Aprendizagem por Reforço com Deep Learning, PyTorch e Python

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Conteúdo do Curso

O que você aprenderá neste curso:

- Parte 1 – Fundamentos de Aprendizagem por Reforço (Q-Learning)
- Parte 2 – Deep Q-Learning
- Parte 3 – Implementação Deep Q-Learning

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Pré-requisitos

- Lógica de programação
- Programação básica em Python
- Instalação de softwares
- Redes Neurais Artificiais (desejável)
- PyTorch (desejável)

- Nível do curso: intermediário
- Dica: aumentar a velocidade do player
- Avaliação do curso!

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Conteúdo

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Conteúdo

O que você aprenderá nesta seção:

- O que é aprendizagem por reforço?
- A Equação de Bellman
- O "Plano"
- Markov Decision Process (MDP)
- Política x Plano
- Adição de penalidades ("Living Penalty”)
- Q-Learning – Intuição
- Diferença Temporal
- Q-Learning – Visualização

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O que é Aprendizagem por Reforço?

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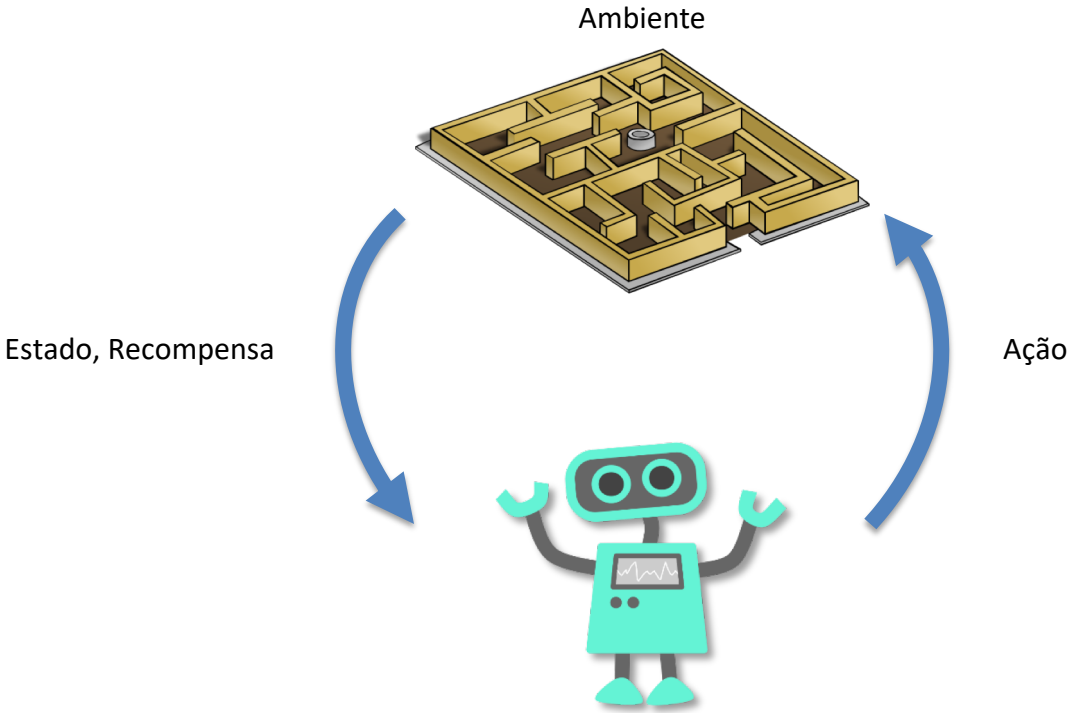
O que é Aprendizagem por Reforço?



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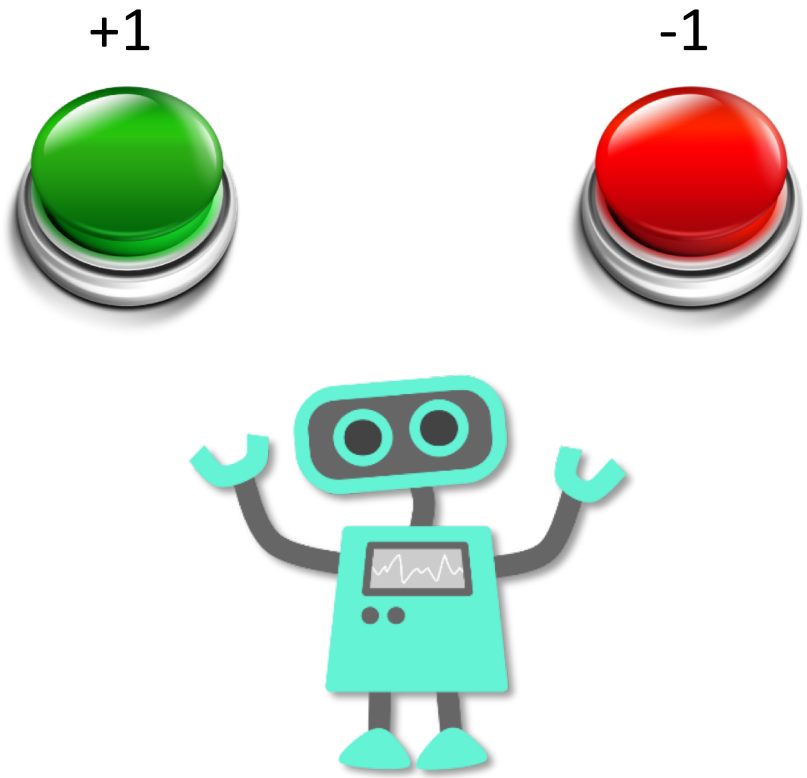

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O que é Aprendizagem por Reforço?

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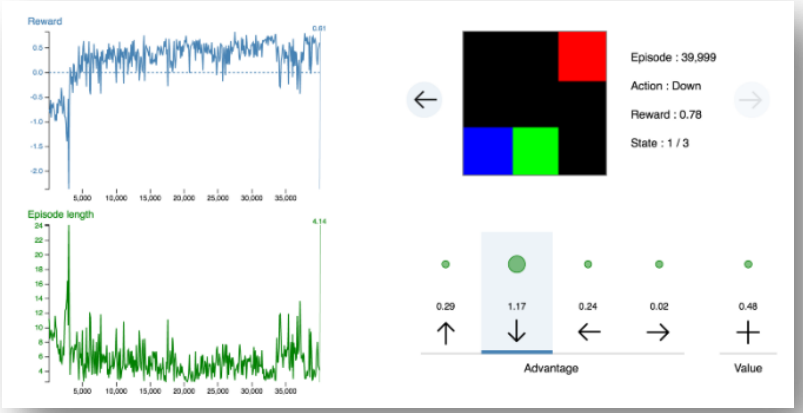
Leitura Adicional

Leitura Adicional:

Simple Reinforcement Learning with Tensorflow (10 Parts)

Arthur Juliani (2016)



Link:

https://medium.com/emergent-future/simple-reinforcement-learning-with-tensorflow-part-0-q-learning-with-tables-and-neural-networks-d195264329d0

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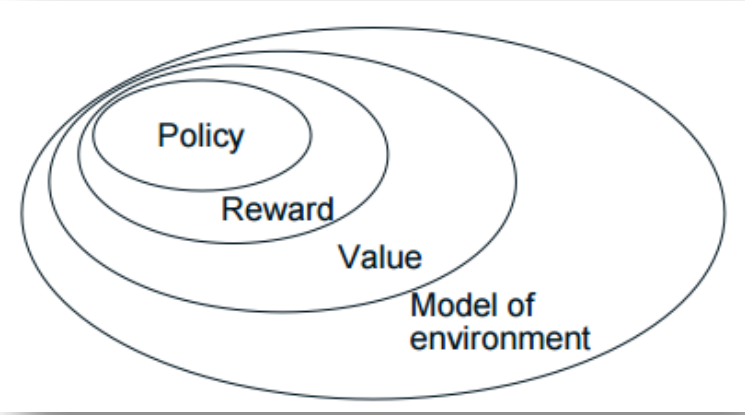
Leitura Adicional

Leitura Adicional:

Reinforcement Learning I: Introduction

Richard Sutton et al. (1998)



Link:

http://citeseer.ist.psu.edu/viewdoc/summary?doi=10.1.1.32.7692

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A Equação de Bellman

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A Equação de Bellman

Conceitos:

- s – Estado
- a – Ação
- R – Recompensa
- γ – Desconto

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A Equação de Bellman

Richard Ernest Bellman

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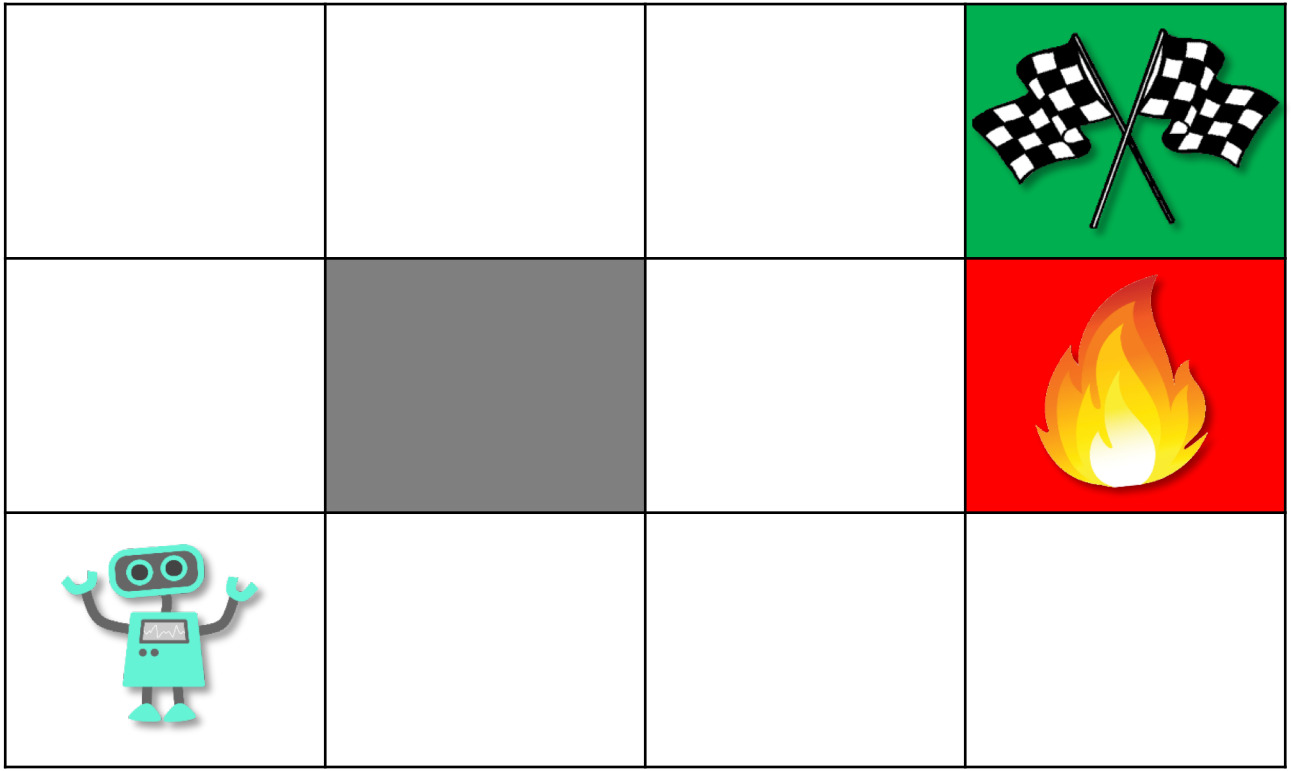

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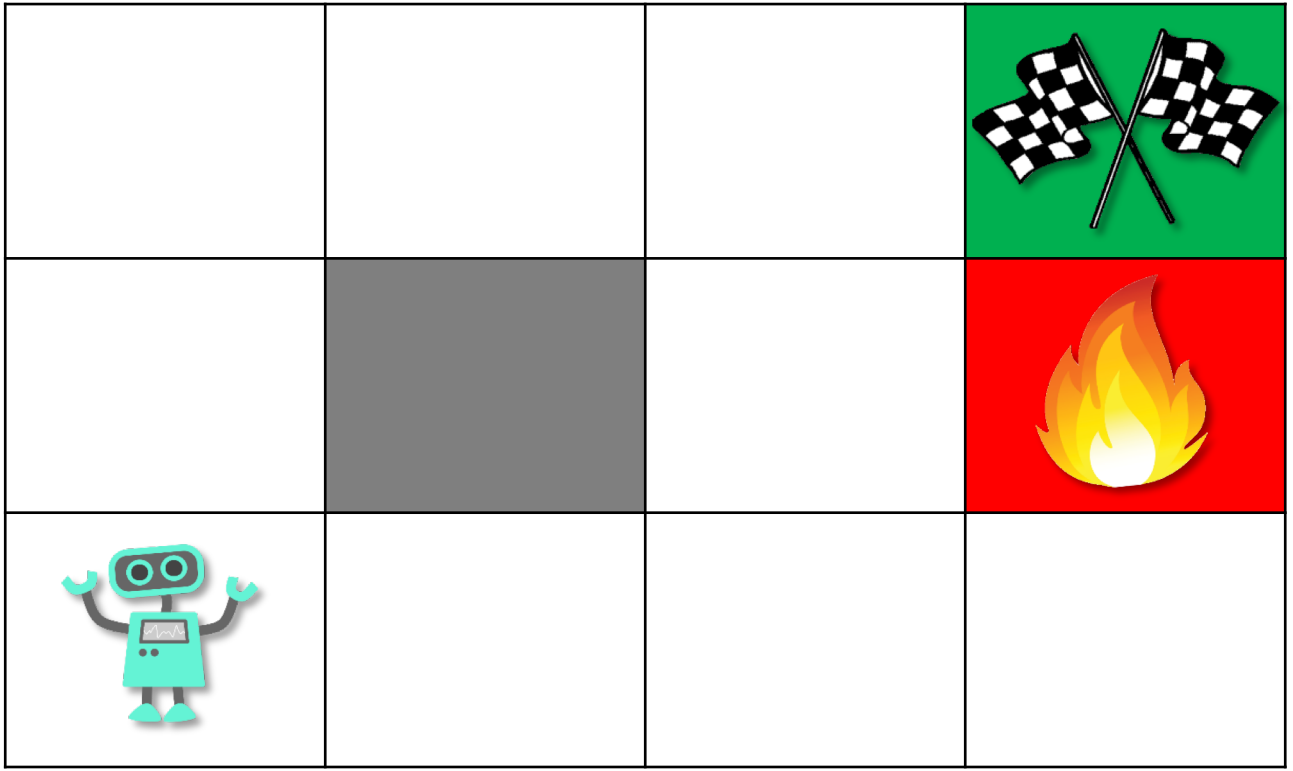

