0	0	0	0
0	0	0	0	0
0	0	0	0	0
0	0	0	0	4
0	0	5	17	28

FUNÇÃO DE ATIVAÇÃO

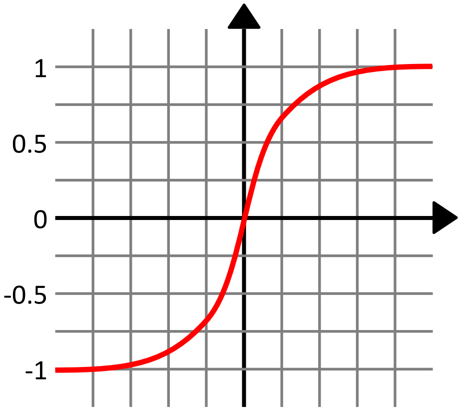
Função de ativação

Logística



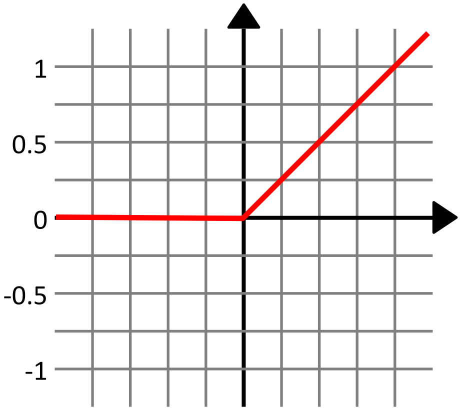
$$y = \frac{1}{1 + e^{-v}}$$

Tangente hiperbólica



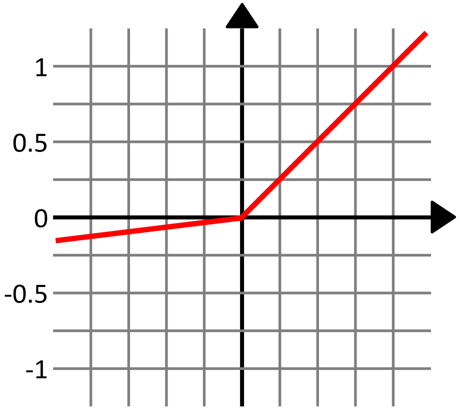
$$y = tanh(v) = \frac{sen(v)}{\cos(v)}$$

