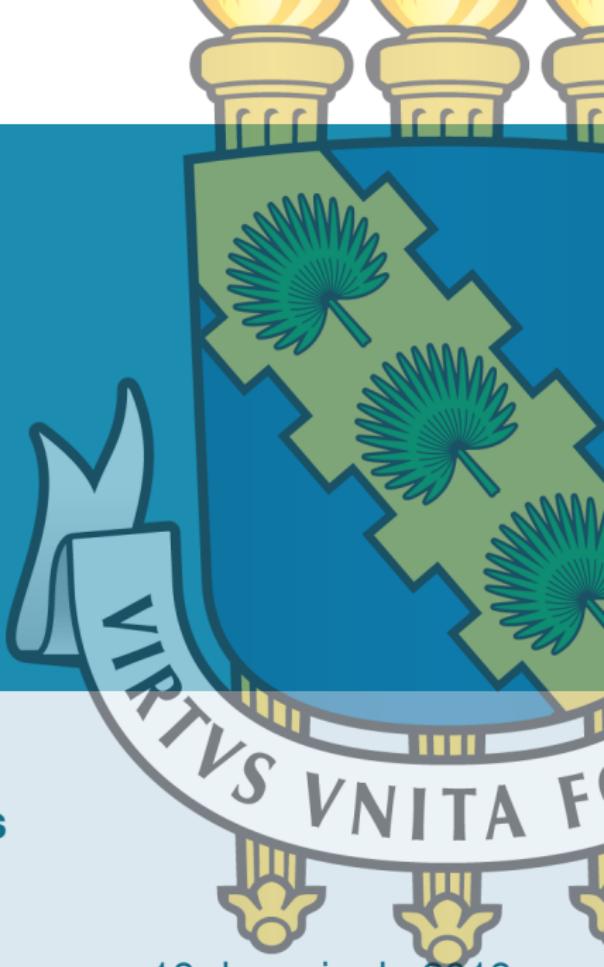


Behavioral Cloning

NEMO

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Departamento de Computação*



19 de maio de 2019

Instrutor



F. Nauber Bernardo Gois

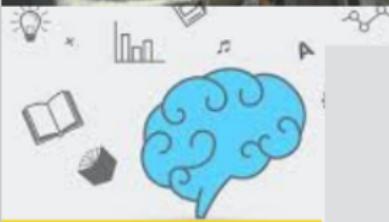
Dsc. Informática Aplicada
Professor Adjunto
Campus/ UFC Russas



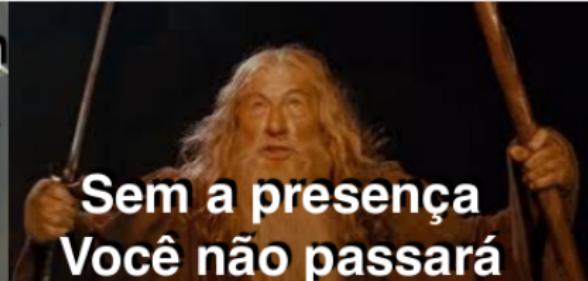
**Jovem Padawan
procure na aula**



ao telefone
não falar



**Procure
não
conversar
durante a
aula**



**Sem a presença
Você não passará**



**Para melhor
desempenho na
aula**

**Buscar
aprendizado
ao invés de
pontos**



**Não
teremos
pontuação fora dos
trabalhos e provas
da disciplina**



Índice

Índice

Objetivo da Aula

Behavioral Cloning

Extração de Feature de Imagens

Conclusão



Objetivo de Aprendizado

Ao final da aula você deve estar apto a:

Compreender qual o objetivo do uso de Behavioral Cloning

Compreender aplicação de Imitation Learning

Compreender como funcionam Redes Convolucionais



Behavioral Cloning

Definição

- Técnica que permite clonar um comportamento humano para realizar determinada tarefa