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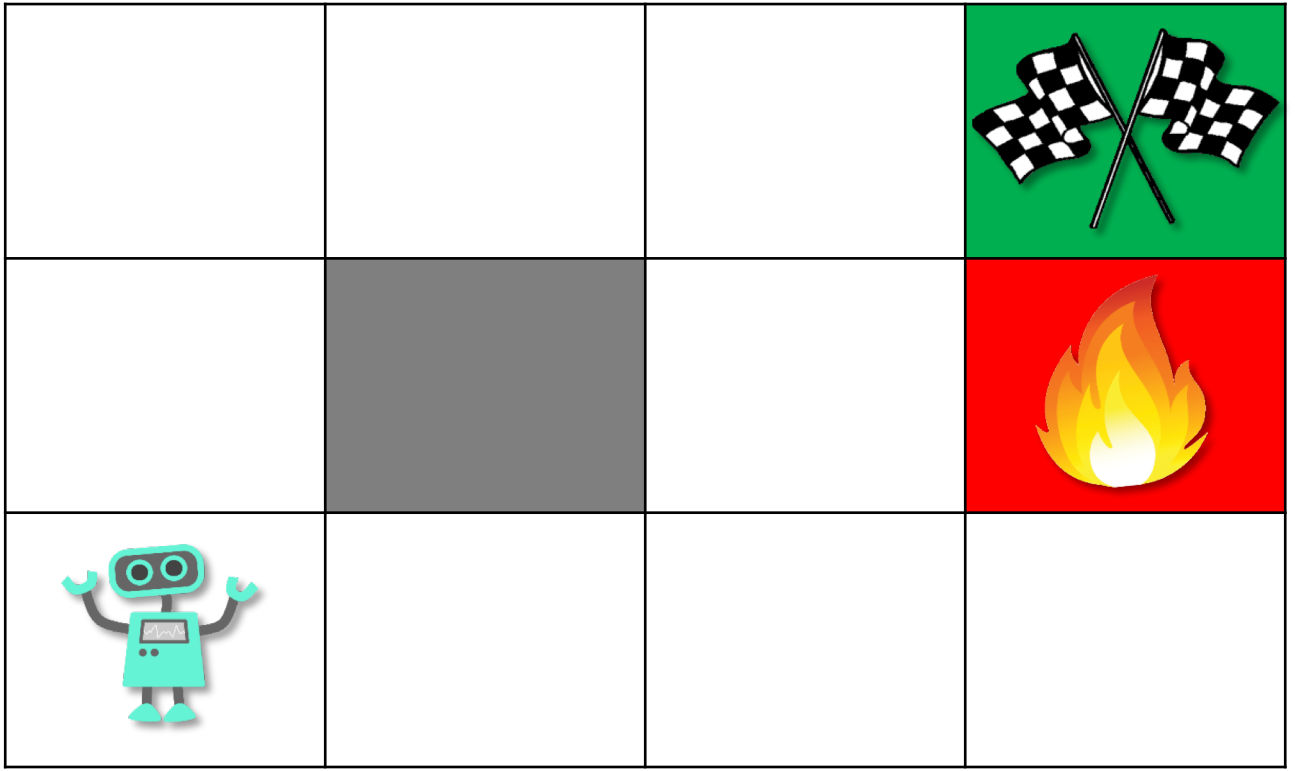

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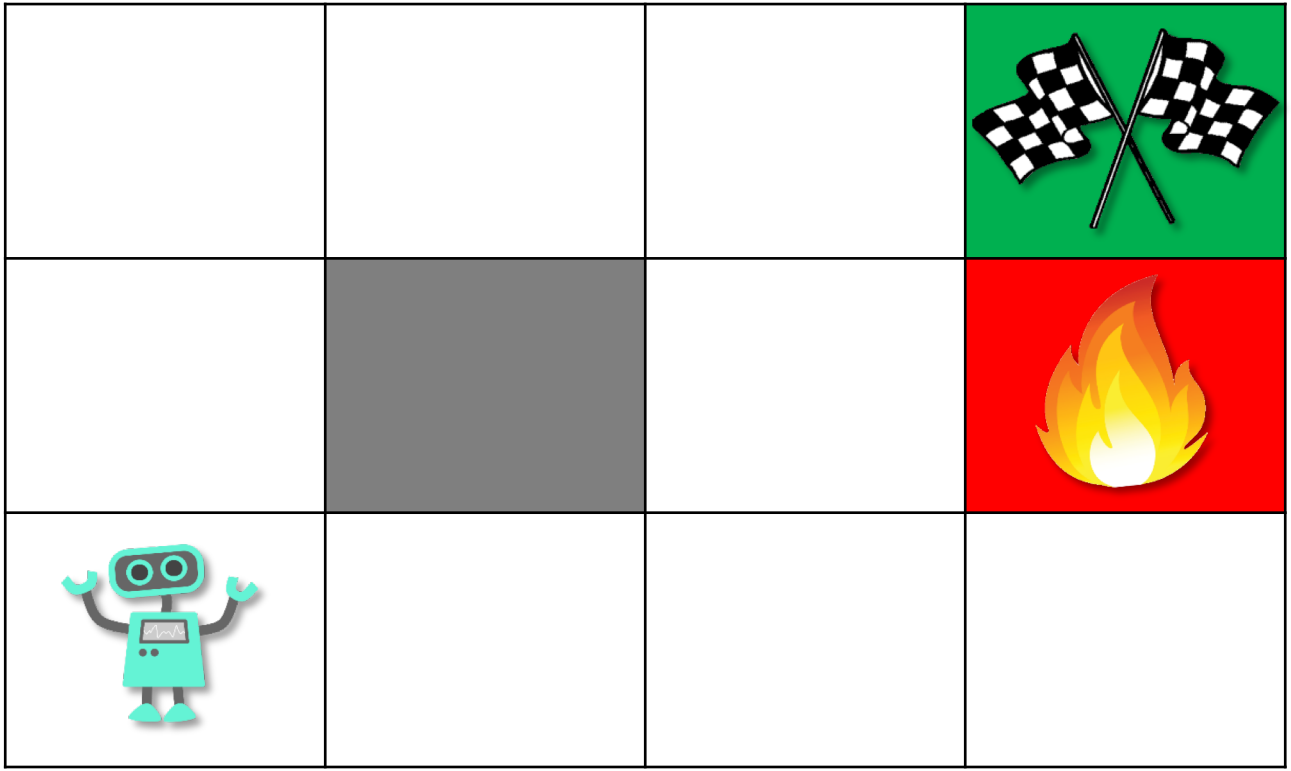

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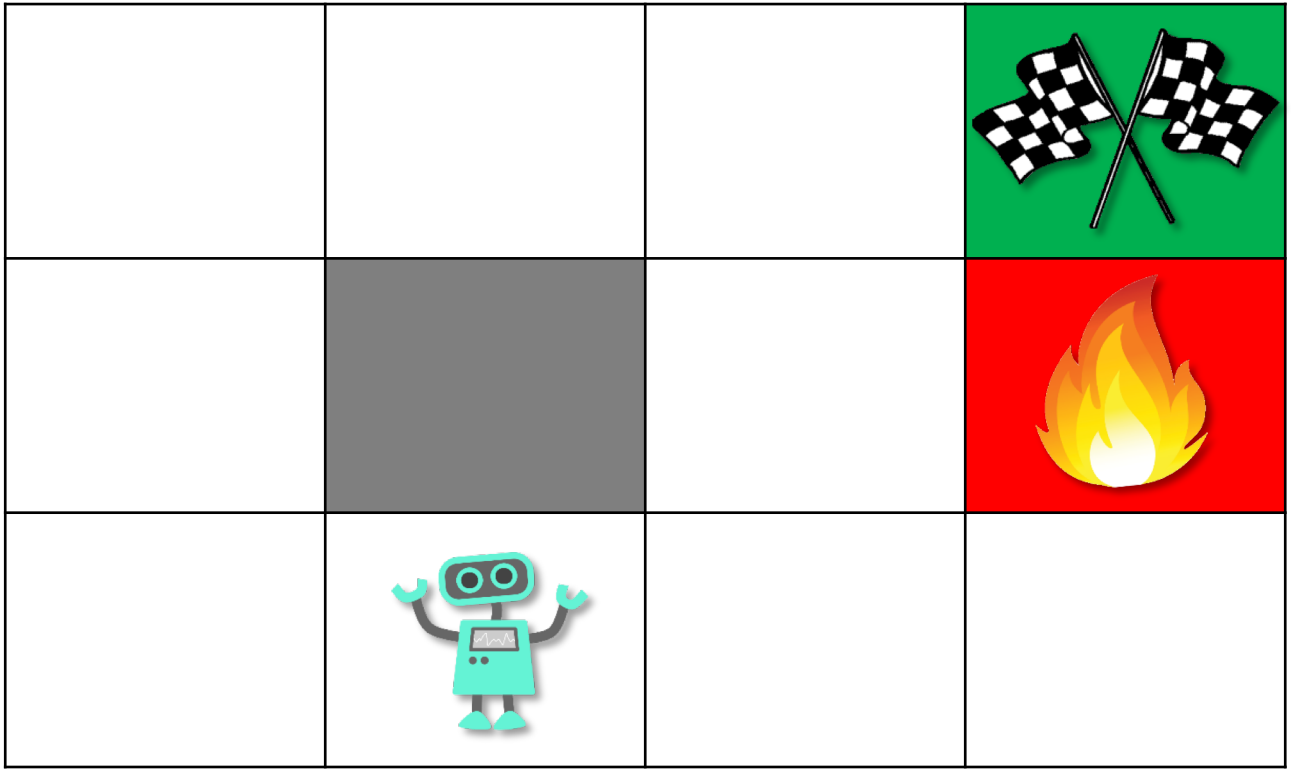

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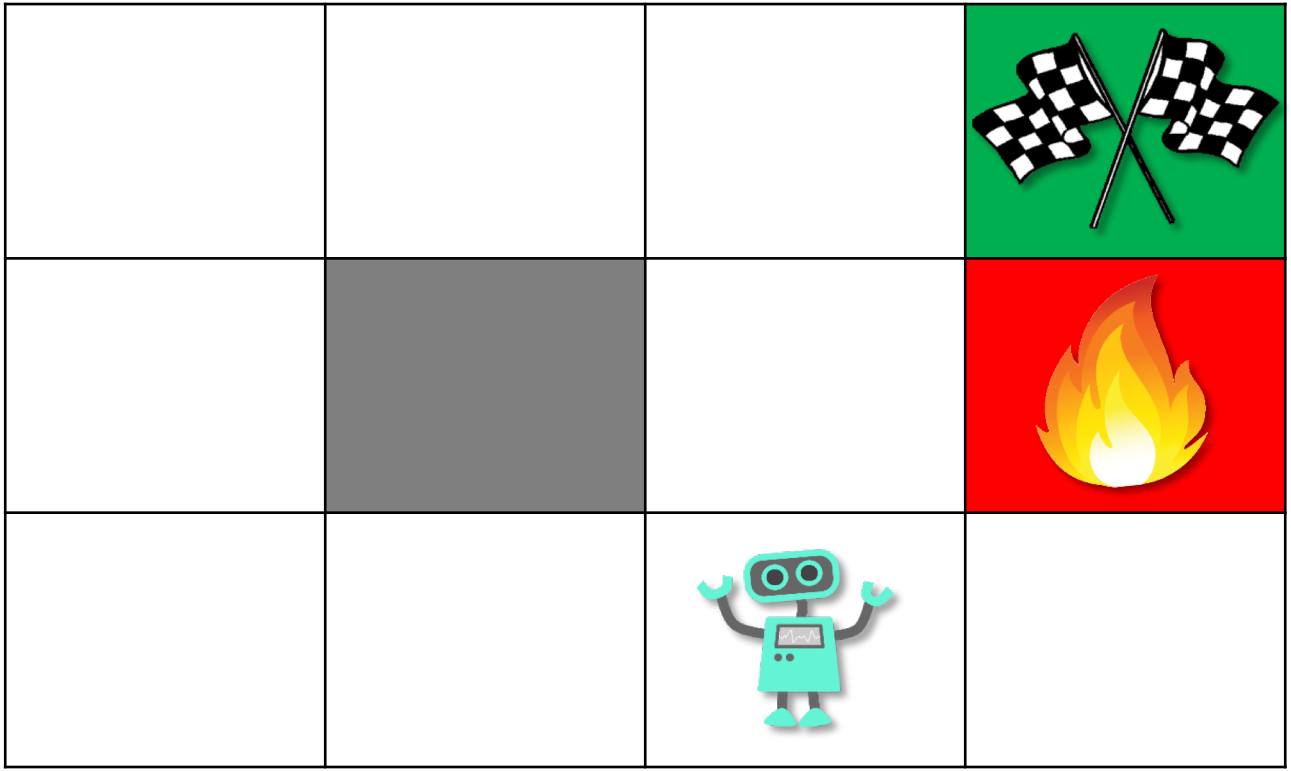