ReLu



$$y = max(0, v)$$

PReLu

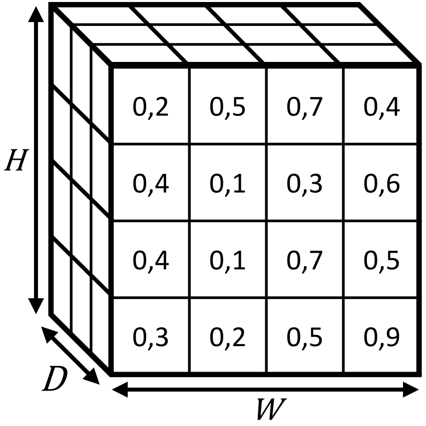


$$y = max(av, v)$$

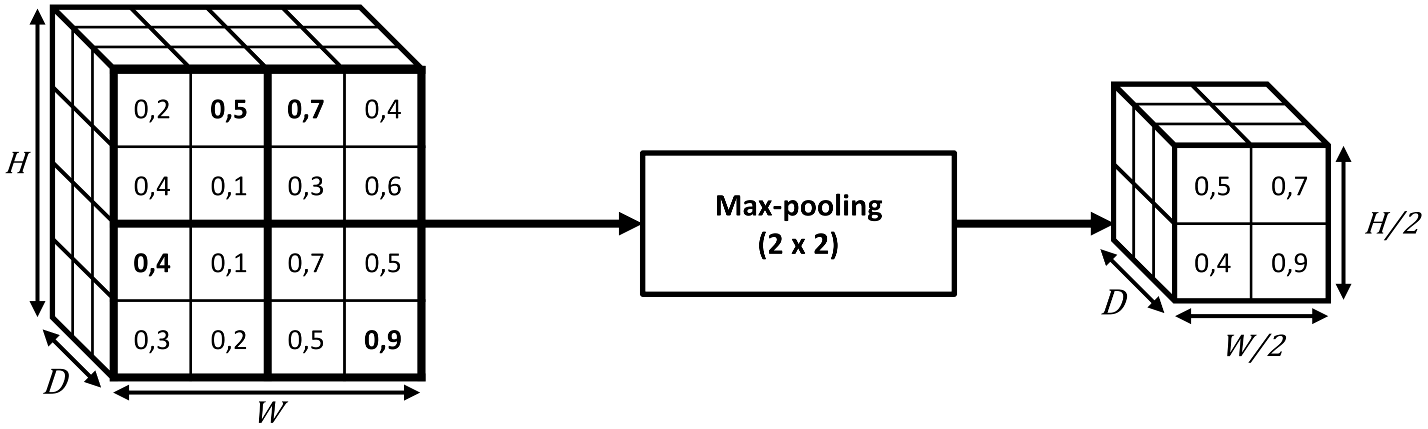
- Se *a*=0,01 → Leak ReLu

CAMADA DE POOLING

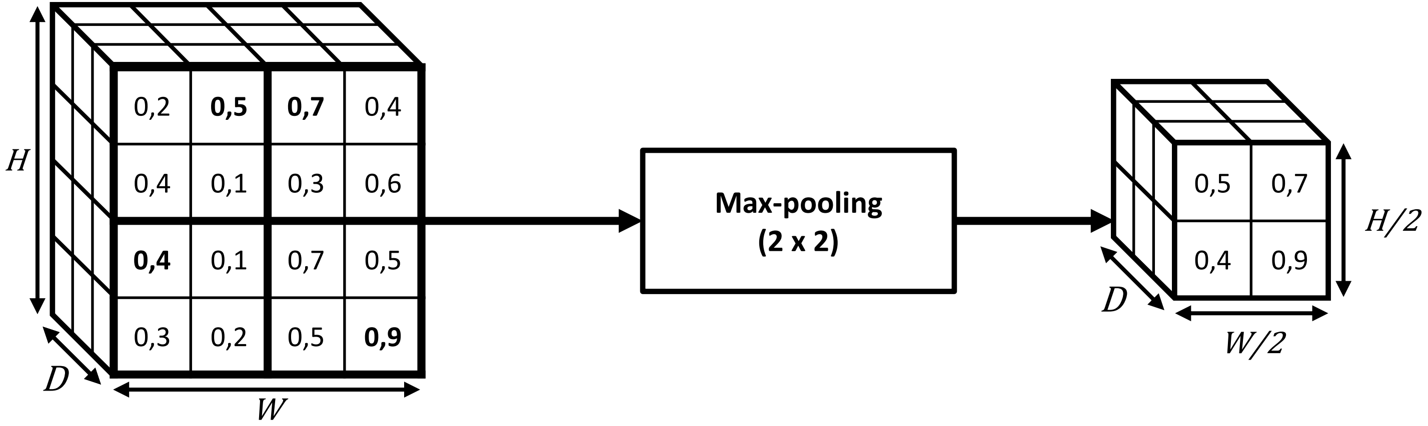
Camada de pooling

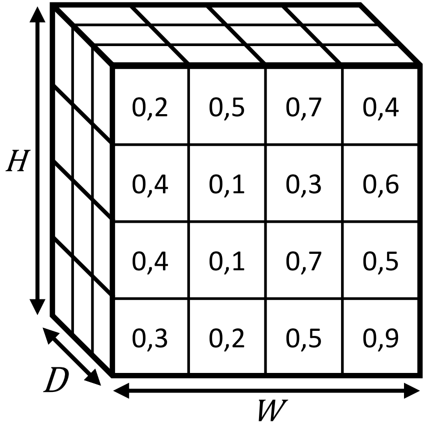


Camada de pooling

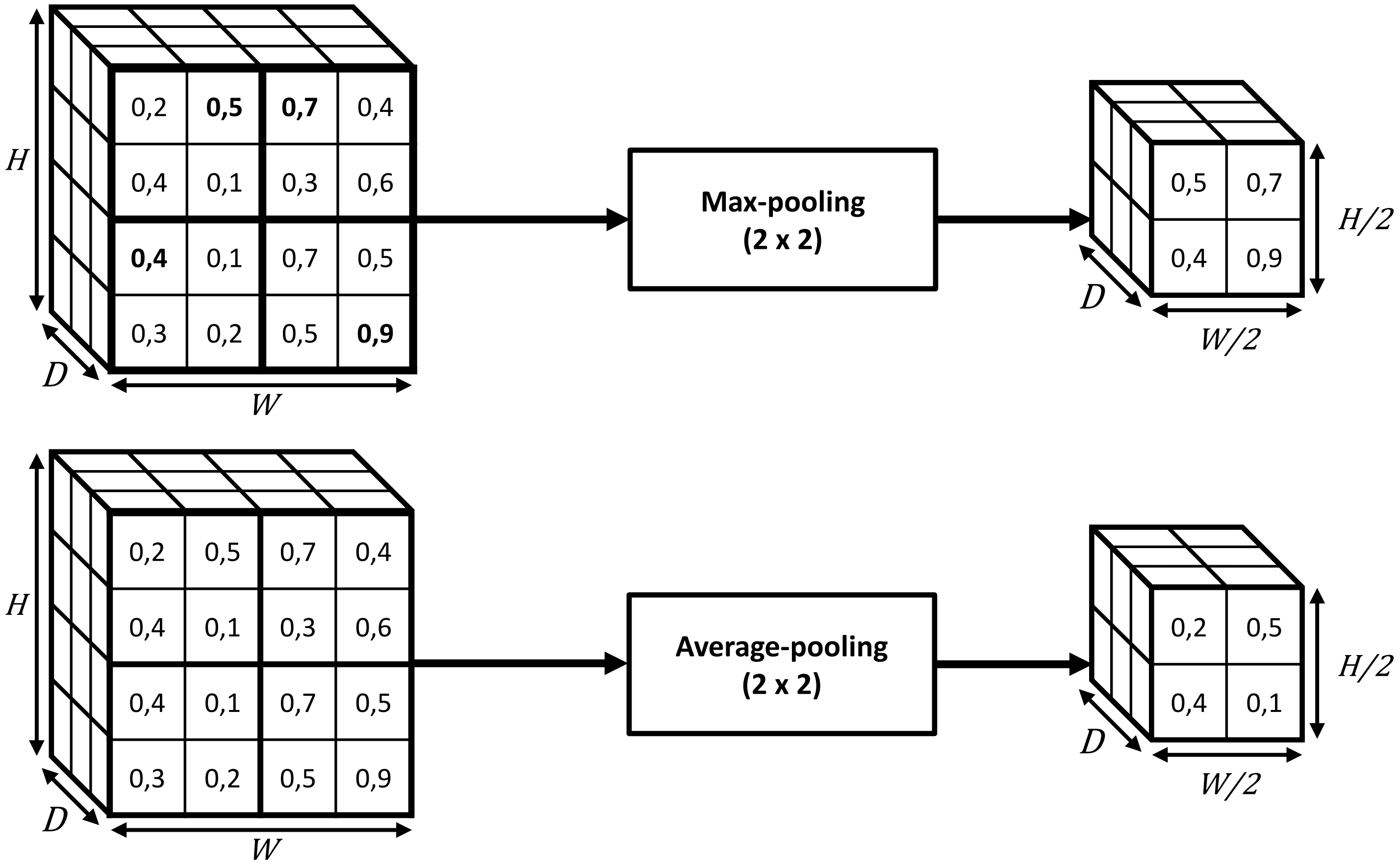


Camada de pooling



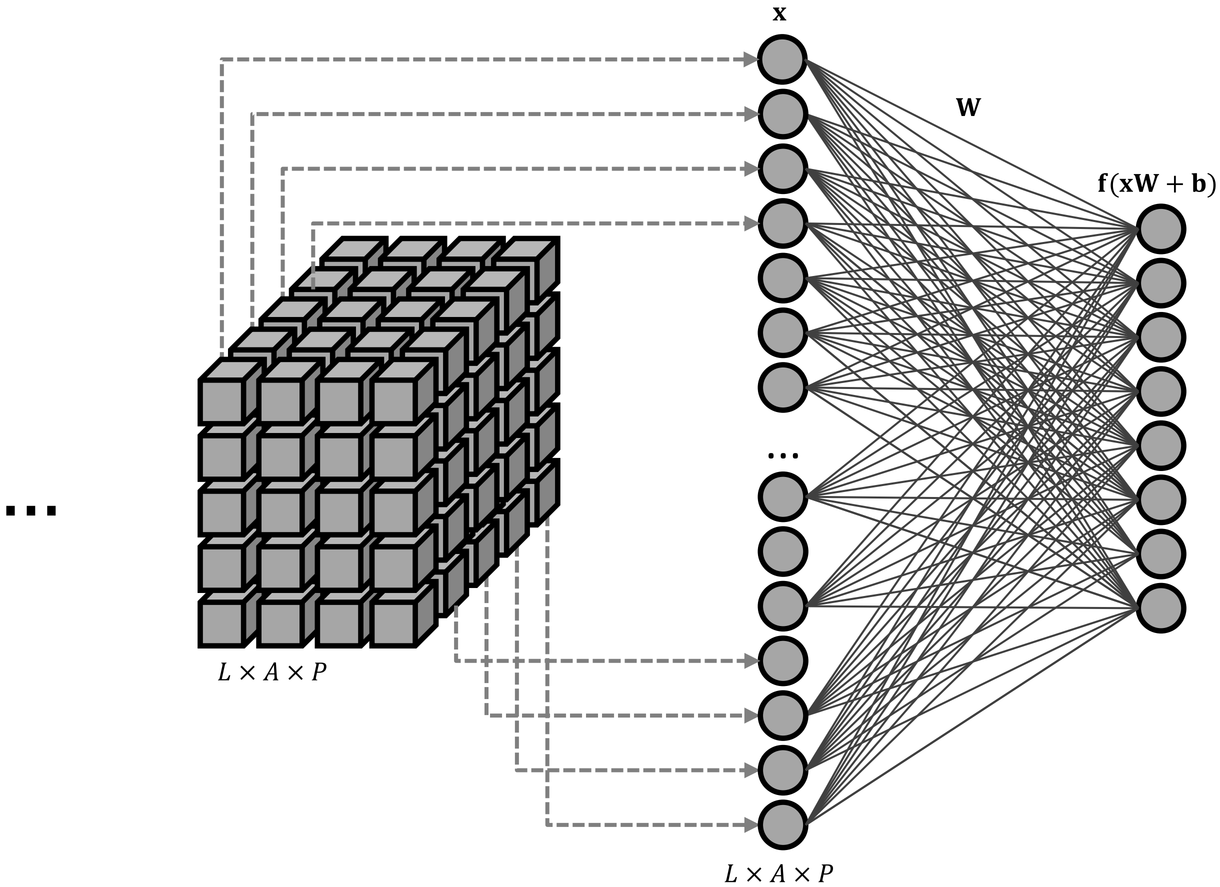


Camada de pooling



CAMADA COMPLETAMENTE CONECTADA

Camada completamente conectada



CAMADA DE SAÍDA - SOFTMAX

Camada de saída – softmax

- Função softmax para M classes:
  - $softmax(x_i) = \frac{e^{x_i}}{\sum_{j=0}^{M-1} e^{x_j}}$