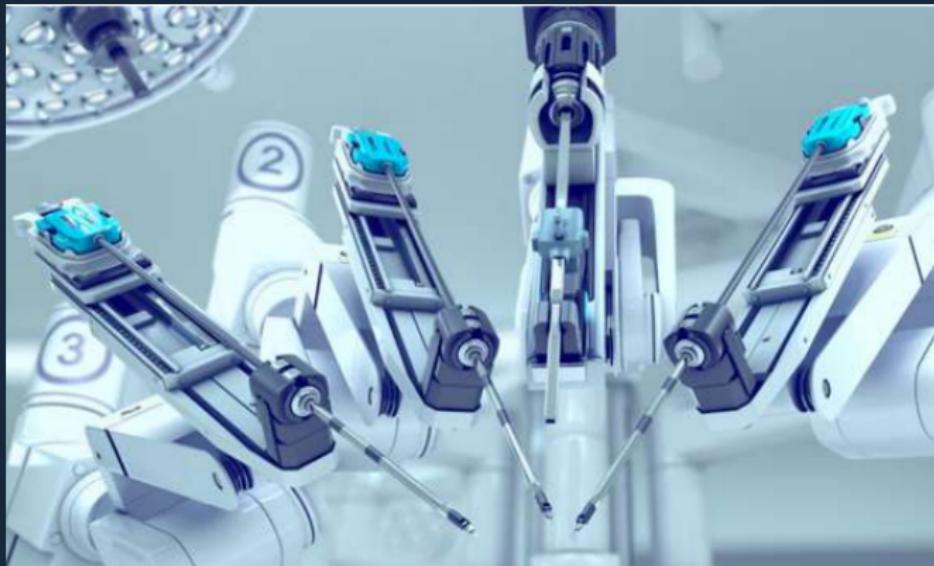
Behavioral Cloning



Autonomous Driving



Behavioral Cloning



Robotic Surgery

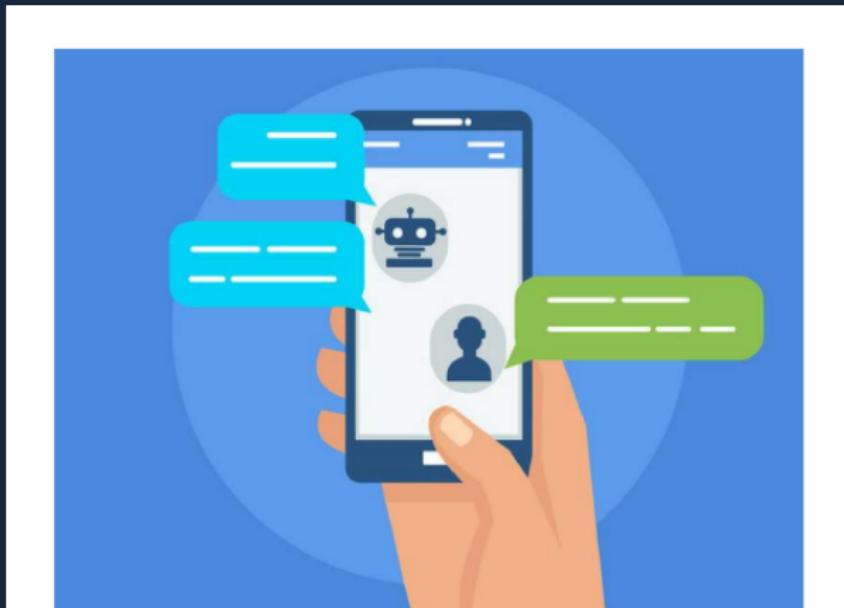


Behavioral Cloning



Assistive Robotics

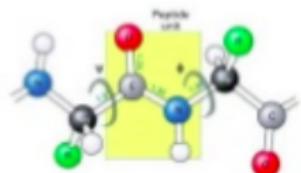
Behavioral Cloning



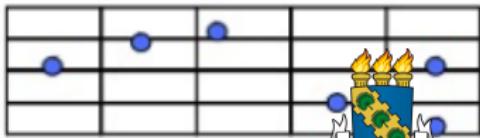
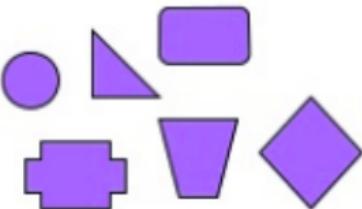
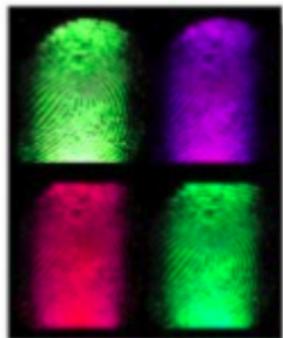
Conversational Agents



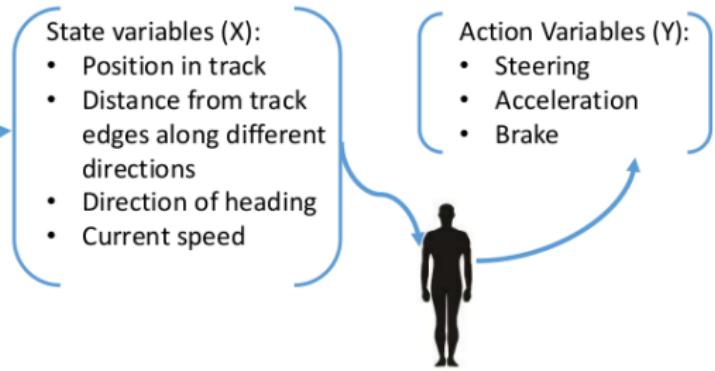
O que é um padrão



act-a A A



Behavioral Cloning



A quick primer on Machine Learning



Behavioral Cloning



Behavioral Cloning



Reconhecimento de Padrões

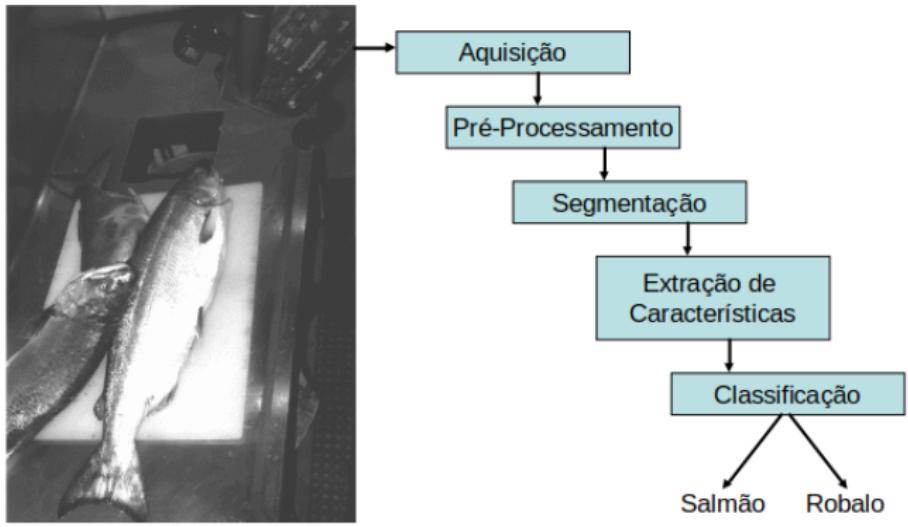
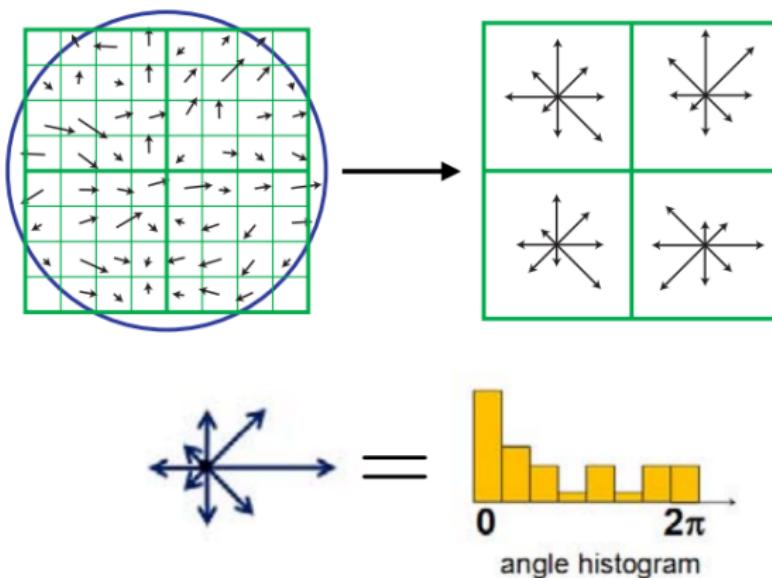