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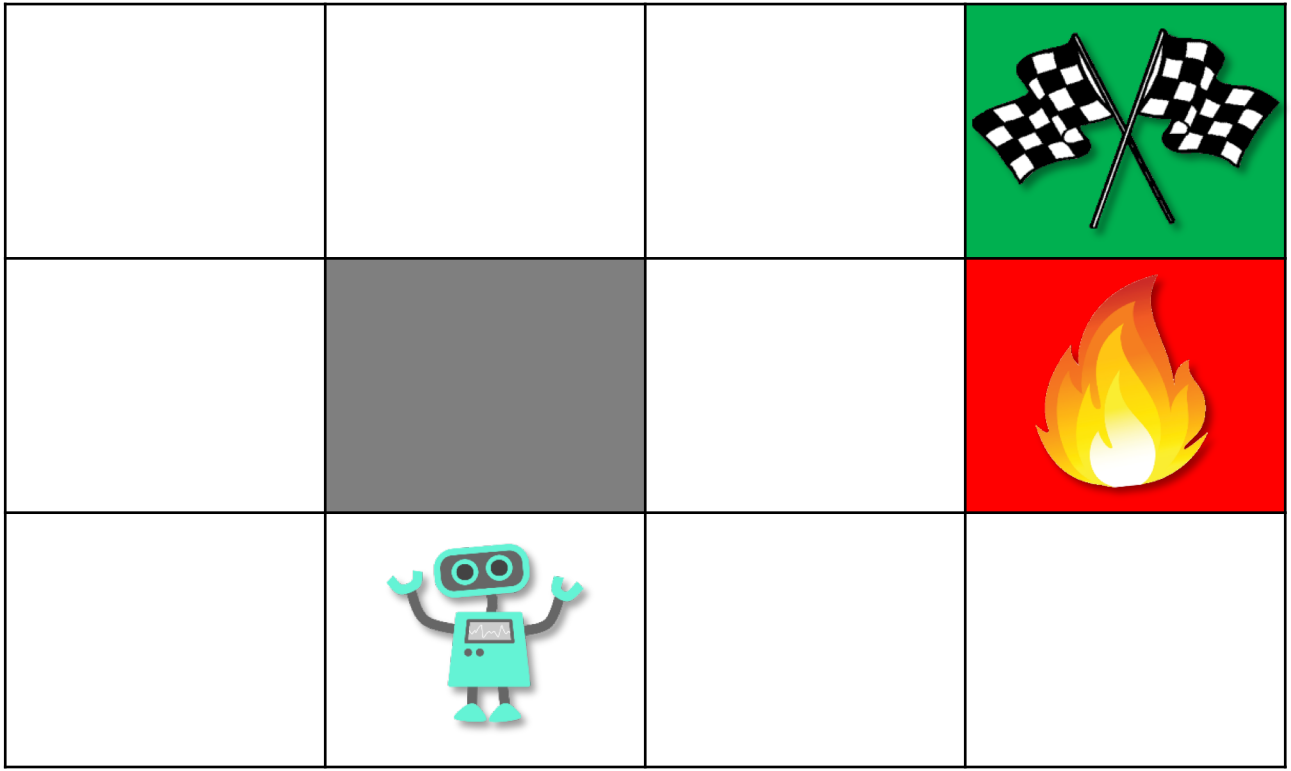

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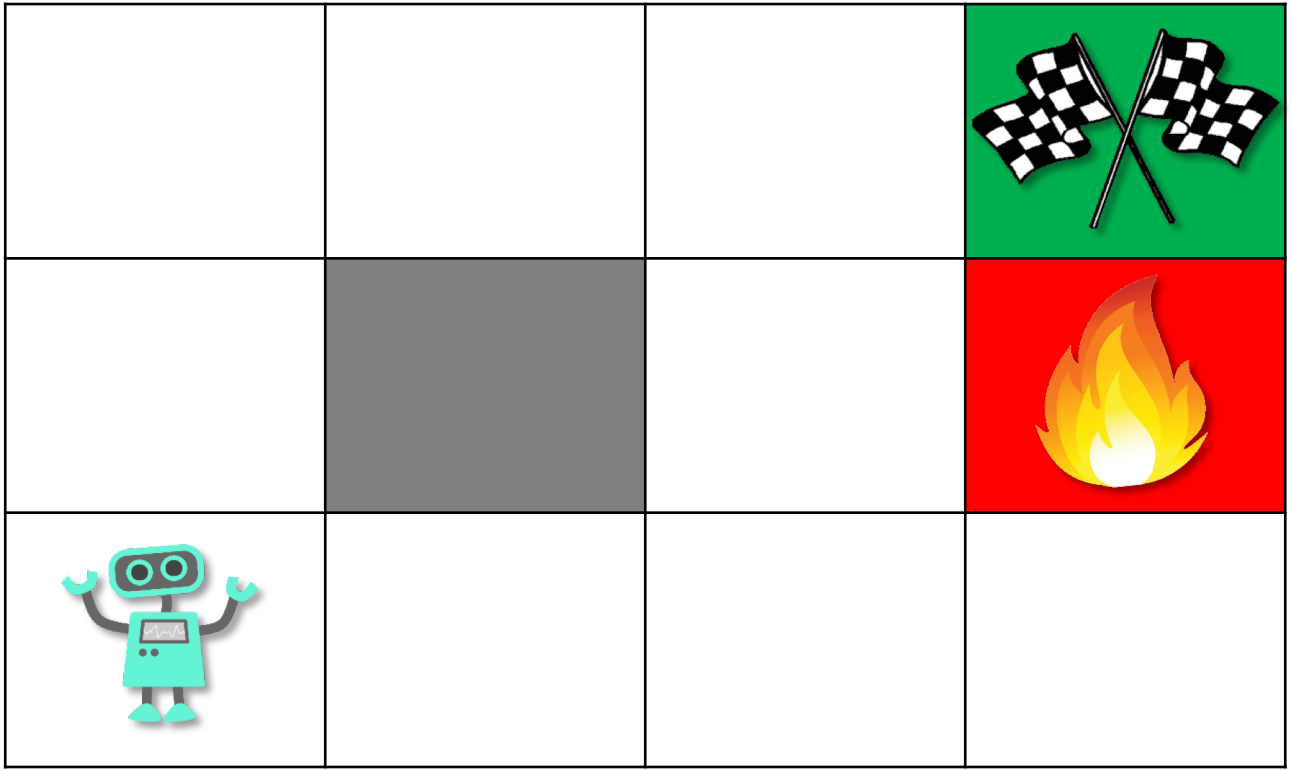

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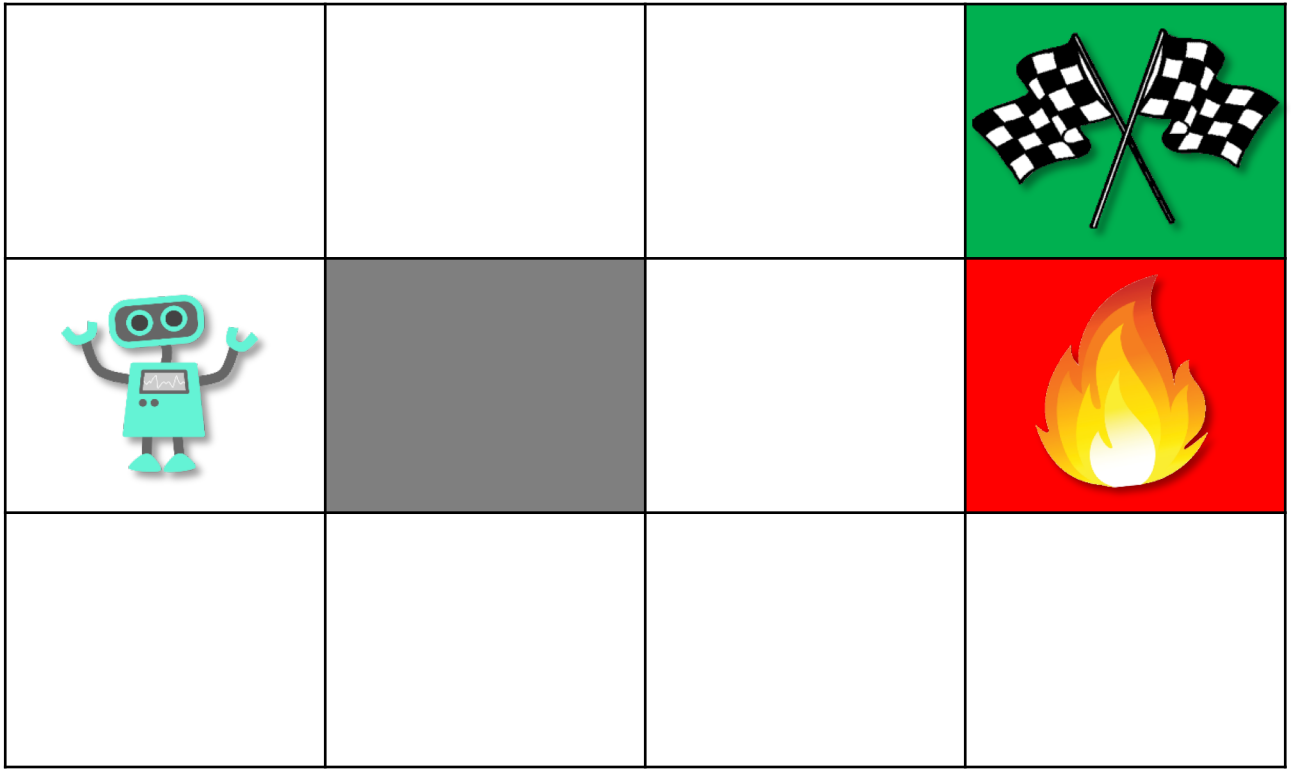

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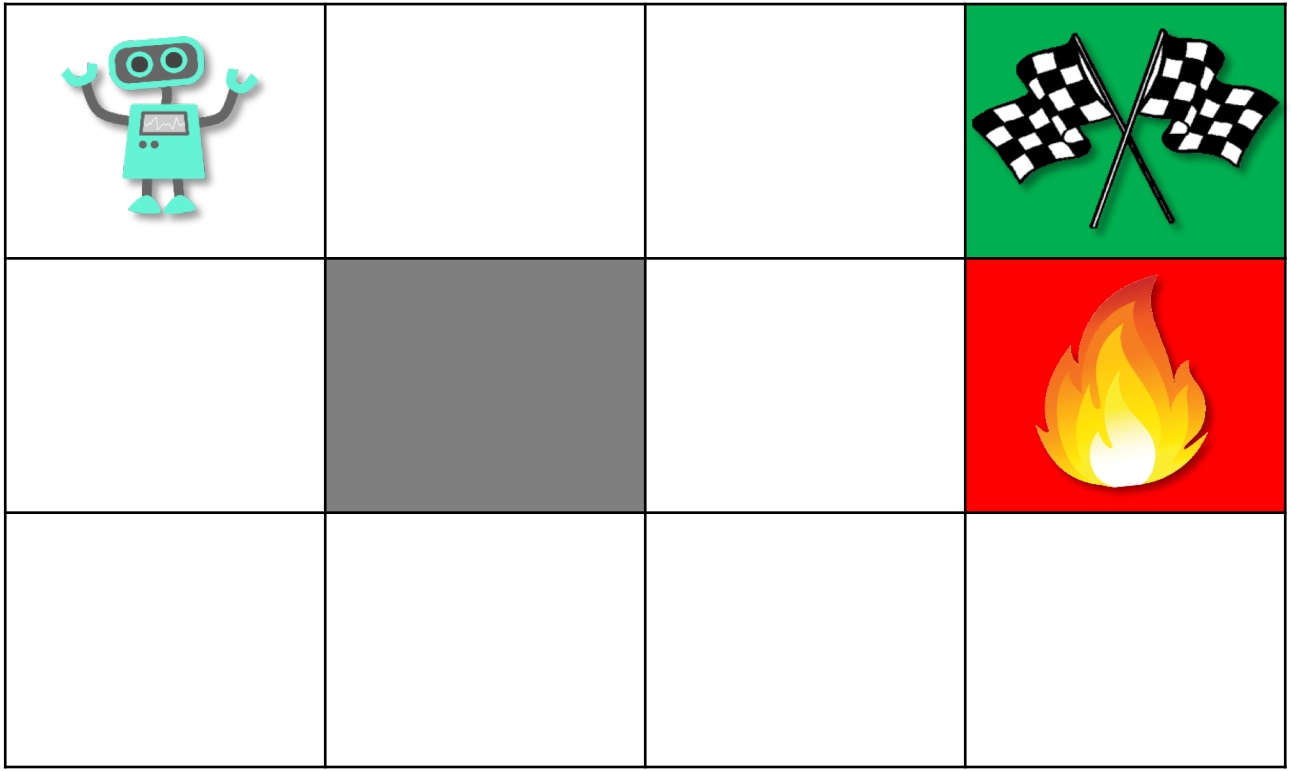

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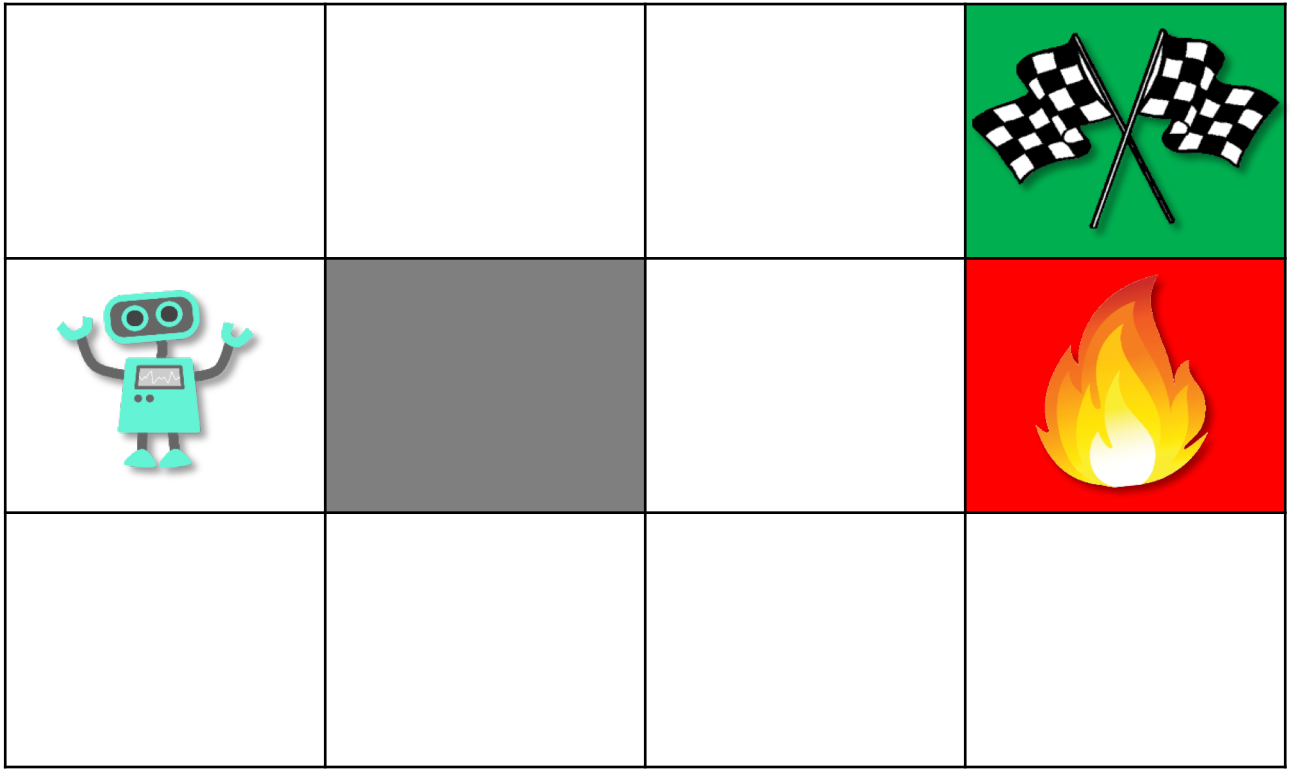