- **Exemplo:**
  - $\mathbf{x} = [-0{,}8 \quad 2{,}0 \quad 6.0 \quad -2{,}7 \quad 0{,}8]$
    - $\sum_{j=0}^{M-1} x_j = 5{,}3$
    - *Soma != de 1,0. Não pode ser interpretado como probabilidades.*
  - $\sum_{j=0}^{M-1} e^{x_j} = 0{,}4493 + 7{,}3891 + 403{,}4288 + 0{,}0672 + 2{,}2255 = 413{,}5599$
  - $softmax(x_i) = [0{,}0011 \quad 0{,}0179 \quad 0{,}9755 \quad 0{,}0002 \quad 0{,}0054]$
    - $\sum_{j=0}^{M-1} softmax(x_i) = 1{,}0$
    - *Representa a probabilidade da amostra pertencer a cada classe.*

FUNÇÃO DE PERDA (LOSS)

Função de perda (loss)

- Entropia cruzada para mais de 2 classes (M>2):
  - $L(\boldsymbol{y}, \widehat{\boldsymbol{y}}) = -\sum_{j=0}^{M-1} \boldsymbol{y}_j \cdot \log(\widehat{\boldsymbol{y}}_j)$

- Entropia cruzada para 2 classes (M=2):
  - $L(\boldsymbol{y}, \widehat{\boldsymbol{y}}) = -(\boldsymbol{y} \cdot \log(\widehat{\boldsymbol{y}}) + (1 - \boldsymbol{y}) \log(1 - \widehat{\boldsymbol{y}}))$

Entropia cruzada para M>2

- 5 classes, classificação **correta**, com 72% de probabilidade:
  - $\boldsymbol{y} = [0 \quad 0 \quad 0 \quad 1 \quad 0]$
  - $\hat{\boldsymbol{y}} = [0{,}20 \quad 0{,}0 \quad 0{,}05 \quad 0{,}72 \quad 0{,}03]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}2 + 0 \times \log 0{,}0 + 0 \times \log 0{,}5 + 1 \times \log 0{,}72 + 0 \times \log 0{,}03)$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(\log 0{,}72) = 0{,}14267$

Entropia cruzada para M>2

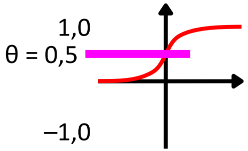
- 5 classes, classificação **correta**, com 72% de probabilidade:
  - $\boldsymbol{y} = [0 \quad 0 \quad 0 \quad 1 \quad 0]$
  - $\widehat{\boldsymbol{y}} = [0{,}20 \quad 0{,}0 \quad 0{,}05 \quad 0{,}72 \quad 0{,}03]$
  - $L(\boldsymbol{y}, \widehat{\boldsymbol{y}}) = -(0 \times \log 0{,}2 + 0 \times \log 0{,}0 + 0 \times \log 0{,}5 + 1 \times \log 0{,}72 + 0 \times \log 0{,}03)$
  - $L(\boldsymbol{y}, \widehat{\boldsymbol{y}}) = -(\log 0{,}72) = 0{,}14267$
- 5 classes, classificação **correta**, com 52% de probabilidade:
  - $\boldsymbol{y} = [0 \quad 0 \quad 0 \quad 1 \quad 0]$
  - $\widehat{\boldsymbol{y}} = [0{,}30 \quad 0{,}0 \quad 0{,}05 \quad 0{,}52 \quad 0{,}13]$
  - $L(\boldsymbol{y}, \widehat{\boldsymbol{y}}) = -(0 \times \log 0{,}3 + 0 \times \log 0{,}0 + 0 \times \log 0{,}5 + 1 \times \log 0{,}52 + 0 \times \log 0{,}13)$
  - $L(\boldsymbol{y}, \widehat{\boldsymbol{y}}) = -(\log 0{,}52) = 0{,}284$

Entropia cruzada para M>2

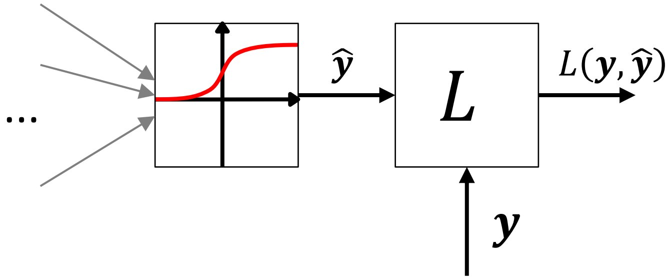
- 5 classes, classificação **correta**, com 72% de probabilidade:
  - $\boldsymbol{y} = [0 \quad 0 \quad 0 \quad 1 \quad 0]$
  - $\hat{\boldsymbol{y}} = [0{,}20 \quad 0{,}0 \quad 0{,}05 \quad 0{,}72 \quad 0{,}03]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}2 + 0 \times \log 0{,}0 + 0 \times \log 0{,}5 + 1 \times \log 0{,}72 + 0 \times \log 0{,}03)$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(\log 0{,}72) = 0{,}14267$
- 5 classes, classificação **correta**, com 52% de probabilidade:
  - $\boldsymbol{y} = [0 \quad 0 \quad 0 \quad 1 \quad 0]$
  - $\hat{\boldsymbol{y}} = [0{,}30 \quad 0{,}0 \quad 0{,}05 \quad 0{,}52 \quad 0{,}13]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}3 + 0 \times \log 0{,}0 + 0 \times \log 0{,}5 + 1 \times \log 0{,}52 + 0 \times \log 0{,}13)$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(\log 0{,}52) = 0{,}284$
- 5 classes, classificação **incorreta**:
  - $\boldsymbol{y} = [0 \quad 0 \quad 0 \quad 1 \quad 0]$
  - $\hat{\boldsymbol{y}} = [0{,}60 \quad 0{,}0 \quad 0{,}07 \quad 0{,}30 \quad 0{,}03]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}6 + 0 \times \log 0{,}0 + 0 \times \log 0{,}07 + 1 \times \log 0{,}3 + 0 \times \log 0{,}03)$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(\log 0{,}3) = 0{,}5229$

Entropia cruzada para M=2

- 2 classes, classificação correta:
  - $\boldsymbol{y} = [0]$
  - $\hat{\boldsymbol{y}} = [0{,}20]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}2 + (1-0) \times \log(1-0{,}2))$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}2 + (1) \times \log(0{,}8)) = -(\log(0{,}8)) = 0{,}09691$