Figura: Caption



SIFT

- Describe local region by distribution (over angle) of gradients



SIFT

- Extract SIFT features from an image



Each image might generate 100's or 1000's of SIFT descriptors

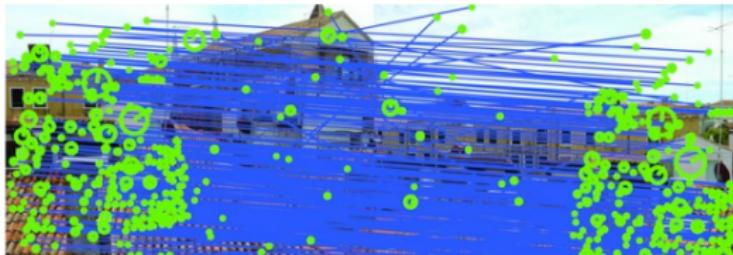


SIFT

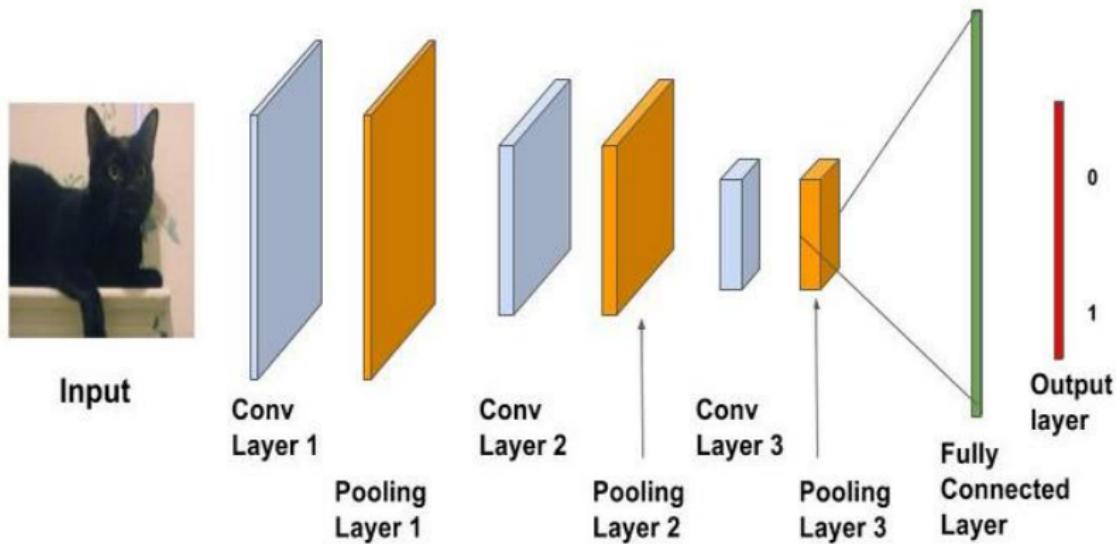
- Goal: Find all correspondences between a pair of images