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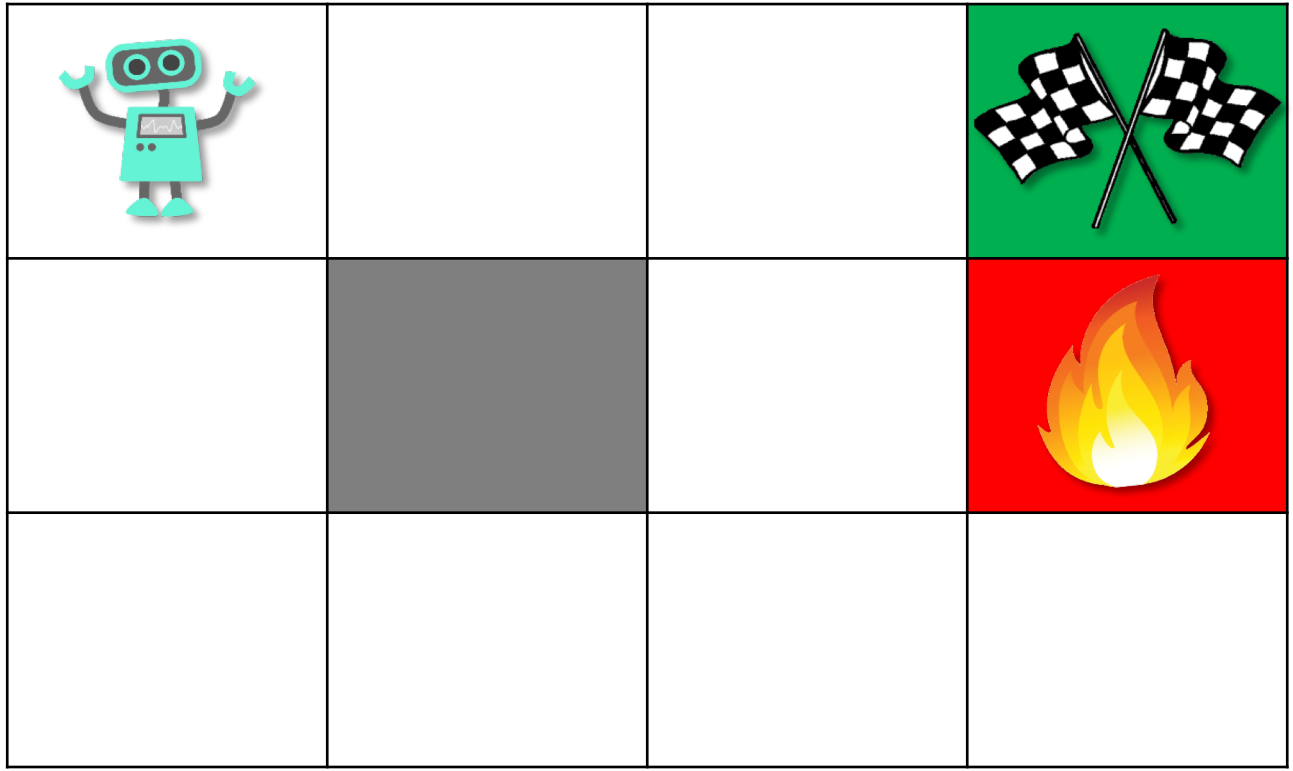

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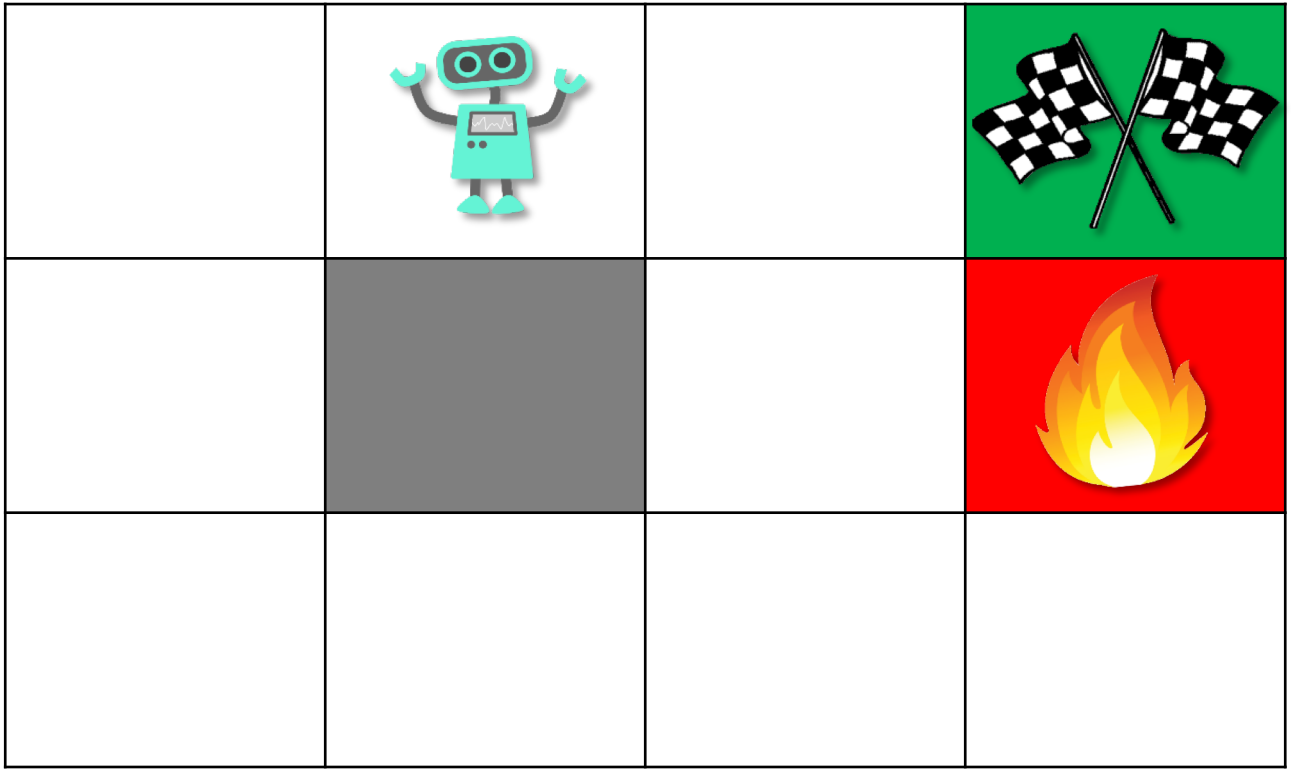

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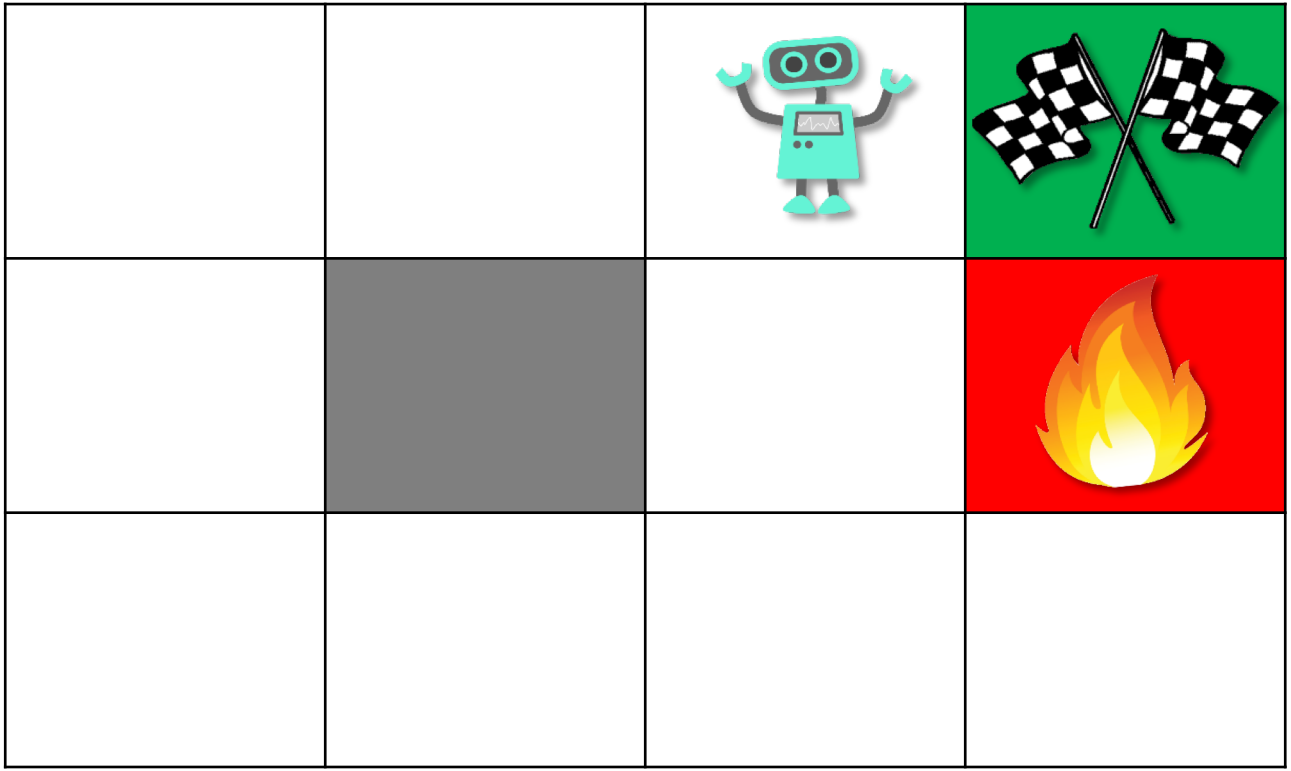

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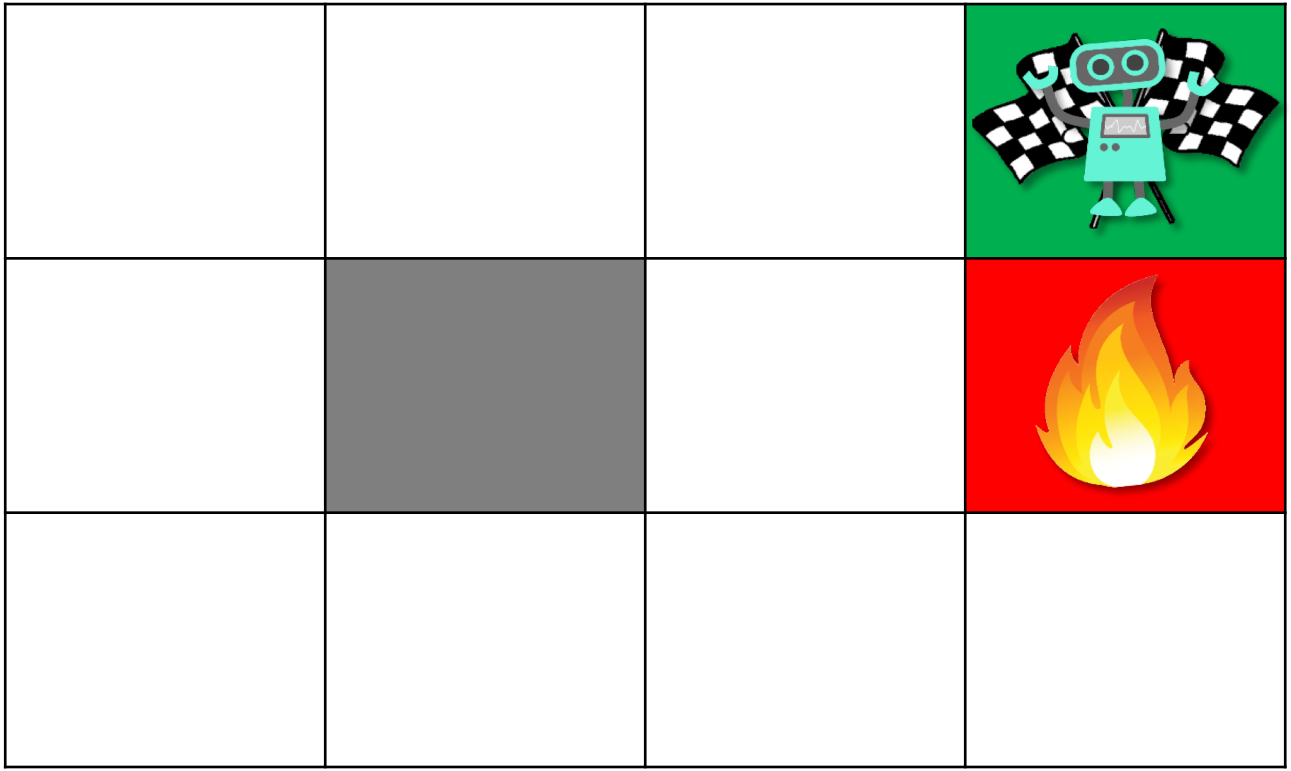