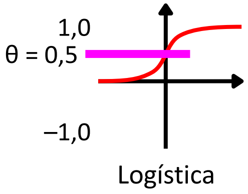


Logística

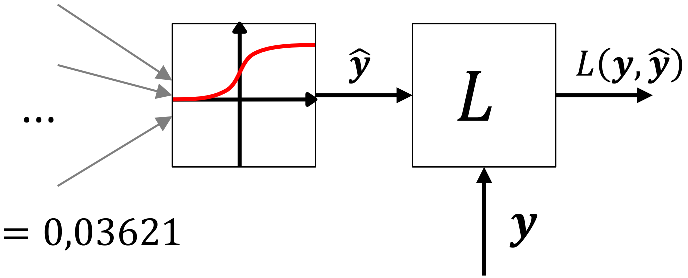


Entropia cruzada para M=2

- 2 classes, classificação correta:
  - $\boldsymbol{y} = [0]$
  - $\hat{\boldsymbol{y}} = [0{,}20]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}2 + (1-0) \times \log(1-0{,}2))$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}2 + (1) \times \log(0{,}8)) = -(\log(0{,}8)) = 0{,}09691$

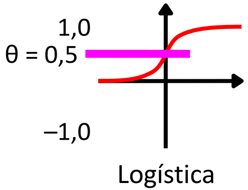


- 2 classes, classificação correta:
  - $\boldsymbol{y} = [1]$
  - $\hat{\boldsymbol{y}} = [0{,}92]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(1 \times \log 0{,}92 + (1-1) \times \log(1-0{,}92))$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(1 \times \log 0{,}92 + (0) \times \log(0{,}08)) = -(\log(0{,}92)) = 0{,}03621$

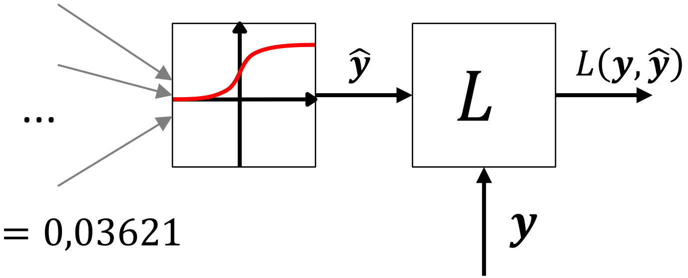


Entropia cruzada para M=2

- 2 classes, classificação correta:
  - $\boldsymbol{y} = [0]$
  - $\hat{\boldsymbol{y}} = [0{,}20]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}2 + (1-0) \times \log(1 - 0{,}2))$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}2 + (1) \times \log(0{,}8)) = -(\log(0{,}8)) = 0{,}09691$



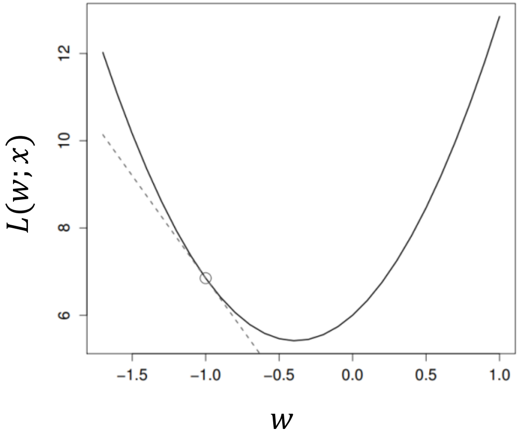
- 2 classes, classificação correta:
  - $\boldsymbol{y} = [1]$
  - $\hat{\boldsymbol{y}} = [0{,}92]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(1 \times \log 0{,}92 + (1-1) \times \log(1 - 0{,}92))$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(1 \times \log 0{,}92 + (0) \times \log(0{,}08)) = -(\log(0{,}92)) = 0{,}03621$

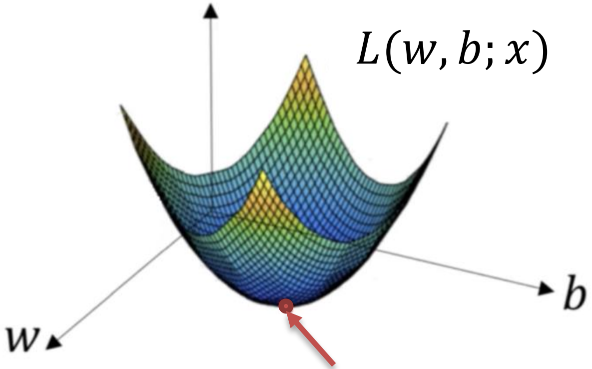


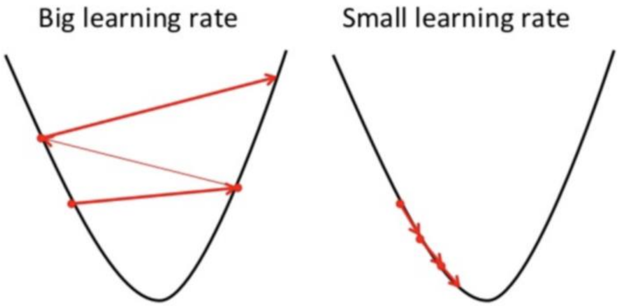
- 2 classes, classificação incorreta:
  - $\boldsymbol{y} = [0]$
  - $\hat{\boldsymbol{y}} = [0{,}65]$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}65 + (1-0) \times \log(1 - 0{,}65))$
  - $L(\boldsymbol{y}, \hat{\boldsymbol{y}}) = -(0 \times \log 0{,}65 + (1) \times \log(0{,}35)) = -(\log(0{,}35)) = 0{,}45593$

OTIMIZADORES

- Gradiente descendente (GD - *Gradient descent)*:
  - $W_{t+1} = W_t - \eta \sum_{j=1}^{N} \nabla L(W; x_j)$
  - N é o tamanho do conjunto de treinamento





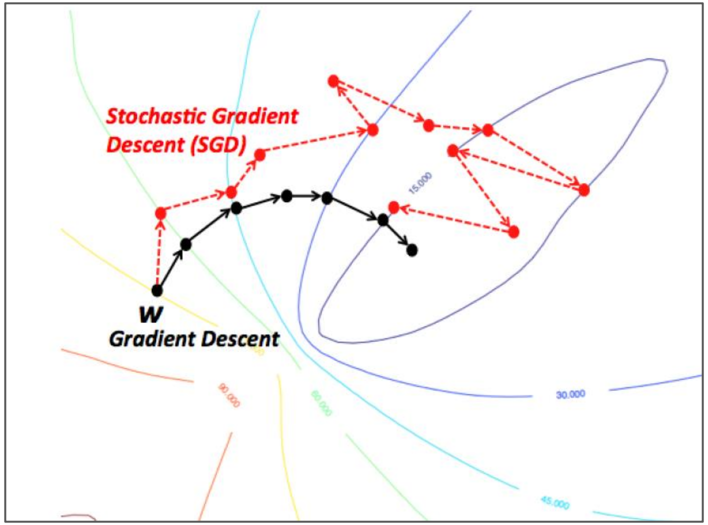


Moacir Ponti. *http://conteudo.icmc.usp.br/pessoas/moacir/p17sibgrapi-tutorial/*

Donges. Gradient Descent in Machine Learning: A Basic Introduction. *https://builtin.com/data-science/gradient-descent*