- Extract and match all SIFT descriptors from both images



Redes Convolucionais



Feature Extractor

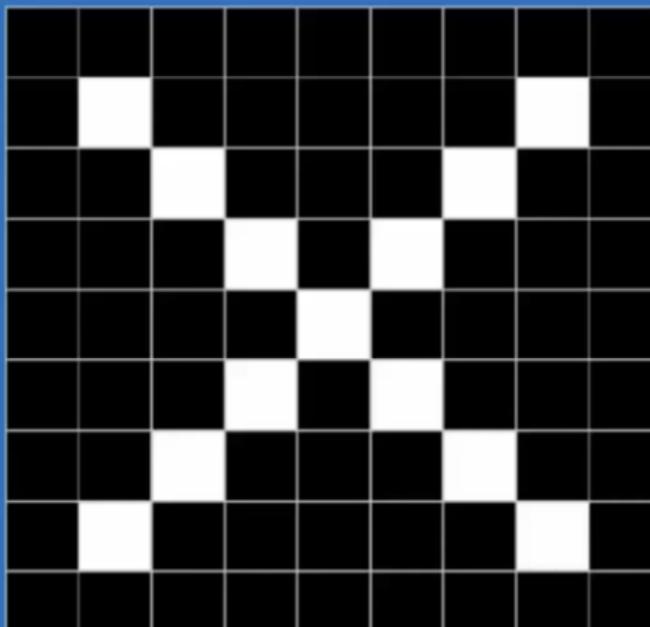
Classifier



Redes Convolucionais

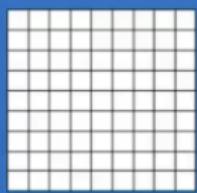
Columns of pixels →

Rows of pixels ↓

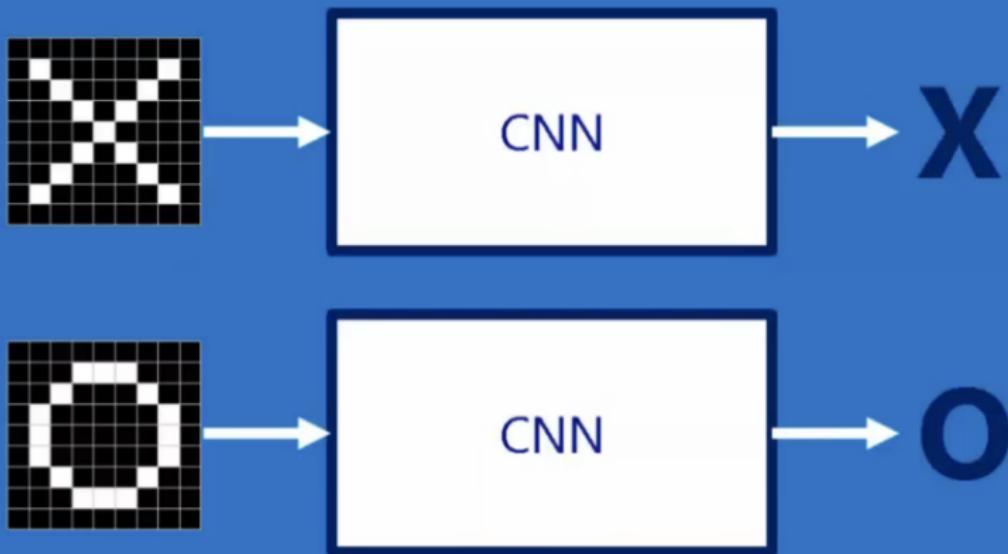


Redes Convolucionais

A two-dimensional
array of pixels

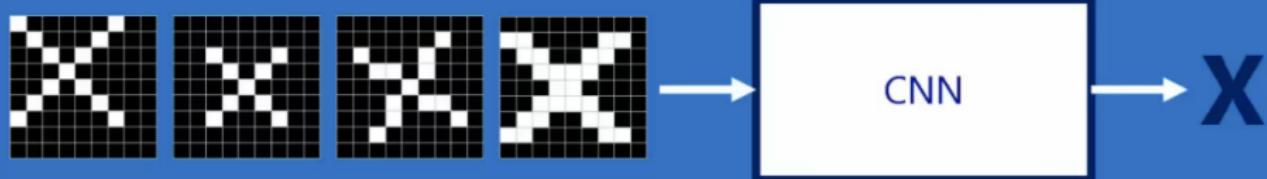


Redes Convolucionais

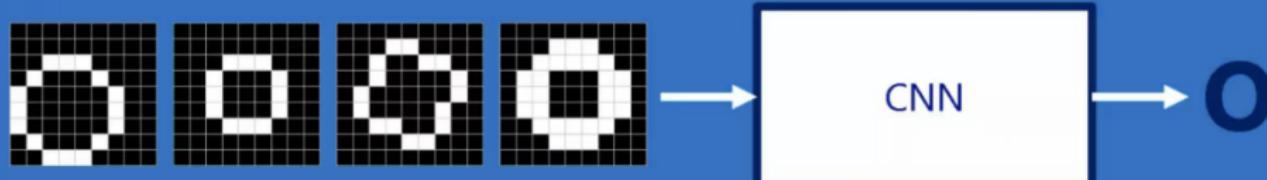


Redes Convolucionais

Trickier cases



translation scaling rotation weight



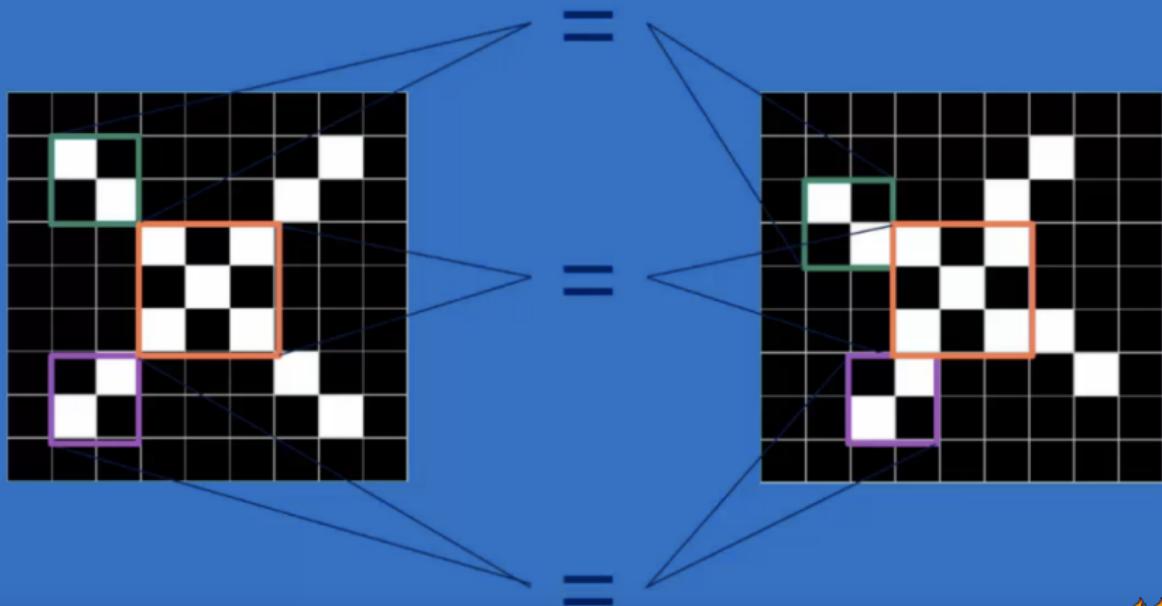
Redes Convolucionais

-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	1	-1	-1	-1	-1	-1	1	-1	-1
-1	-1	1	-1	-1	-1	1	-1	-1	-1
-1	-1	-1	1	-1	1	-1	-1	-1	-1
-1	-1	-1	-1	1	-1	-1	-1	-1	-1
-1	-1	-1	-1	1	-1	-1	-1	-1	-1
-1	-1	-1	1	-1	1	-1	-1	-1	-1
-1	-1	1	-1	-1	-1	1	-1	-1	-1
-1	1	-1	-1	-1	-1	-1	1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1



-1	-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	-1	-1	-1	-1	-1	-1	1	-1	-1
-1	1	-1	-1	-1	-1	1	-1	-1	-1
-1	-1	1	1	1	-1	1	-1	-1	-1
-1	-1	-1	1	1	-1	1	1	-1	-1
-1	-1	-1	-1	1	-1	-1	1	-1	-1
-1	-1	-1	1	-1	1	-1	1	1	-1
-1	-1	1	-1	-1	-1	1	-1	-1	1
-1	1	-1	-1	-1	-1	-1	1	-1	-1
-1	-1	-1	-1	-1	-1	-1	-1	-1	-1