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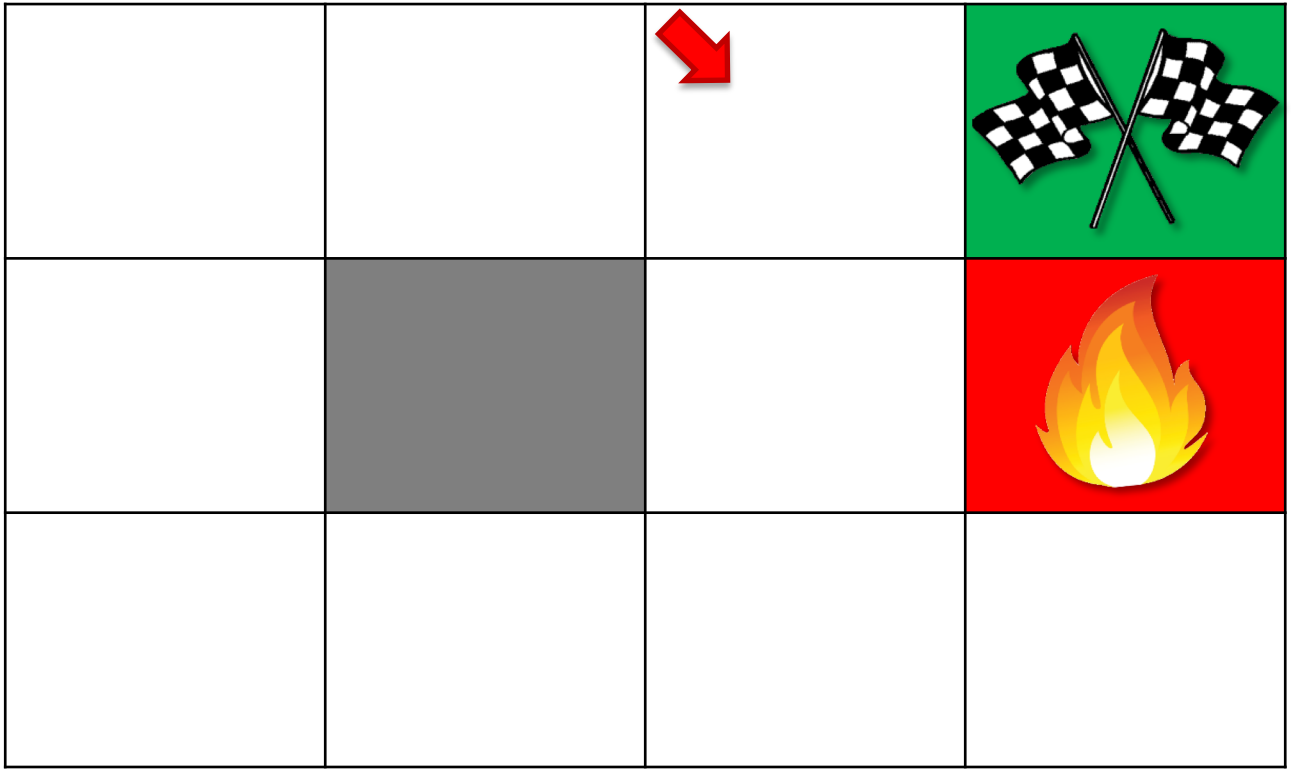

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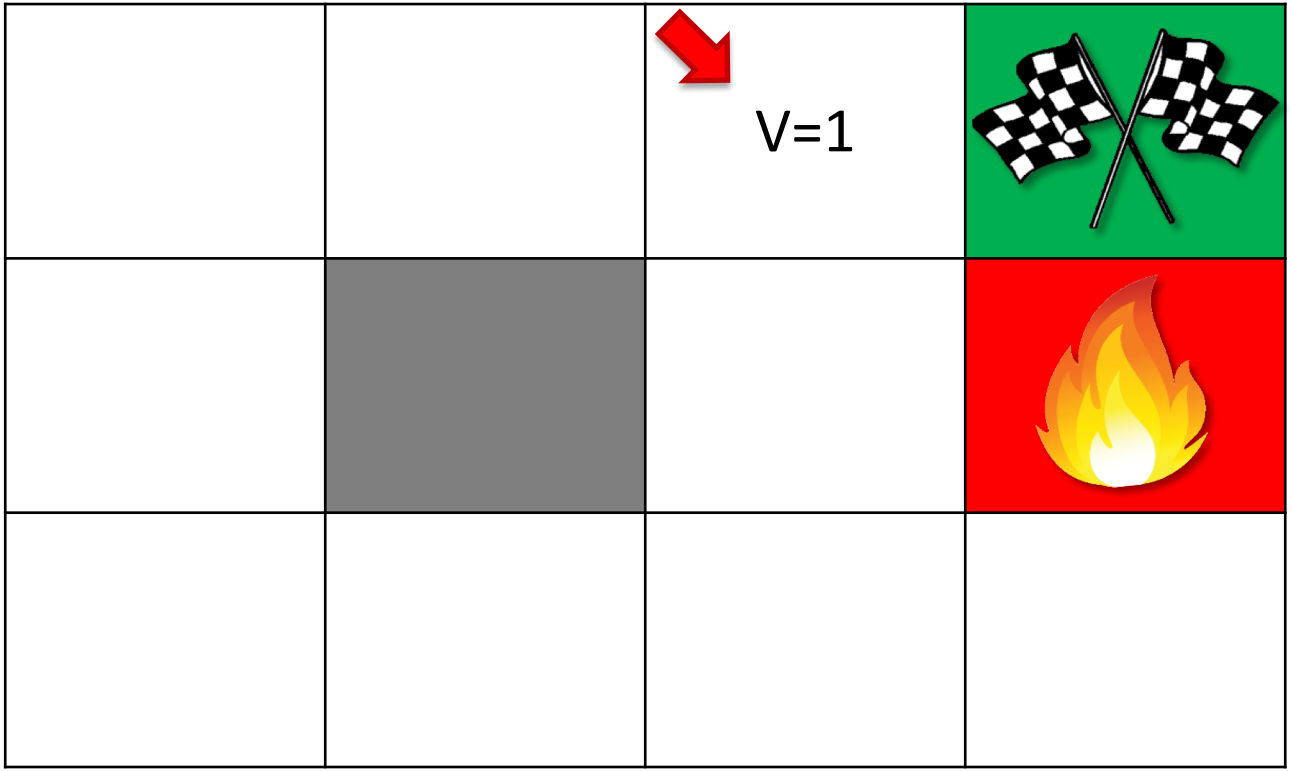

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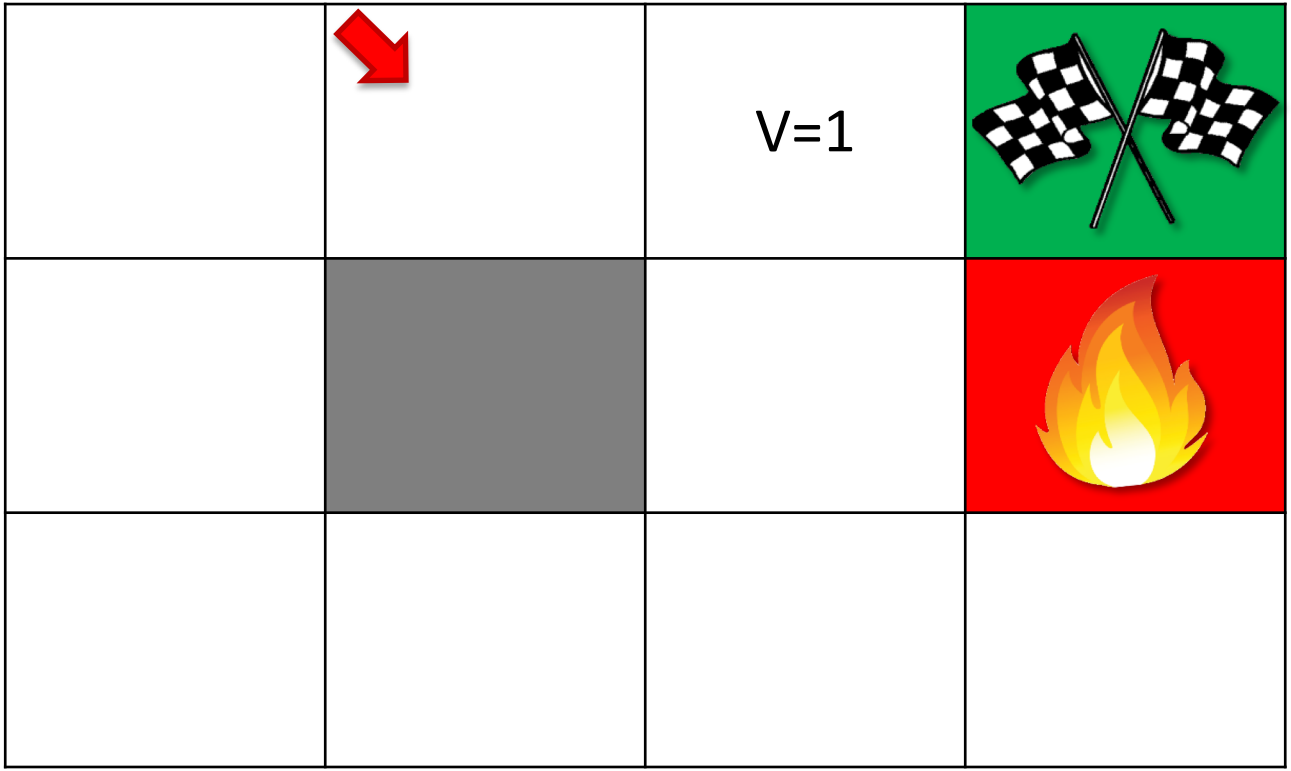

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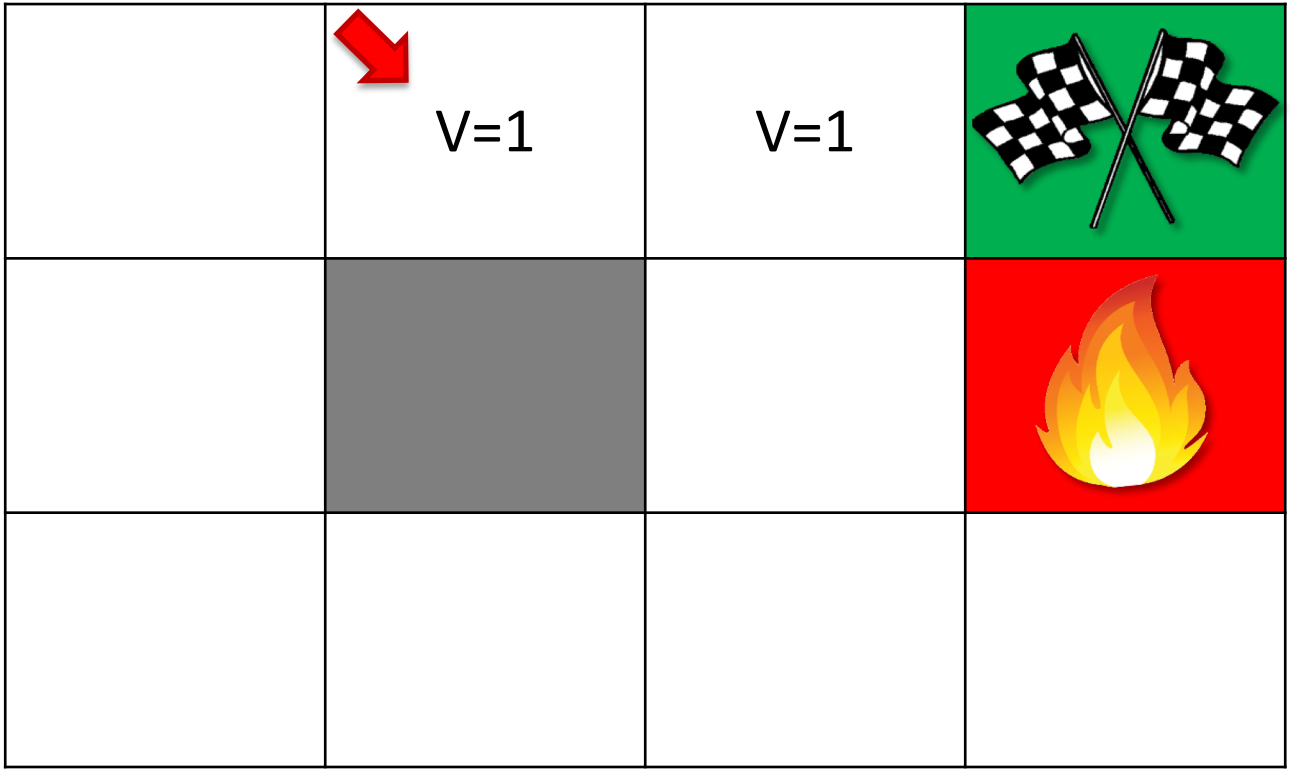