Otimizadores

- Gradiente descendente estocástico (SGD – *Stochastic gradient descent*):
  - $W_{t+1} = W_t - \eta \sum_{j=1}^{B} \nabla L(W; x_j^B)$
  - B é o tamanho do mini-lote (*mini-batch*)



https://wikidocs.net/3413

Otimizadores

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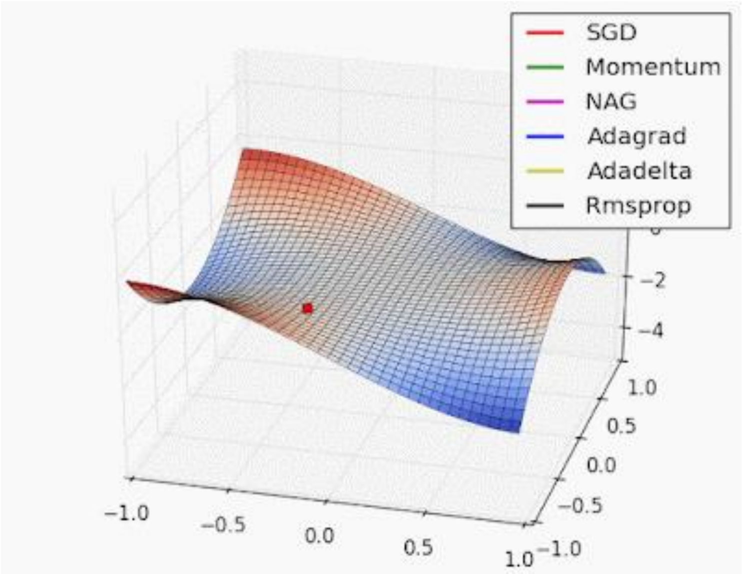
- SGD com momentum:
  - $W_{t+1} = W_t - \eta \sum_{j=1}^{B} \nabla L(W; x_j^B)$
    - B é o tamanho do mini-lote (*mini-batch*)
  - $W_{t+1} = W_t + \alpha(W_t - W_{t-1}) + (1 - \alpha)[-\eta \sum_{j=1}^{B} \nabla L(W; x_j^B)]$



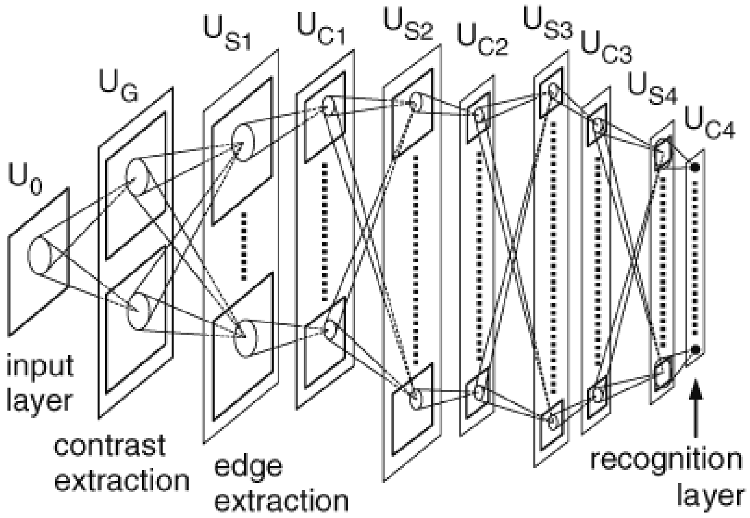
http://www.denizyuret.com/2015/03/alec-radfords-animations-for.html

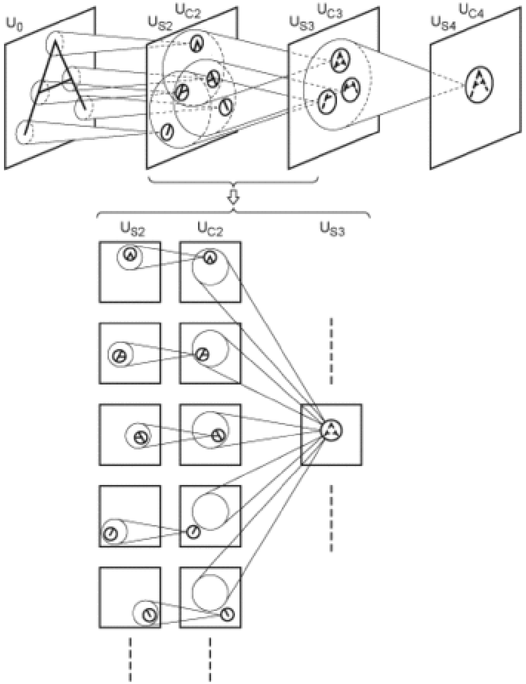
Otimizadores

- Outros otimizadores:
  - AdaGrad - *Adaptive Gradient*
  - AdaDelta - *Adaptive learning rate*
  - RMSProp - *Root Mean Squared Propagation*
  - Adam - *Adaptive moment estimation*
  - ...

ARQUITETURAS

- Neocognitron (1979)



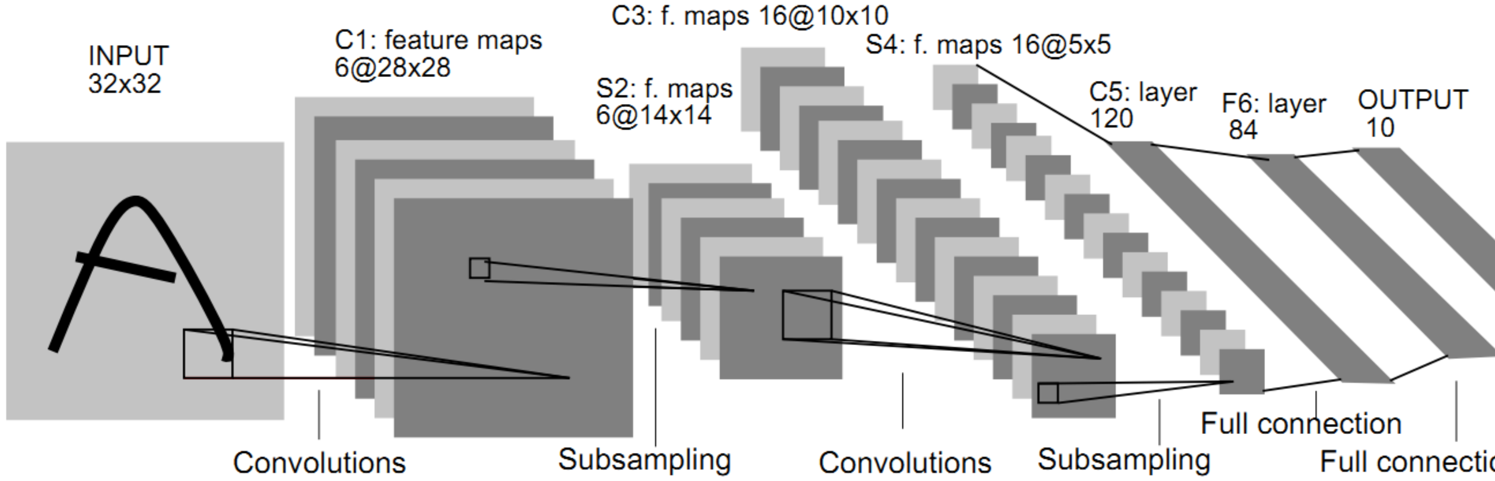


Kunihiko Fukushima

Fukushima, K. (1980). "Neocognitron: A self-organizing neural network model for a mechanism of pattern recognition unaffected by shift in position". Biological Cybernetics. 36 (4)