Redes Convolucionais



Redes Convolucionais

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

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

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

Redes Convolucionais

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

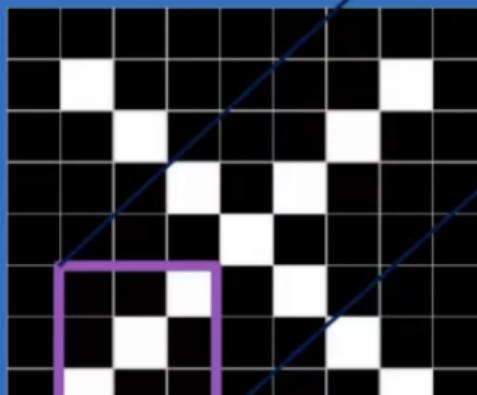
$$\begin{matrix} -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & \textcolor{white}{1} & -1 & -1 & -1 & -1 & -1 & 1 & -1 \\ -1 & -1 & \textcolor{white}{1} & -1 & -1 & -1 & 1 & -1 & -1 \\ -1 & -1 & -1 & \textcolor{white}{1} & -1 & 1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & \textcolor{white}{1} & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & 1 & -1 & \textcolor{white}{1} & -1 & -1 & -1 \\ -1 & -1 & 1 & -1 & -1 & -1 & \textcolor{white}{1} & -1 & -1 \end{matrix}$$

Redes Convolucionais

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

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

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



Behavioral Cloning

Redes Convolucionais

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

$$\begin{bmatrix} 1 \end{bmatrix} \times \begin{bmatrix} 1 \end{bmatrix} = 1$$

$$\begin{bmatrix} -1 & 1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & \textcolor{blue}{1} & -1 & -1 & -1 & -1 & -1 & 1 & -1 \\ -1 & -1 & 1 & -1 & -1 & -1 & 1 & -1 & -1 \\ -1 & -1 & -1 & 1 & -1 & 1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & 1 & -1 & 1 & -1 & -1 & -1 \\ -1 & -1 & \textcolor{red}{1} & -1 & -1 & -1 & 1 & -1 & -1 \\ -1 & 1 & -1 & -1 & -1 & -1 & -1 & 1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \end{bmatrix}$$



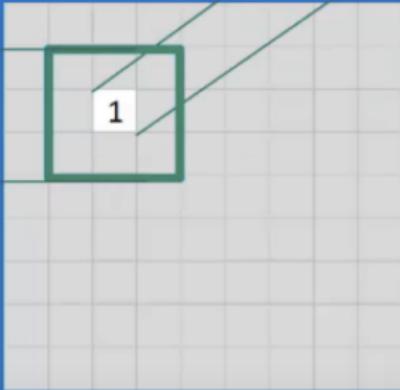
Redes Convolucionais

$$\begin{array}{|c|c|c|} \hline 1 & -1 & -1 \\ \hline -1 & 1 & -1 \\ \hline -1 & -1 & 1 \\ \hline \end{array}$$

$$\begin{array}{|c|c|c|} \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline 1 & 1 & 1 \\ \hline \end{array}$$

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

$$\begin{array}{cccccccccc} -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \\ -1 & 1 & -1 & -1 & -1 & -1 & -1 & 1 & -1 \\ -1 & -1 & 1 & -1 & -1 & -1 & 1 & -1 & -1 \\ -1 & -1 & -1 & 1 & -1 & 1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 1 & -1 & -1 & -1 & -1 \\ -1 & -1 & -1 & -1 & 1 & -1 & 1 & -1 & -1 \\ -1 & -1 & -1 & 1 & -1 & 1 & -1 & -1 & -1 \\ -1 & 1 & -1 & -1 & -1 & -1 & -1 & 1 & -1 \\ -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 & -1 \end{array}$$



A 3x3 grid representing a feature map. Only the central cell contains the value '1', which is highlighted with a green rectangular border.

Redes Convolucionais

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

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

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

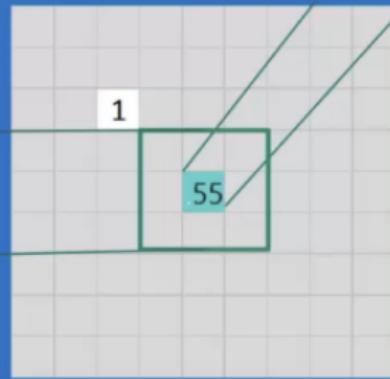
Redes Convolucionais

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

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

$$\frac{1 + 1 - 1 + 1 + 1 + 1 - 1 + 1 + 1}{9} = .55$$

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



Redes Convolucionais

1	-1	-1
-1	1	-1
-1	-1	1

-1	-1	-1	-1	-1	-1	-1	-1	-1
-1	1	-1	-1	-1	-1	-1	1	-1
-1	-1	1	-1	-1	-1	1	-1	-1
-1	-1	-1	1	-1	1	-1	-1	-1
-1	-1	-1	-1	1	-1	-1	-1	-1
-1	-1	-1	1	-1	1	-1	-1	-1
-1	-1	-1	-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

Redes Convolucionais

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



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

=

$$\begin{bmatrix} 0.77 & -0.11 & 0.11 & 0.33 & 0.55 & -0.11 & 0.33 \\ -0.11 & 1.00 & -0.11 & 0.33 & -0.11 & 0.11 & -0.11 \\ 0.11 & -0.11 & 1.00 & -0.33 & 0.11 & -0.11 & 0.55 \\ 0.33 & 0.33 & -0.33 & 0.55 & -0.33 & 0.33 & 0.33 \\ 0.55 & -0.11 & 0.11 & -0.33 & 1.00 & -0.11 & 0.11 \\ -0.11 & 0.11 & -0.11 & 0.33 & -0.11 & 2.00 & -0.11 \\ 0.33 & -0.11 & 0.55 & 0.33 & 0.11 & -0.11 & 0.77 \end{bmatrix}$$

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



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

=

$$\begin{bmatrix} 0.33 & -0.55 & 0.11 & -0.11 & 0.11 & -0.55 & 0.33 \\ -0.55 & 0.55 & -0.55 & 0.33 & -0.55 & 0.55 & -0.55 \\ 0.11 & -0.55 & 0.55 & -0.77 & 0.55 & -0.55 & 0.11 \\ -0.11 & 0.33 & -0.77 & 1.00 & -0.77 & 0.33 & -0.33 \\ 0.11 & -0.55 & 0.55 & -0.77 & 0.55 & -0.55 & 0.11 \\ -0.55 & 0.55 & -0.55 & 0.33 & -0.55 & 0.55 & -0.55 \\ 0.33 & -0.55 & 0.11 & -0.33 & 0.11 & -0.55 & 0.33 \end{bmatrix}$$