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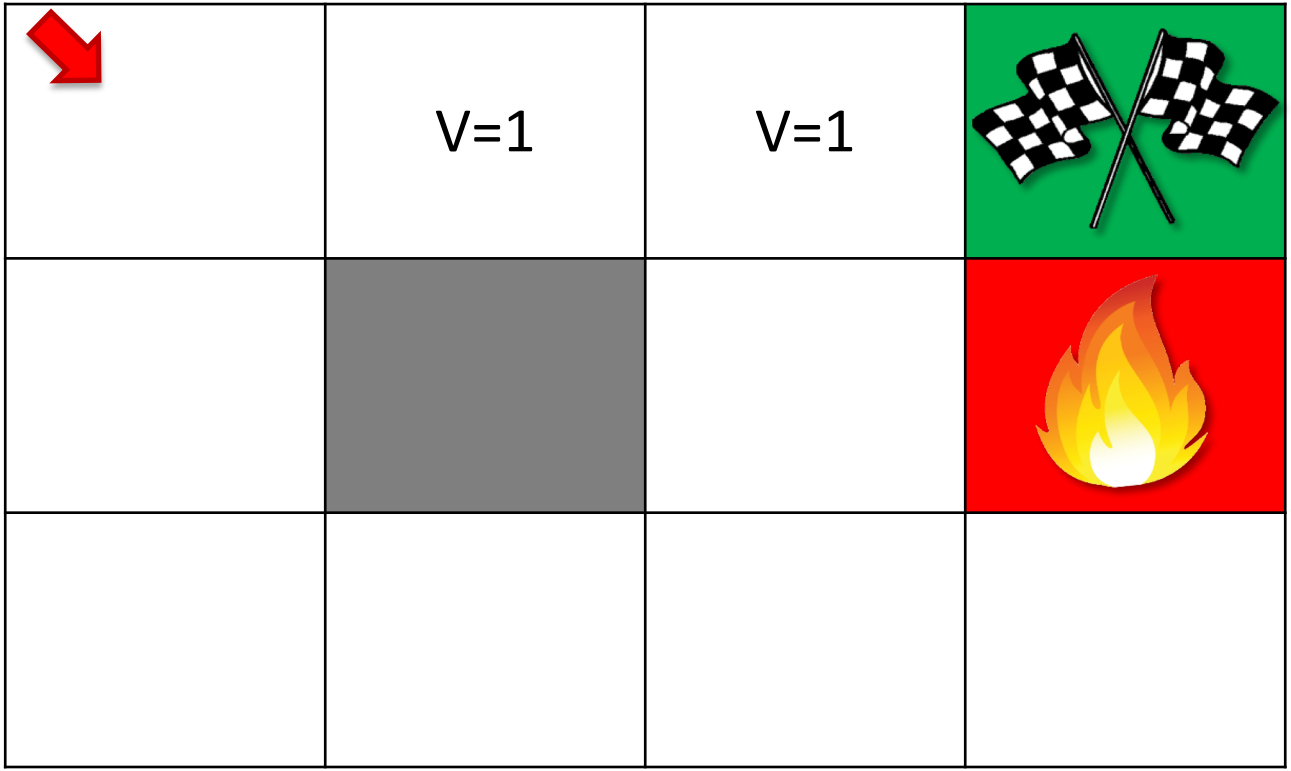

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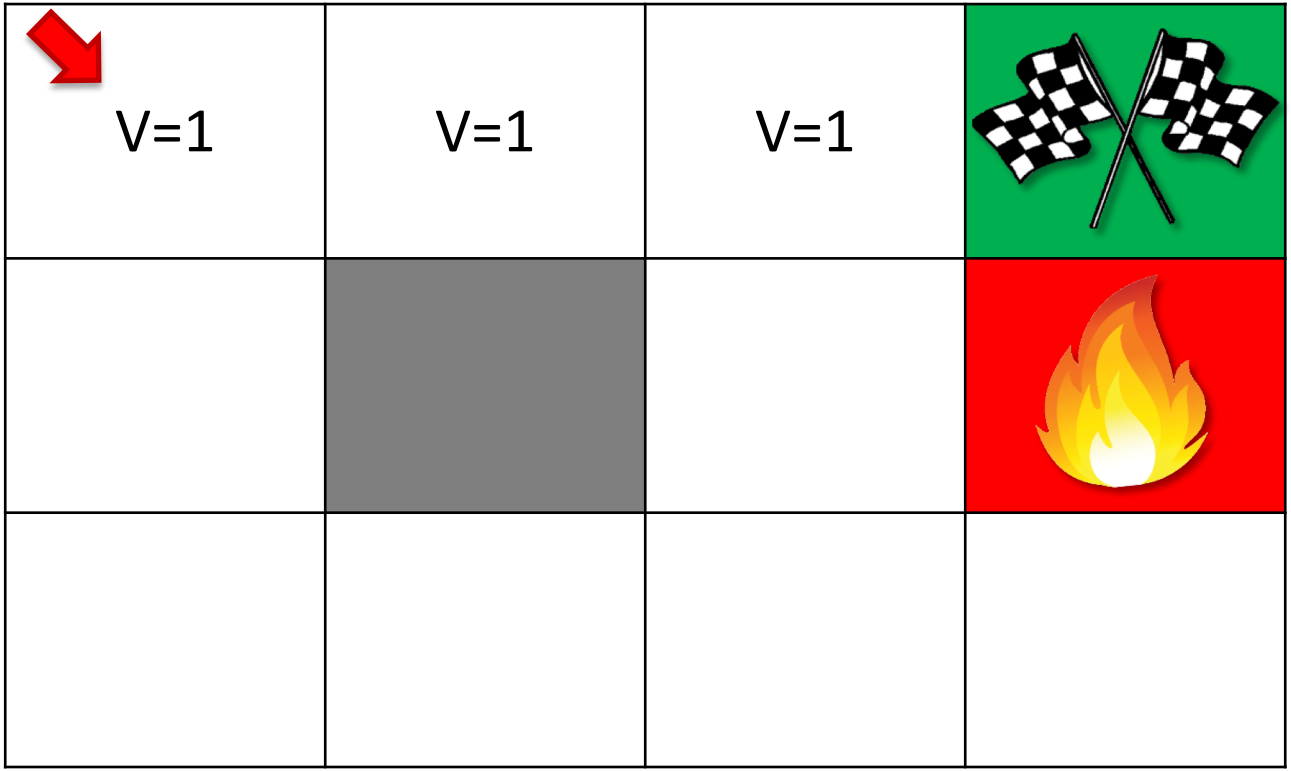

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A Equação de Bellman

V=1	V=1	V=1	
			

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A Equação de Bellman

V=1	V=1	V=1	
V=1			

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A Equação de Bellman

V=1	V=1	V=1	
V=1			
			

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A Equação de Bellman

V=1	V=1	V=1	
V=1			
V=1			

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V=1	V=1	V=1	
V=1			
V=1			

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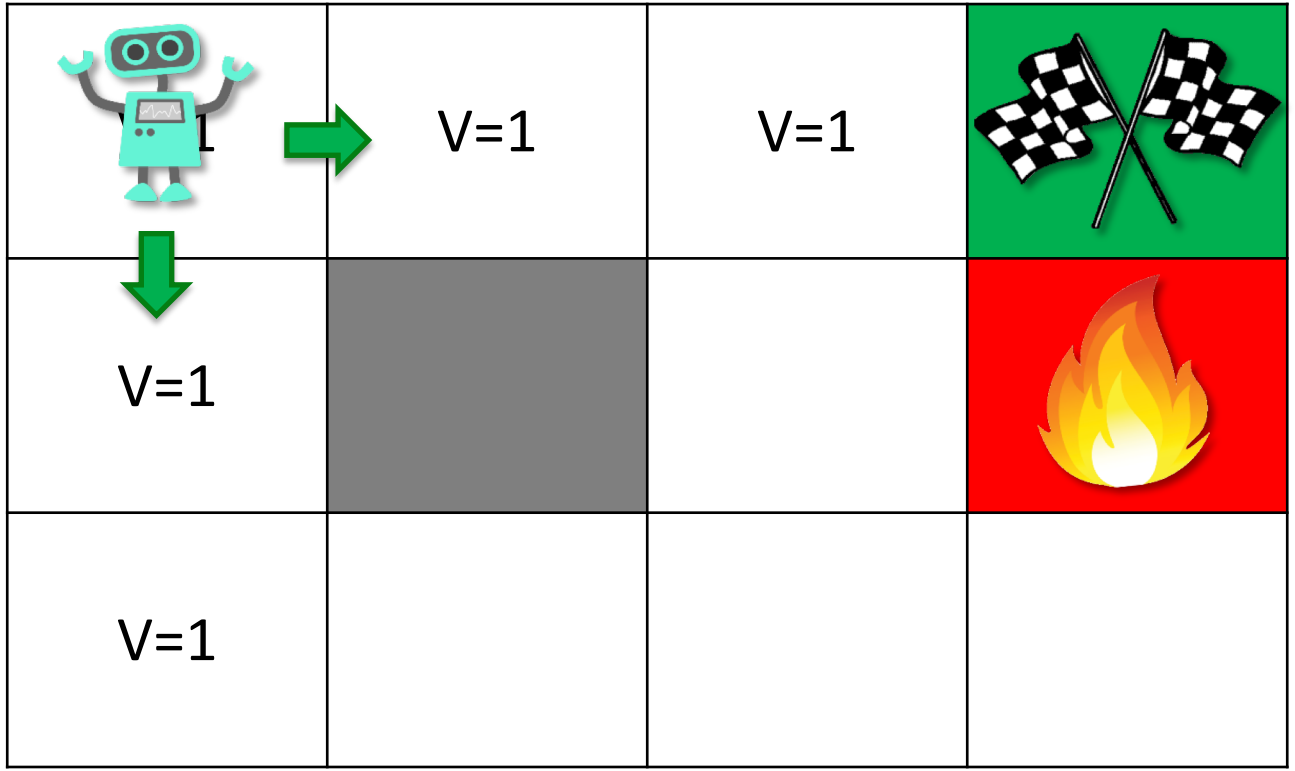

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A Equação de Bellman

V = 1	V = 1	V = 1	
V = 1			
V = 1			

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A Equação de Bellman

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A Equação de Bellman

$$V(s) = \max_{a}(R(s,a) + \gamma V(s'))$$

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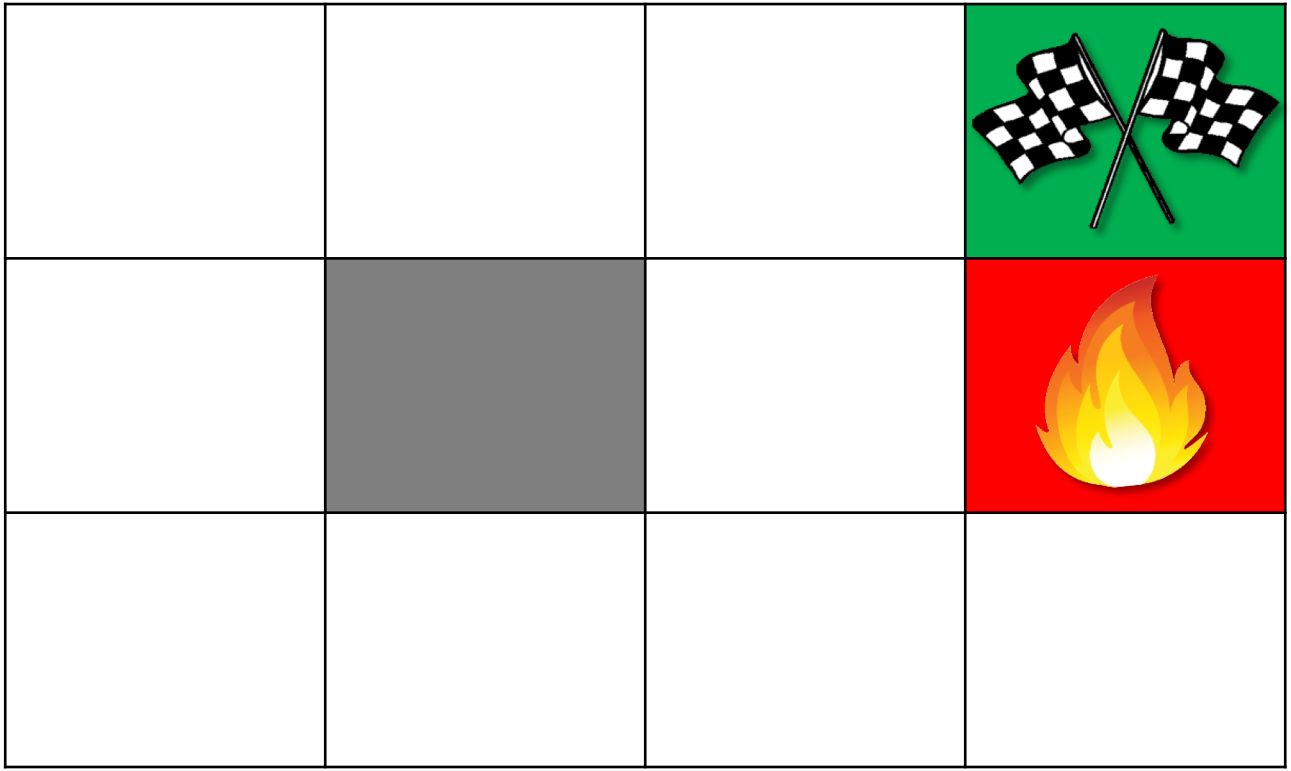
A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$



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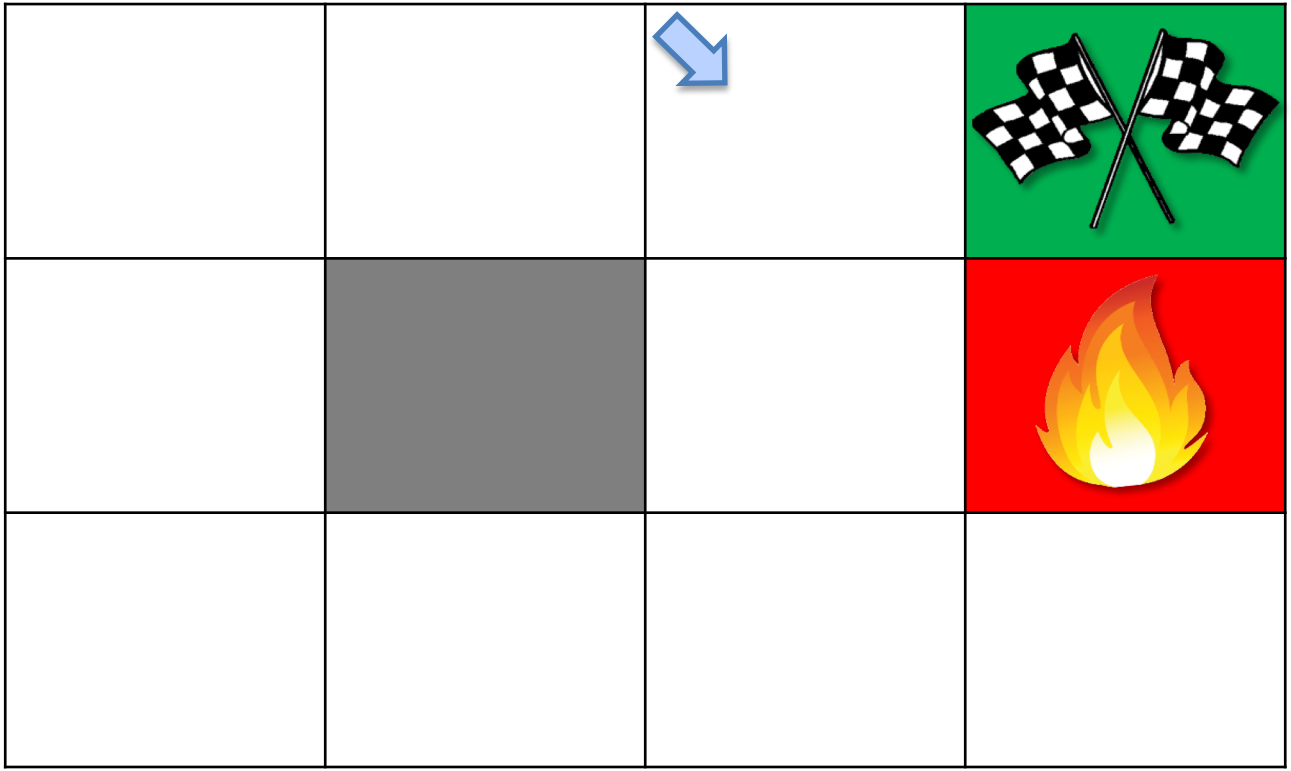