Arquiteturas

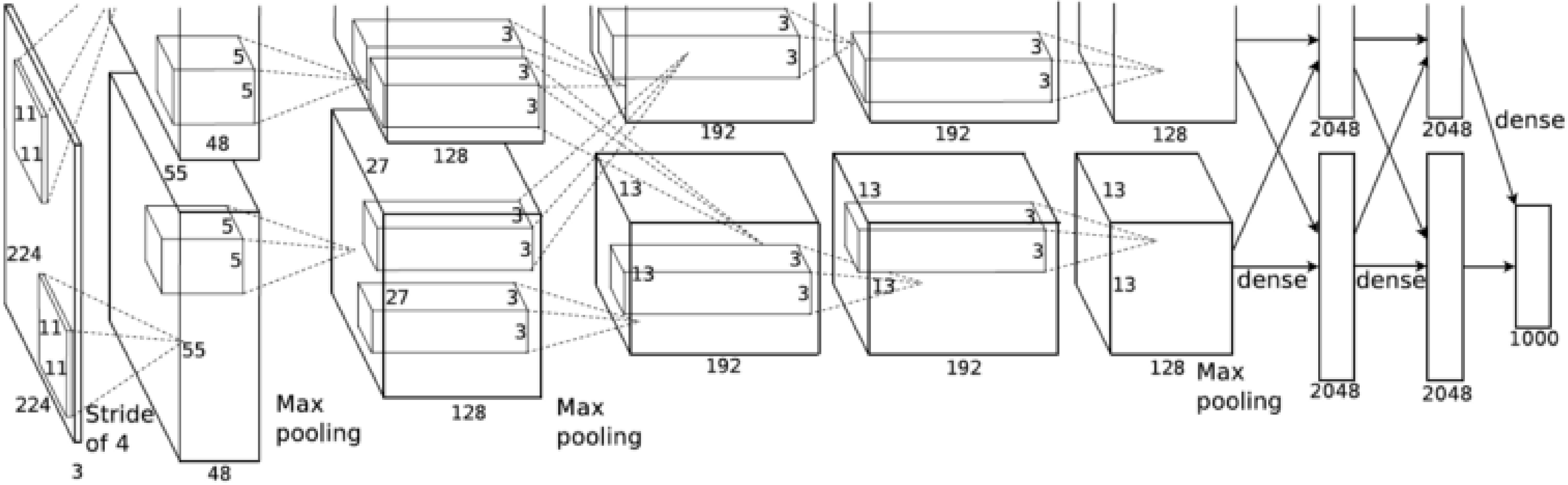
- LeNet-5 (1998)



Yann LeCun

Lecun, Y. et al. (1998). "Gradient-based learning applied to document recognition". Proceedings of the IEEE. 86 (11): 2278–2324.

- AlexNet (2012)



Krizhevsky, Sutskever e Hinton. ImageNet Classification with Deep Convolutional Neural Networks. NeuripIPS 2012

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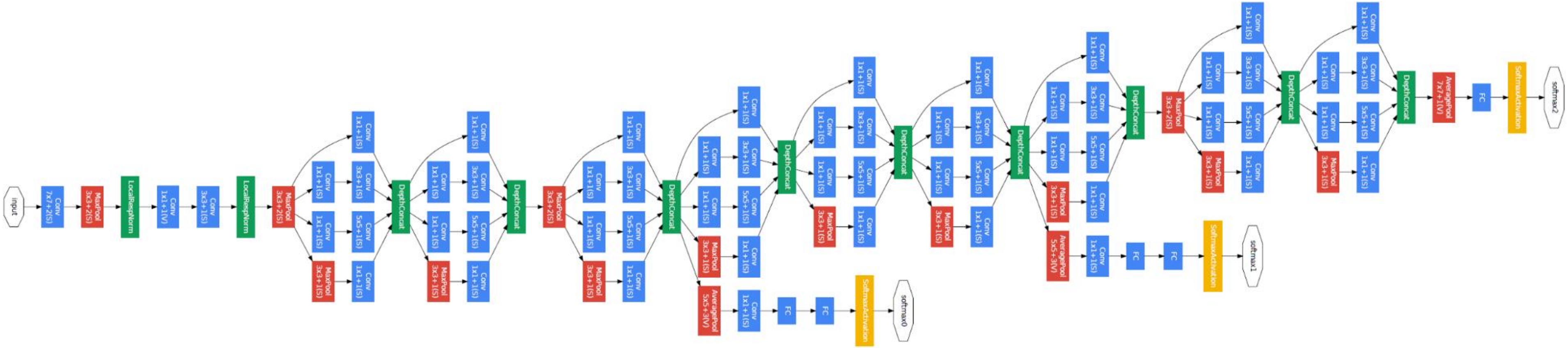
- Inception (GoogLeNet) (2015)



Szegedy, Christian (2015). "Going deeper with convolutions". CVPR2015.

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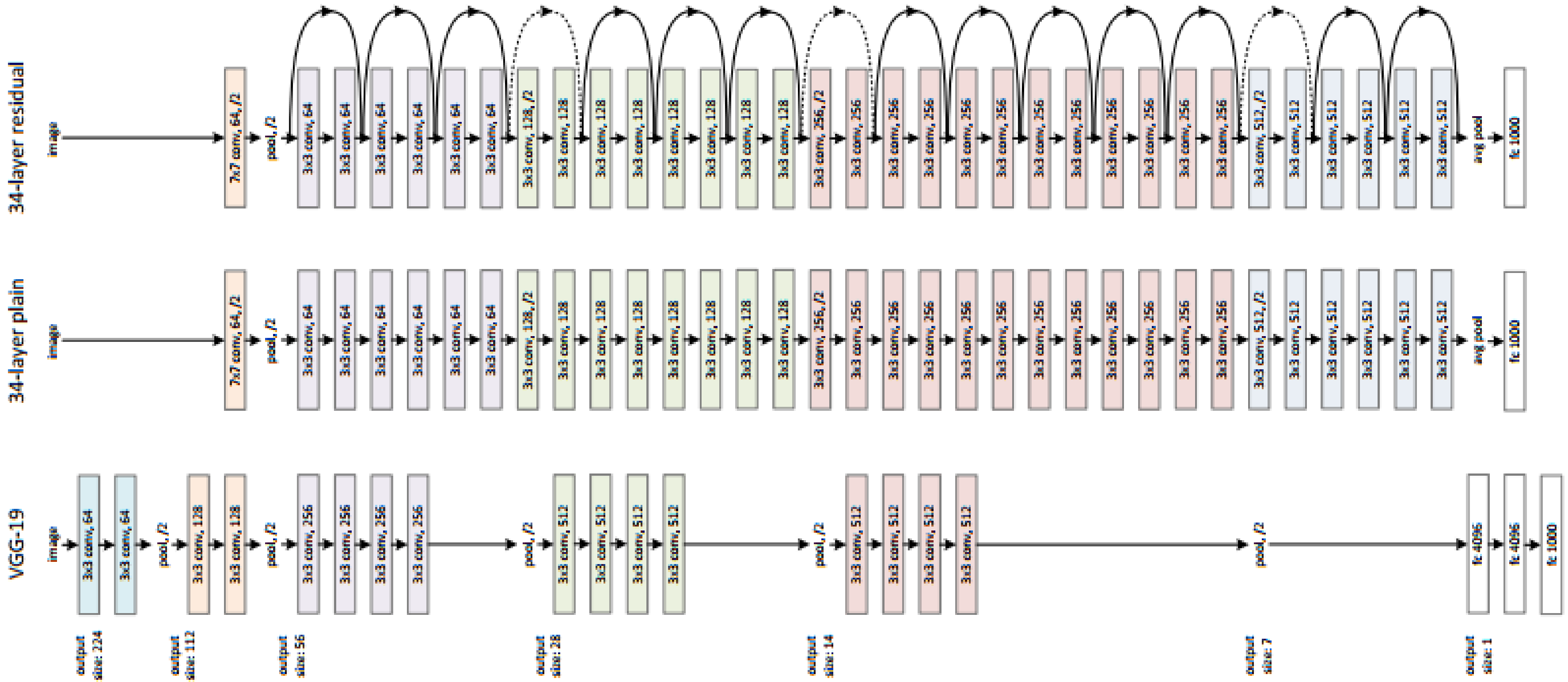
- VGG (2014) e ResNet (2015)