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

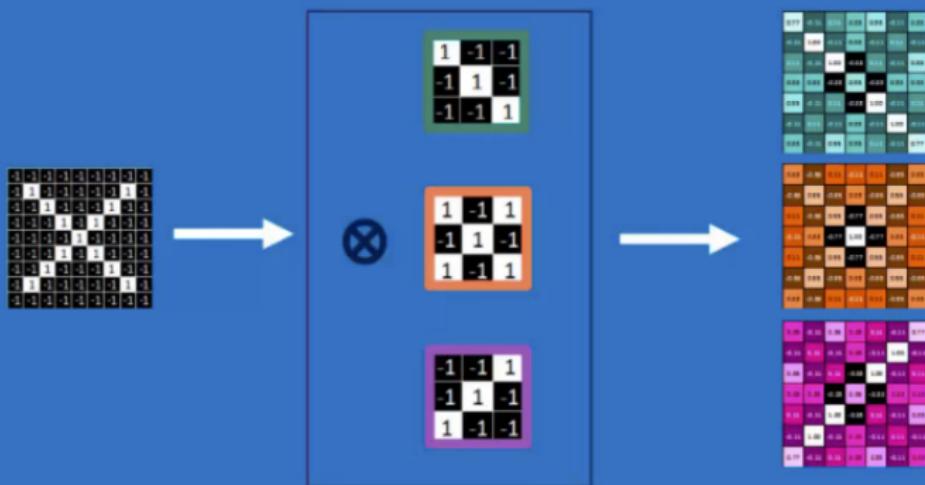


$$\begin{bmatrix} -1 & -1 & 1 \\ -1 & 1 & -1 \\ 1 & -1 & -1 \end{bmatrix}$$

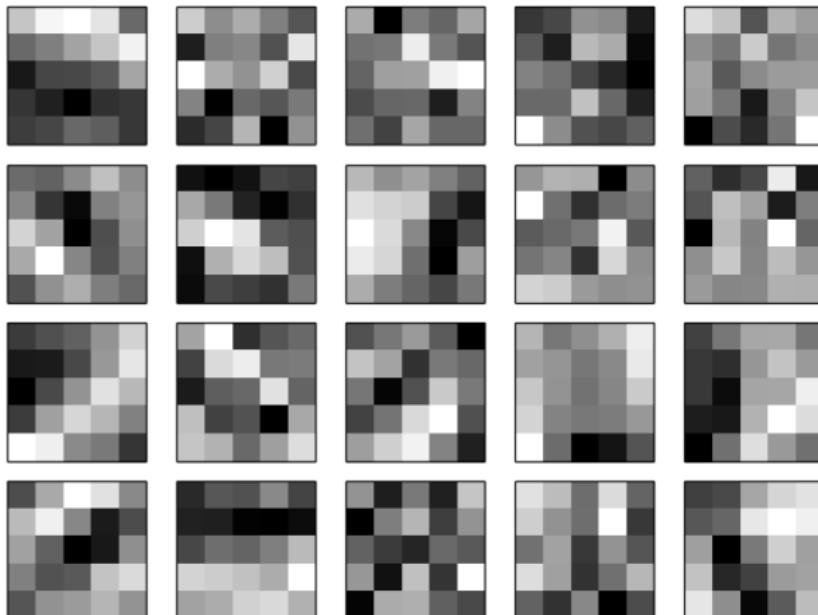
=

$$\begin{bmatrix} 0.33 & -0.11 & 0.55 & 0.33 & 0.11 & -0.11 & 0.77 \\ -0.11 & 0.11 & -0.11 & 0.33 & -0.11 & 1.00 & -0.11 \\ 0.55 & -0.11 & 0.11 & -0.33 & 1.00 & -0.11 & 0.11 \\ 0.11 & 0.33 & -0.33 & 0.55 & -0.33 & 0.33 & 0.55 \\ 0.11 & -0.11 & 1.00 & -0.33 & 0.11 & -0.11 & 0.55 \\ -0.11 & 1.00 & -0.11 & 0.33 & -0.11 & 0.11 & -0.11 \\ 0.77 & -0.11 & 0.11 & 0.33 & 0.55 & -0.11 & 0.55 \end{bmatrix}$$

Redes Convolucionais



Kernels de Convolução



Kernels de Convolução



*

Median Filter
 3×3

=

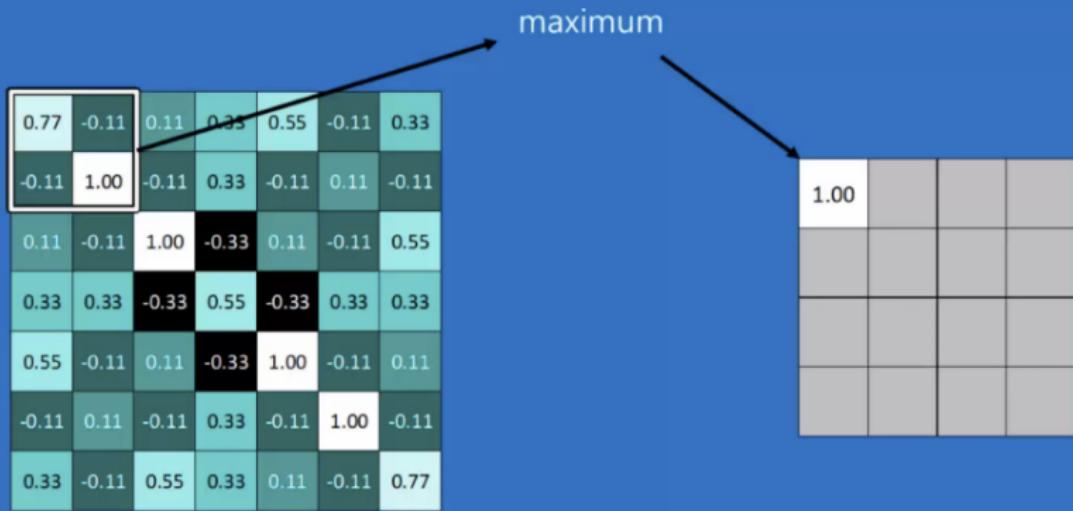


Figure 3-14. Median filter processing

As we can see, the salt and pepper noise has been removed by the Median filter.