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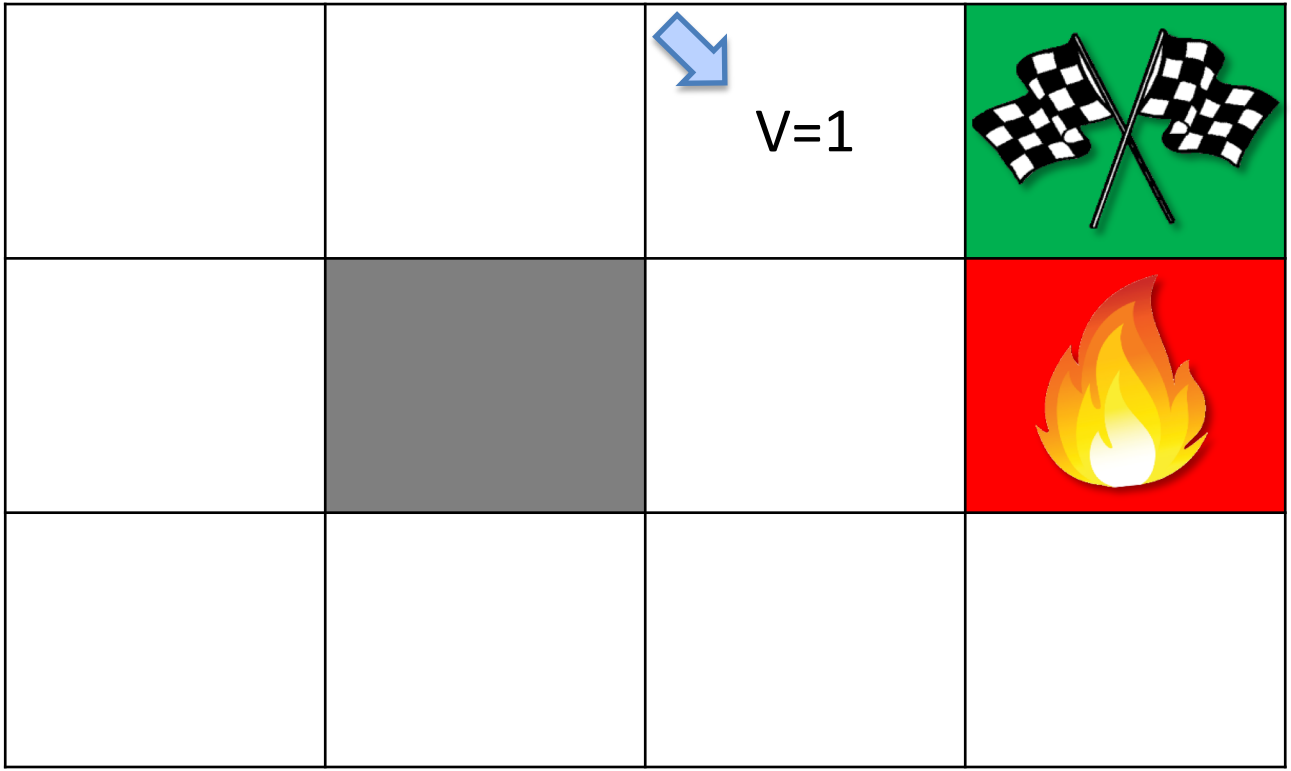

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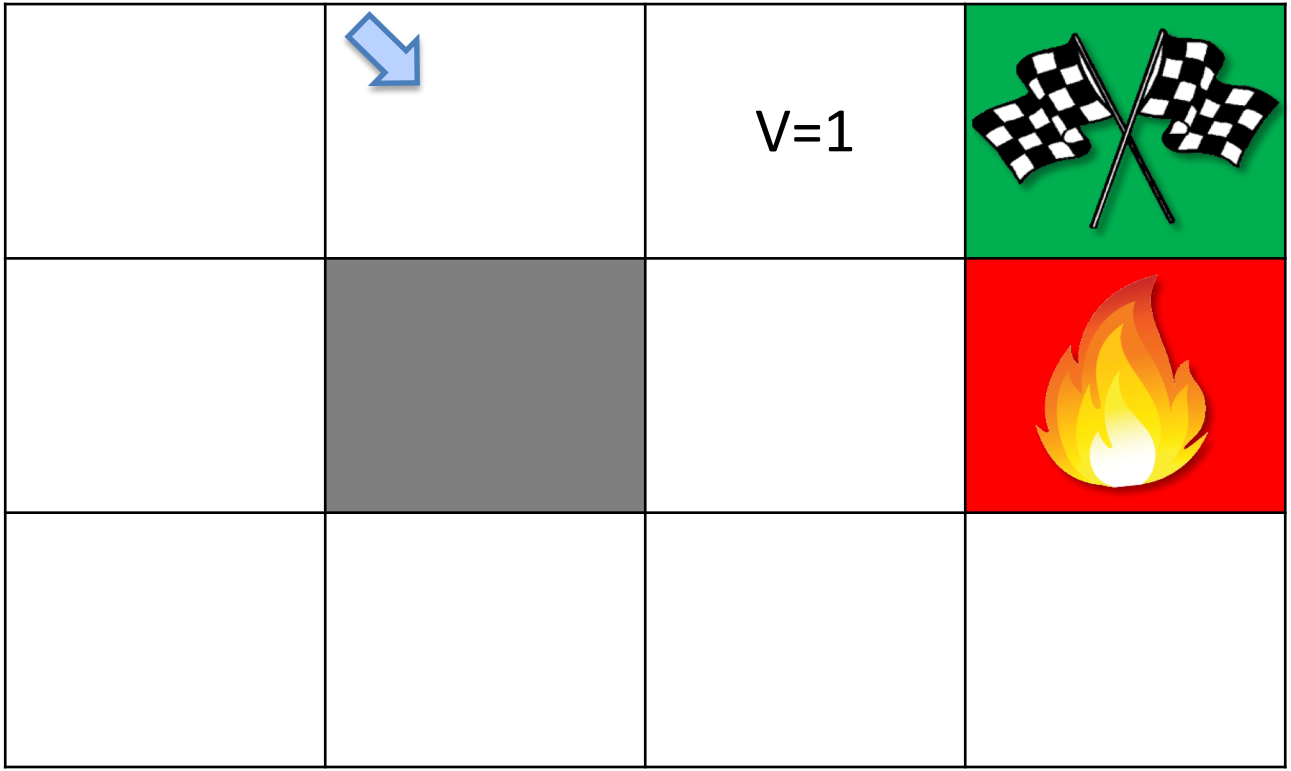

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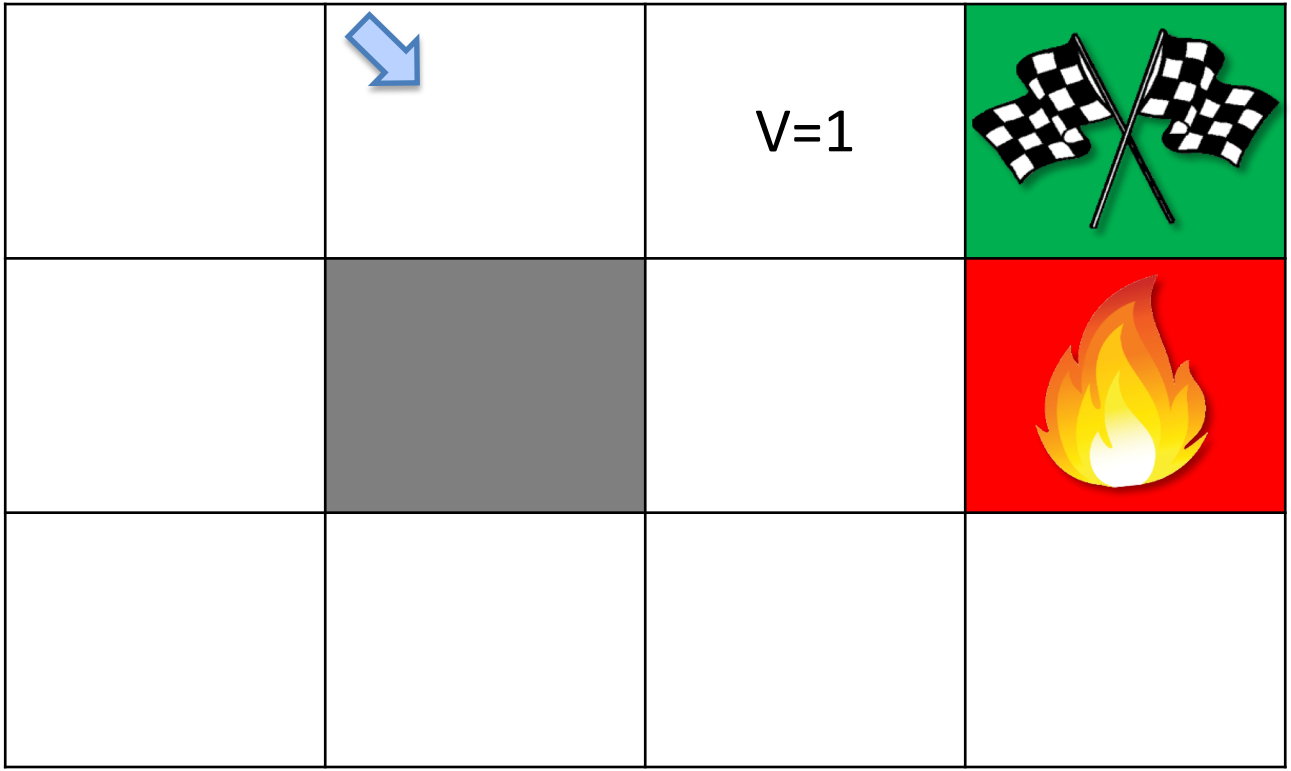
A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$



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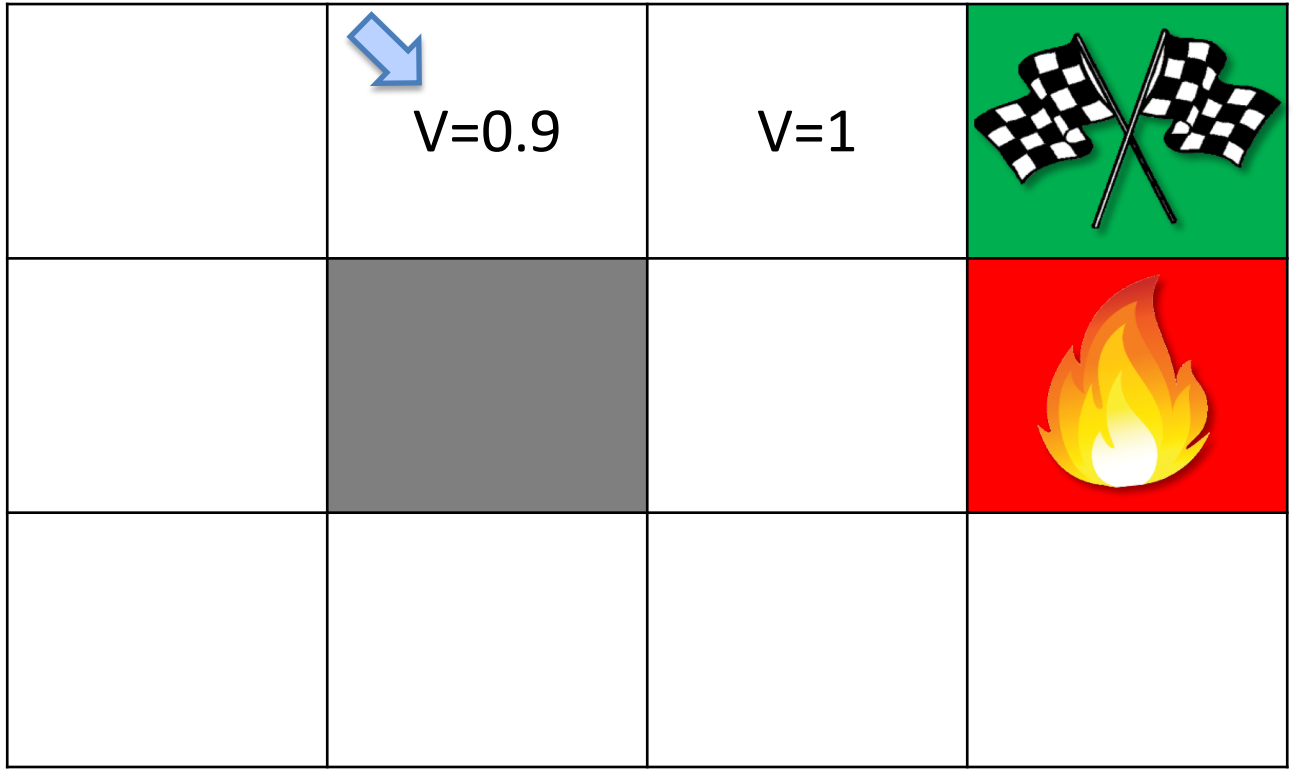