Simonyan e Zisserman. Very Deep Convolutional Networks for Large-Scale Image Recognition. 2014

He et al. Deep Residual Learning for Image Recognition. 2015.

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- DenseNet (2017)

Huang et al. Densely Connected Convolutional Networks. CVPR 2017.

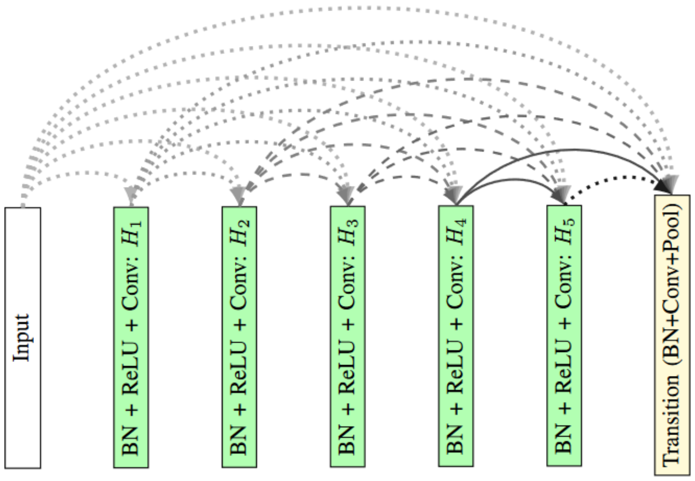


Figure 10. Illustration of a DenseBlock with 5 functions H_l and a Transition Layer.

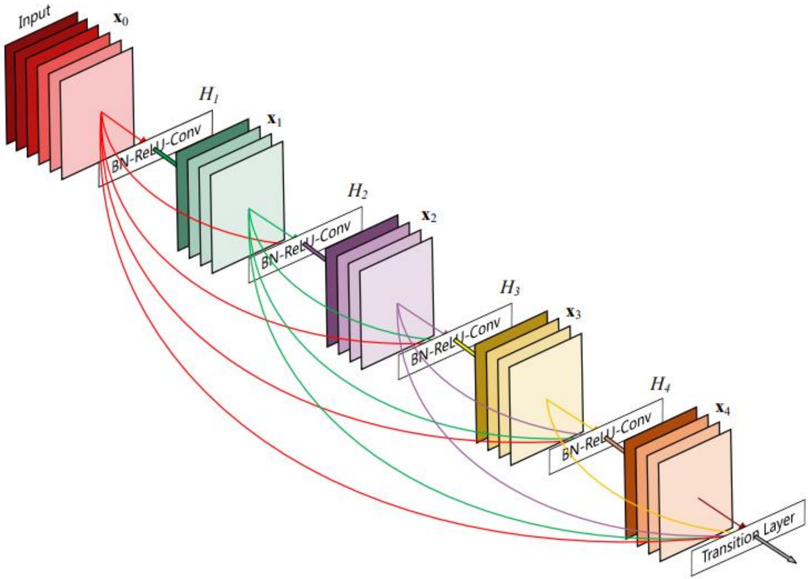
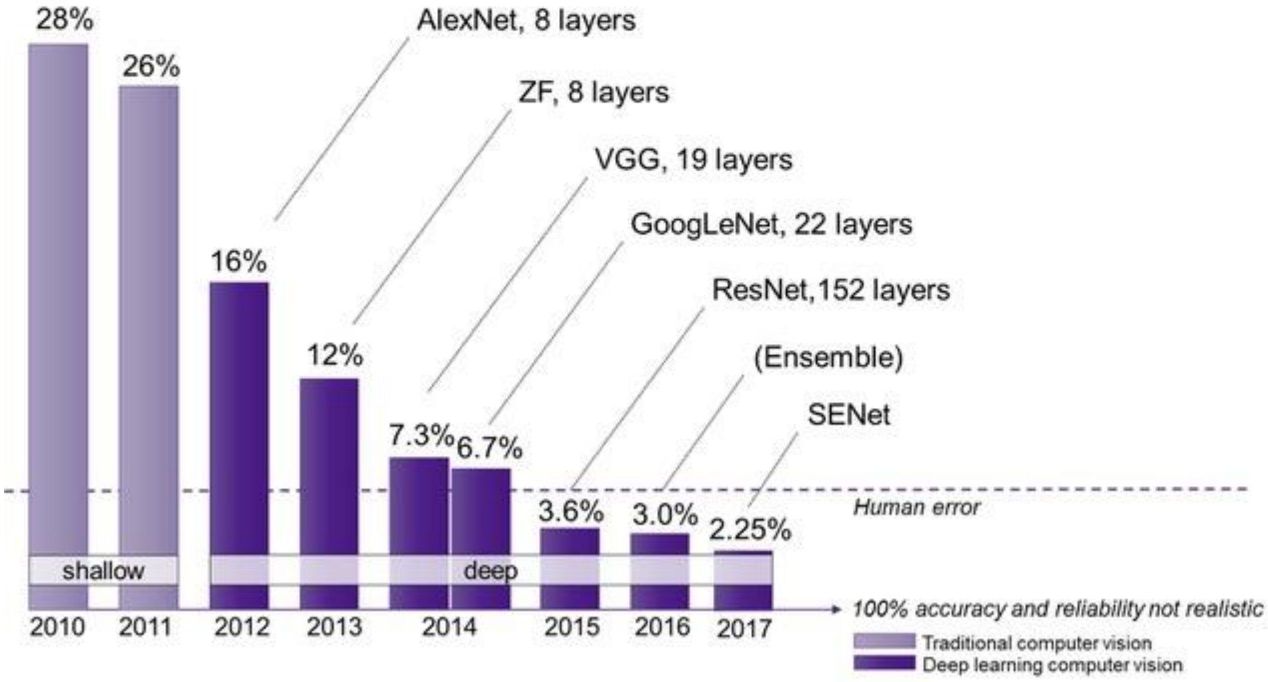


Figure 1: A 5-layer dense block with a growth rate of $k = 4$. Each layer takes all preceding feature-maps as input.