Pooling



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

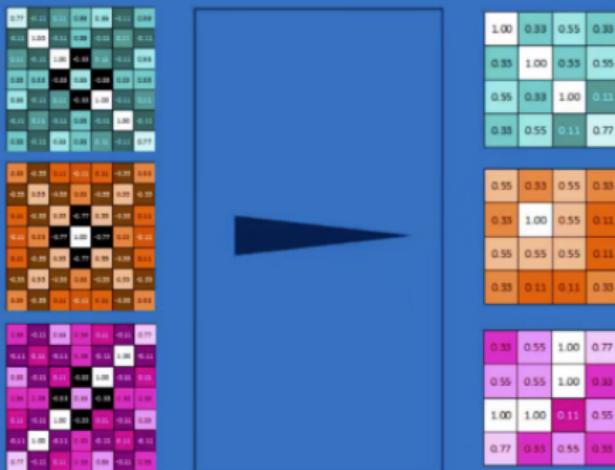
max pooling



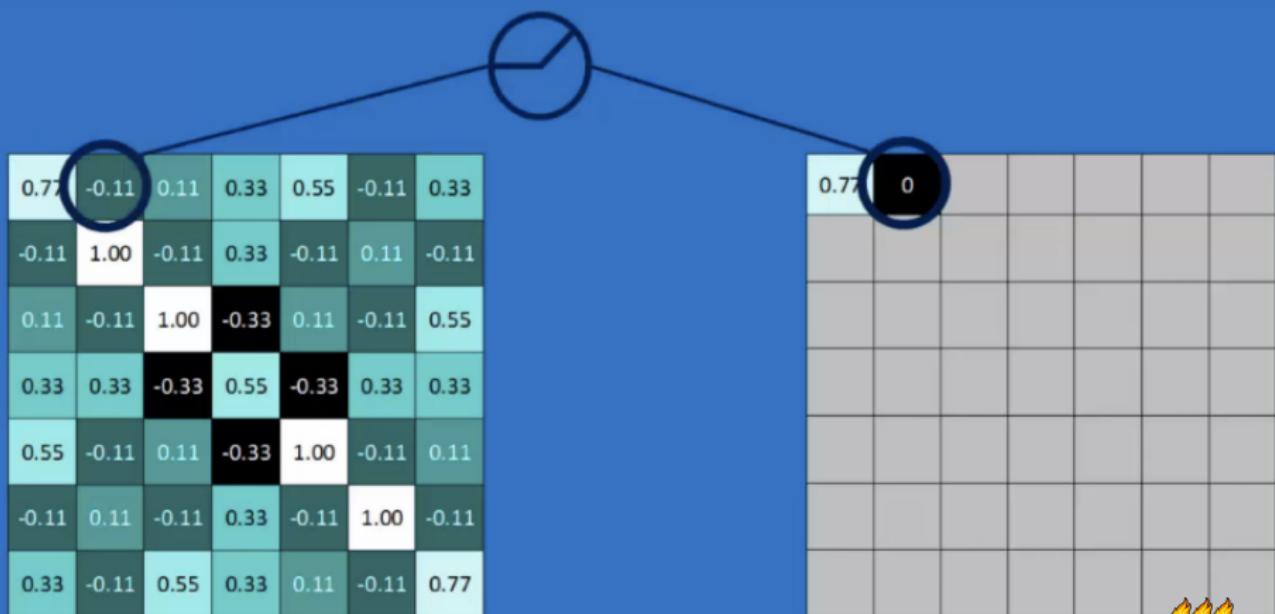
1.00	0.33	0.55	0.33
0.33	1.00	0.33	0.55
0.55	0.33	1.00	0.11
0.33	0.55	0.11	0.77

Pooling

A stack of images becomes a stack of smaller images.



RELU



Extração de Feature de Imagens

RELU

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



0.77	0	0.11	0.33	0.55	0	0.33
0	1.00	0	0.33	0	0.11	0
0.11	0	1.00	0	0.11	0	0.55
0.33	0.33	0	0.55	0	0.33	0.33
0.55	0	0.11	0	1.00	0	0.11
0	0.11	0	0.33	0	1.00	0
0.33	0	0.55	0.33	0.11	0	0.77

RELU

A stack of images becomes a stack of images with no negative values.

0.07	0.02	0.06	0.04	0.03	0.05	0.06
-0.01	0.08	0.01	0.04	0.03	0.05	0.06
0.05	-0.02	-0.03	-0.04	0.01	0.03	0.06
0.08	0.06	0.03	0.04	0.05	0.07	0.08
0.09	0.01	0.04	-0.02	-0.03	0.05	0.06
-0.04	0.02	0.01	0.03	0.04	0.05	0.06
0.08	0.03	0.04	0.05	0.06	0.07	0.08

0.06	0.09	0.07	0.12	0.07	0.10	0.08
-0.03	0.02	0.01	0.03	0.04	0.05	0.06
0.05	-0.01	0.02	0.03	-0.04	-0.05	-0.06
0.03	0.01	0.02	0.03	0.04	0.05	0.06
-0.02	0.01	0.02	0.03	0.04	0.05	0.06
0.06	0.08	0.09	0.10	0.07	0.11	0.08
0.08	0.09	0.08	0.10	0.06	0.12	0.09

0.04	0.05	0.06	0.07	0.08	0.09	0.07
-0.01	0.03	-0.02	0.04	-0.03	0.05	0.06
0.09	0.06	0.07	0.08	0.09	0.10	0.08
0.07	0.08	0.09	0.06	0.07	0.08	0.09
-0.03	0.02	0.03	0.04	-0.01	0.05	0.06
0.06	0.07	0.08	0.09	0.06	0.07	0.08
0.08	0.09	0.07	0.06	0.05	0.06	0.07