Ponti et al. Everything You Wanted to Know about Deep Learning for Computer Vision but Were Afraid to Ask. Sibgrapi 2017.

- ImageNet Large Scale Visual Recognition Challenge
  - https://image-net.org/challenges/LSVRC/



https://semiengineering.com/new-vision-technologies-for-real-world-applications/

BIBLIOTECAS E DESENVOLVIMENTO

Bibliotecas e desenvolvimento

- O treinamento de CNNs possui alto custo computacional.
  - Recomenda-se que sejam treinados usando GPUs.
  - O Google Colab fornece acesso à GPUs (com algumas restrições).

Bibliotecas e desenvolvimento

- Principais bibliotecas para Deep Learning e Redes Neurais Convolucionais
  - PyTorch
    - https://pytorch.org/
  - Tensorflow
    - https://www.tensorflow.org/

Bibliotecas e desenvolvimento

- **Anaconda Distribution:**
  - Distribuição Python com suporte às principais bibliotecas
  - https://www.anaconda.com/products/distribution
- **Google Colab:**
  - Ambiente de execução em nuvem com GPUs.
  - https://colab.research.google.com

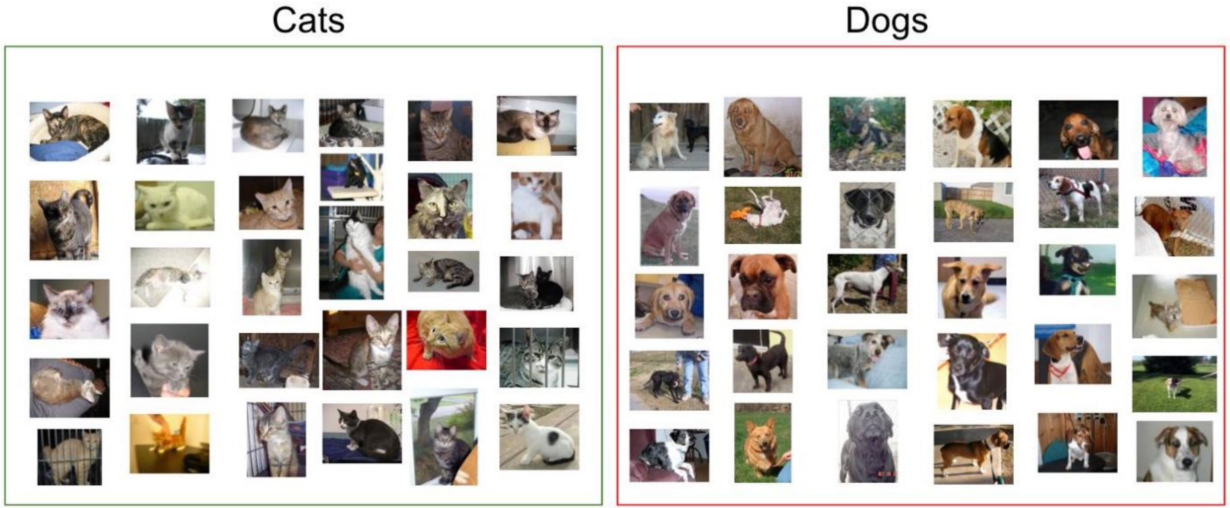
CONJUNTOS DE IMAGENS

Conjuntos de imagens

- MNIST
  - http://yann.lecun.com/exdb/mnist/
  - 60,000 training images
  - 10,000 testing images
  - 28 x 28 pixels
  - Níveis de cinza

Conjuntos de imagens

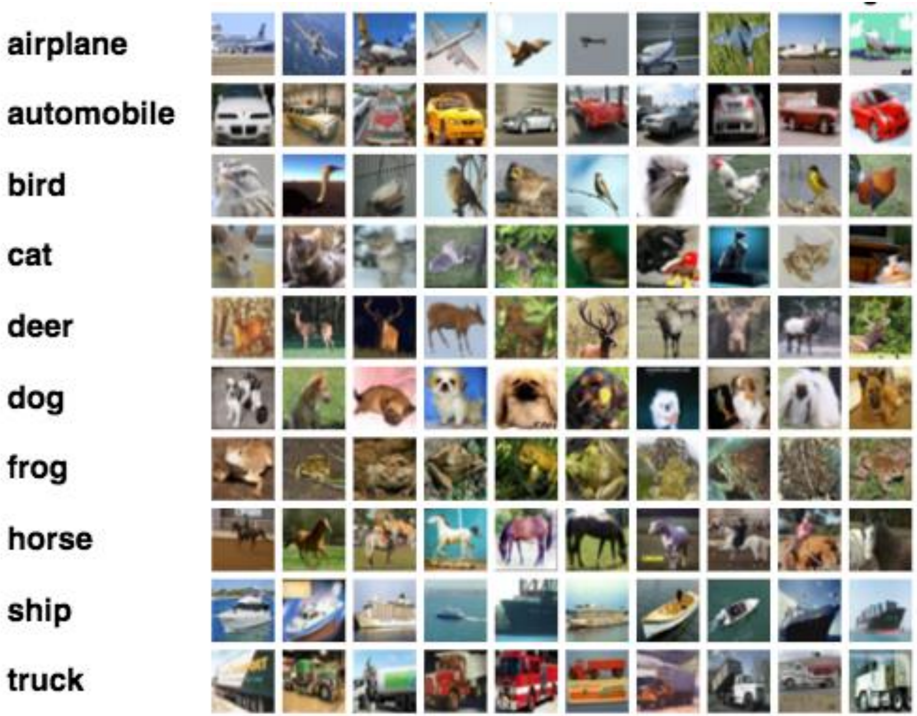
- **Cats vs. Dogs:**
  - https://www.kaggle.com/c/dogs-vs-cats
  - 25,000 images de treinamento
  - 12,500 imagens de teste
  - 2 classes
  - Diversos tamanhos
  - RGB



Sample of cats & dogs images from Kaggle Dataset

Conjuntos de imagens

- **CIFAR10:**
  - https://www.cs.toronto.edu/~kriz/cifar.html
  - 50,000 training images
  - 10,000 testing images
  - 10 classes
  - 32 x 32 pixels
  - RGB



Conjuntos de imagens

- **ImageNet:**
  - https://www.image-net.org/
  - ~1,000,000 imagens
  - 1,000 classes
  - RGB

IMAGENET

Bibliografia

- Ponti et al. **Everything You Wanted to Know about Deep Learning for Computer Vision but Were Afraid to Ask**. Sibgrapi 2017.
- Moacir Ponti (ICMC-USP). **Material para o minicurso *Deep Learning***
  - https://github.com/maponti/deeplearning_intro_datascience
- **Learn TensorFlow and deep learning, without a Ph.D.**
  - https://cloud.google.com/blog/products/gcp/learn-tensorflow-and-deep-learning-without-a-phd
- CS231n: Convolutional Neural Networks for Visual Recognition
  - http://cs231n.github.io/
- Goodfellow, Bengio e Courville. **Deep Learning**. MIT Press, 2016
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