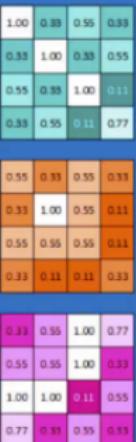
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0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00

0.06	0.09	0.07	0.12	0.07	0.10	0.08
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
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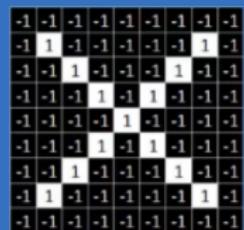
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0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
0.00	0.00	0.00	0.00	0.00	0.00	0.00
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Redes Convolucionais

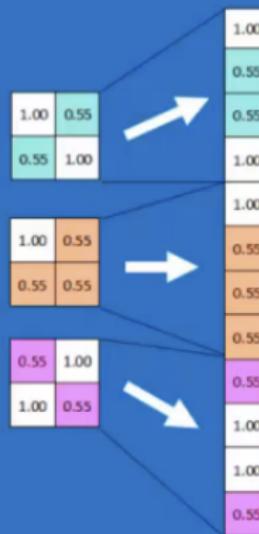
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-1	-1	-1	-1	1	-1	-1	-1	-1
-1	-1	-1	-1	1	-1	-1	-1	-1
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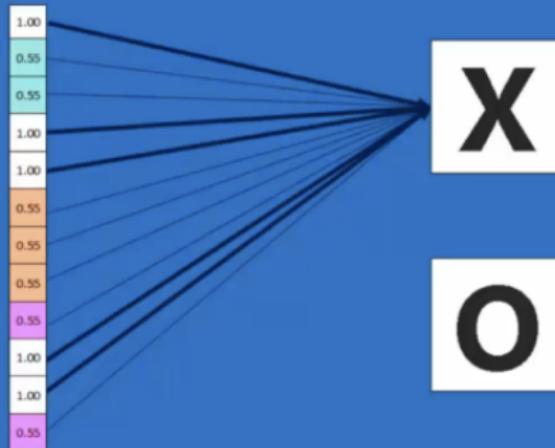
Redes Convolucionais



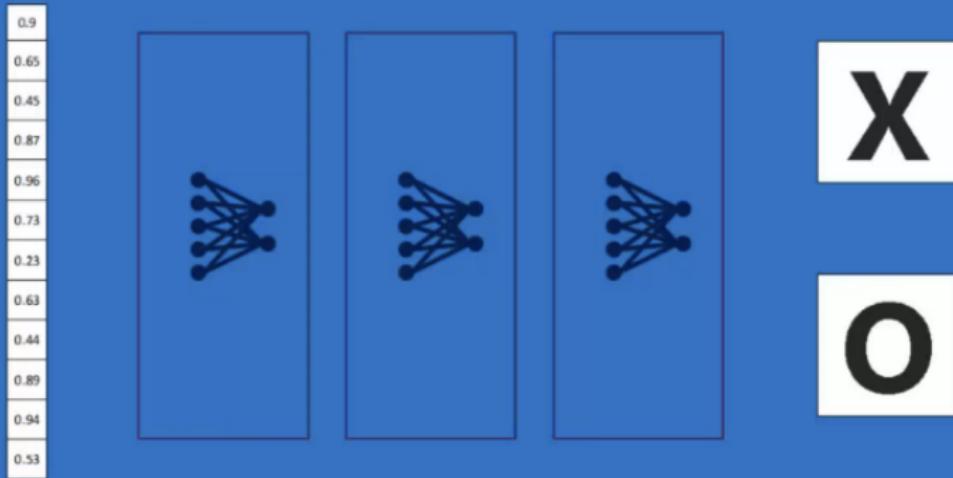
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Redes Convolucionais



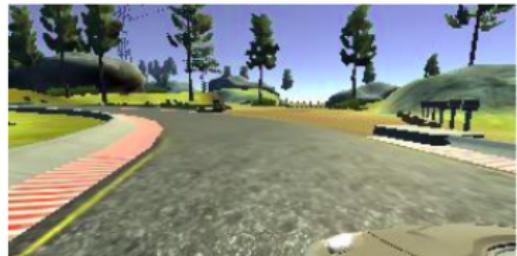
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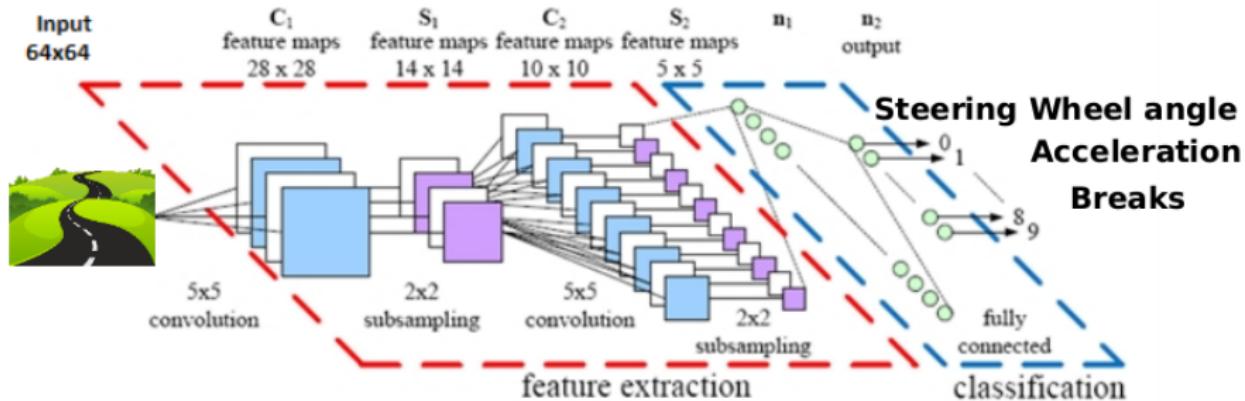
Carros Autônomos



Carros Autônomos



Carros Autônomos



Carros Autônomos

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Carros Autônomos



Conclusão

Você está apto a:

Compreender qual o objetivo do uso de Behavioral Cloning

Compreender aplicação de Imitation Learning

Compreender como funcionam Redes Convolucionais



Bibliografia I