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A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$

↘	V=0.9	V=1	
			

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A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$

V=0.81	V=0.9	V=1	
			

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A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

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V=0.81	V=0.9	V=1	
			

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A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$

V=0.81	V=0.9	V=1	
V=0.73			

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A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$

V=0.81	V=0.9	V=1	
V=0.73			
V=0.66			

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A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$

V=0.81	V=0.9	V=1	
V=0.73			
V=0.66			

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V=0.81	V=0.9	V=1	
V=0.73			
V=0.66			

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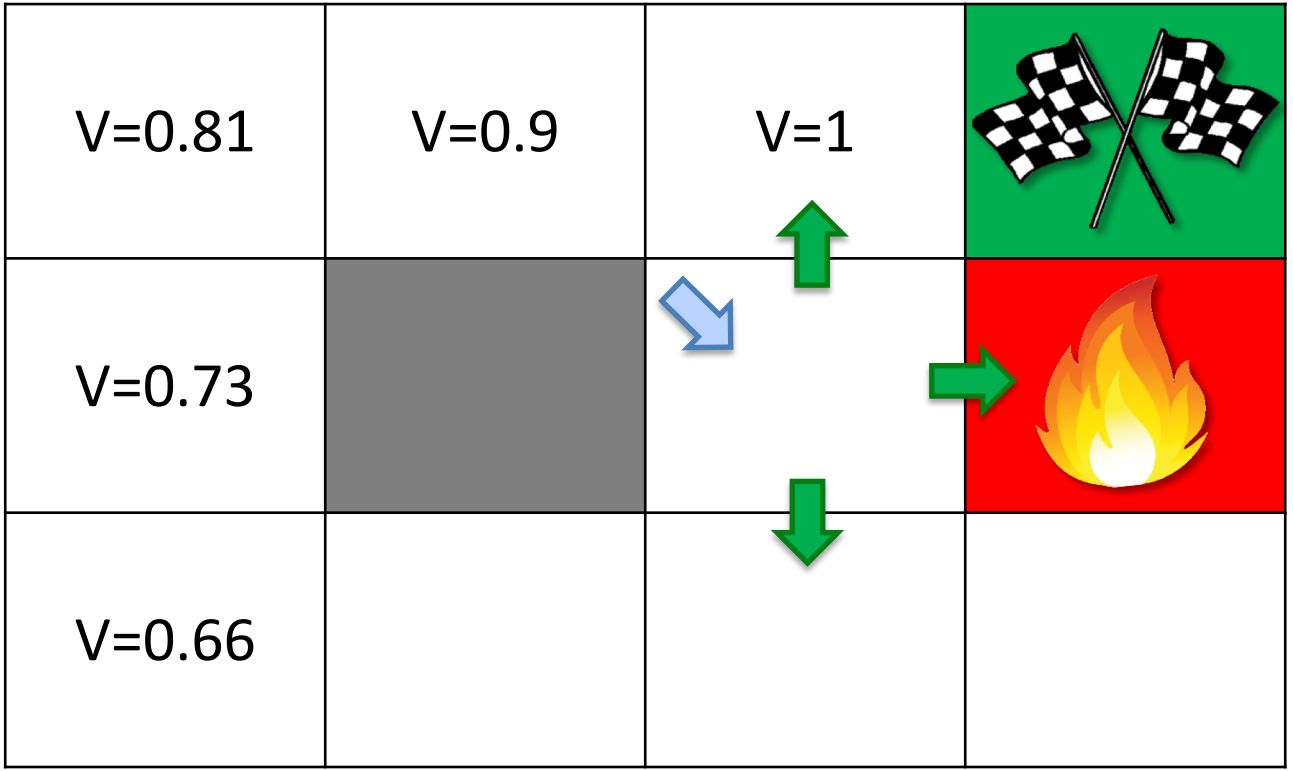

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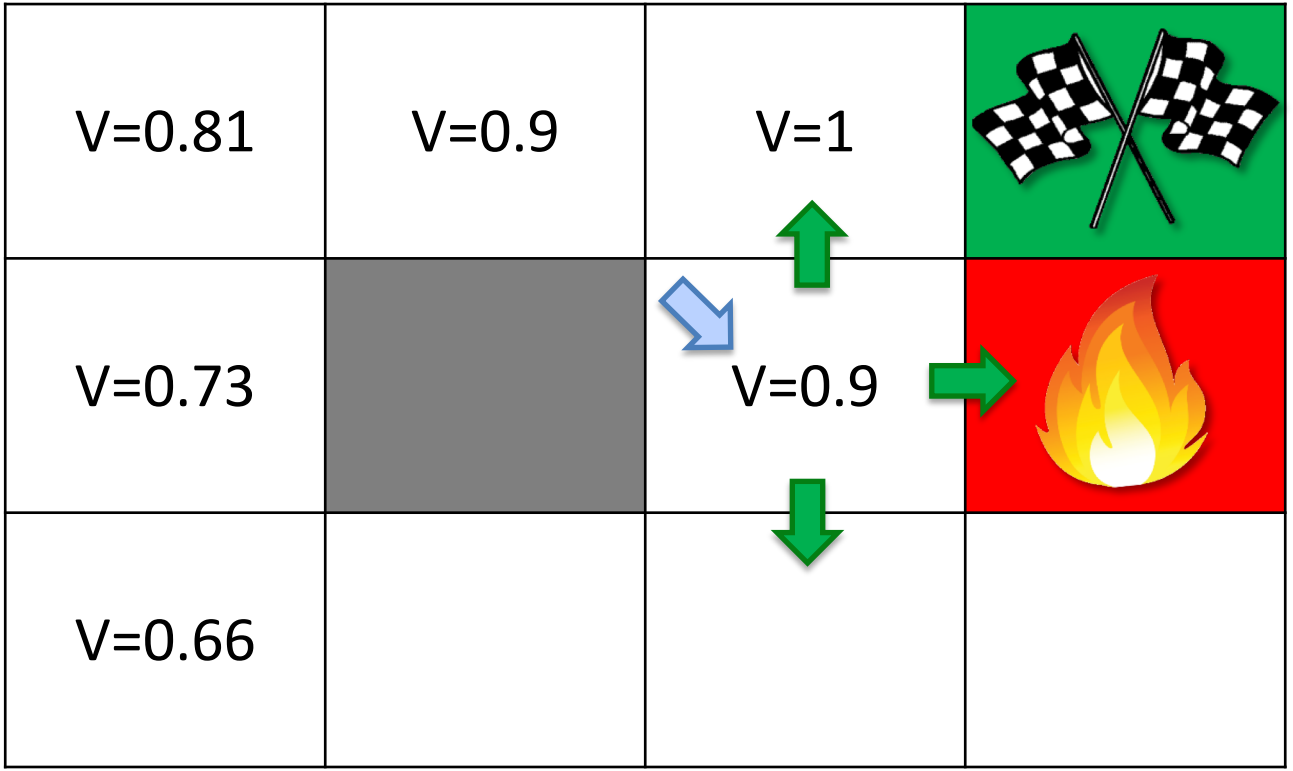

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$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$

V=0.81	V=0.9	V=1	
V=0.73		V=0.9	
V=0.66		↘	

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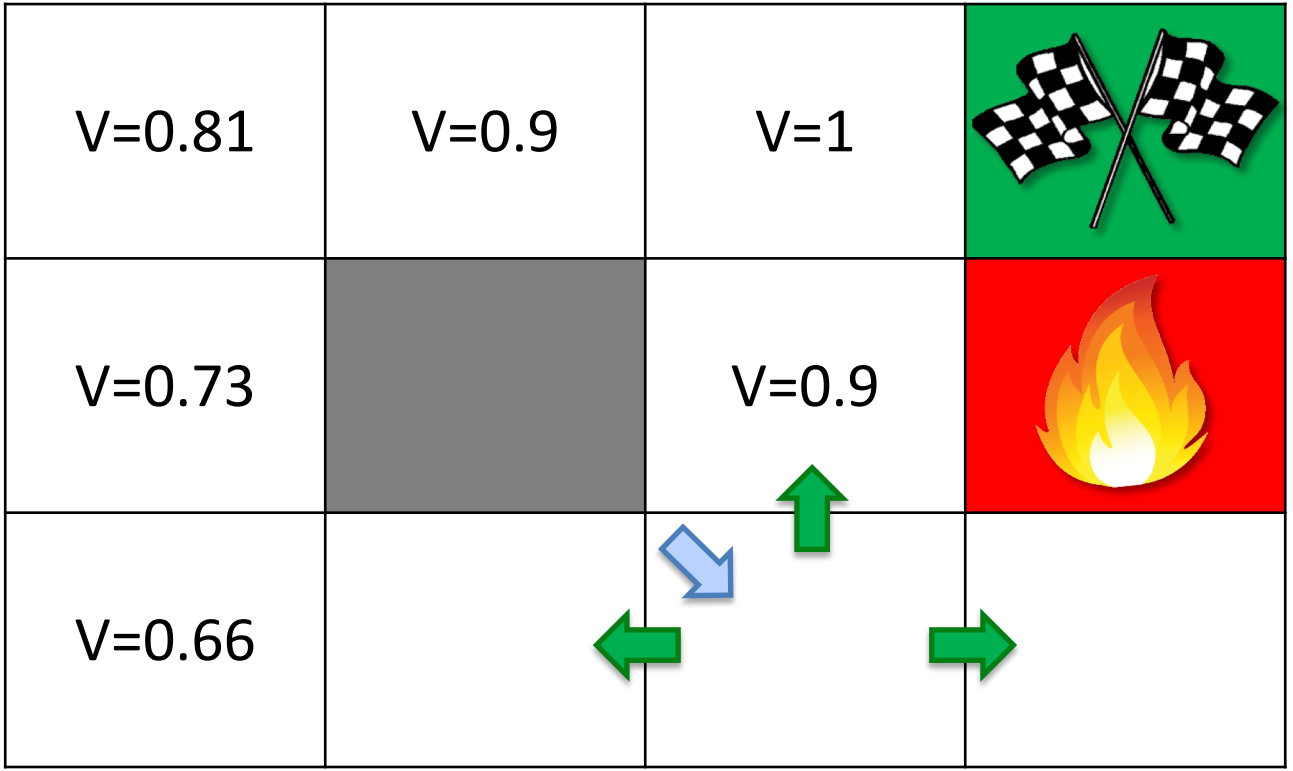

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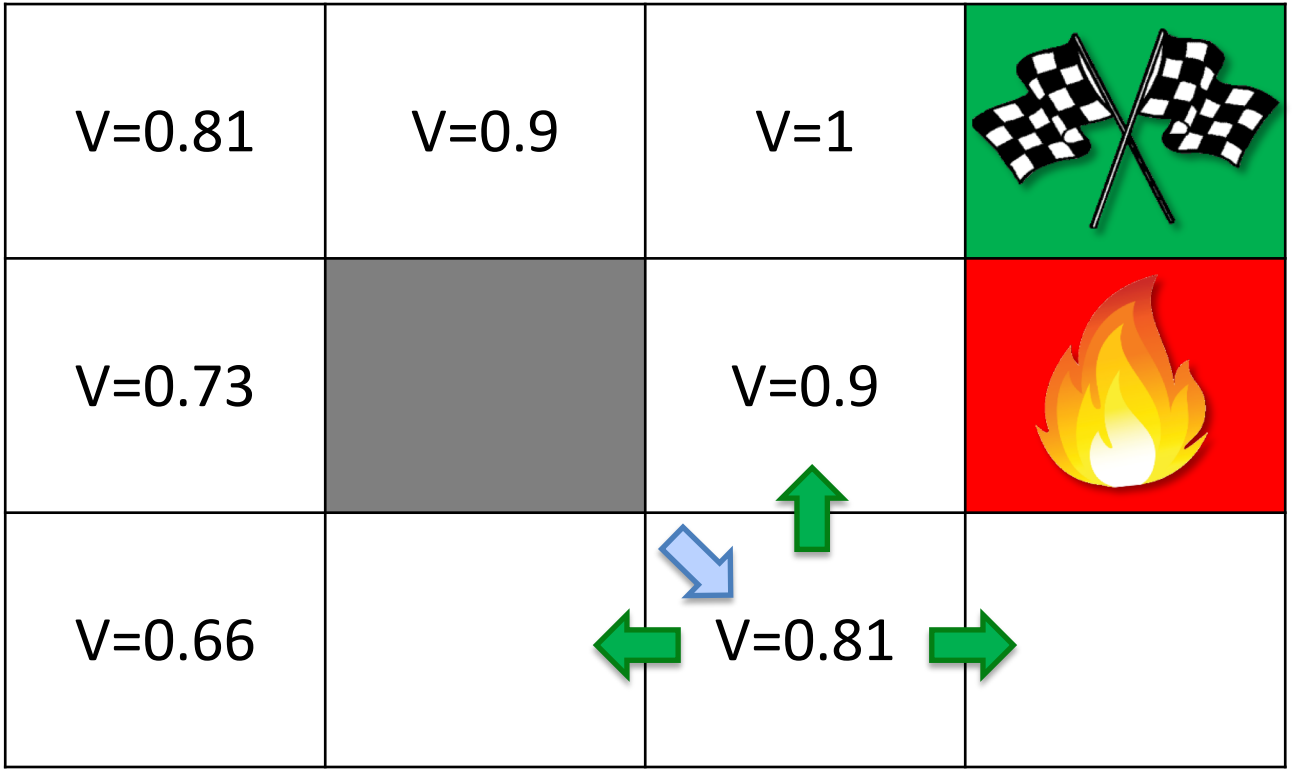

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$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$

V=0.81	V=0.9	V=1	
V=0.73		V=0.9	
V=0.66		V=0.81	

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$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

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V=0.81	V=0.9	V=1	
V=0.73		V=0.9	
V=0.66		V=0.81	

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A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$

V=0.81	V=0.9	V=1	
V=0.73		V=0.9	
V=0.66	V=0.73	V=0.81	

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A Equação de Bellman

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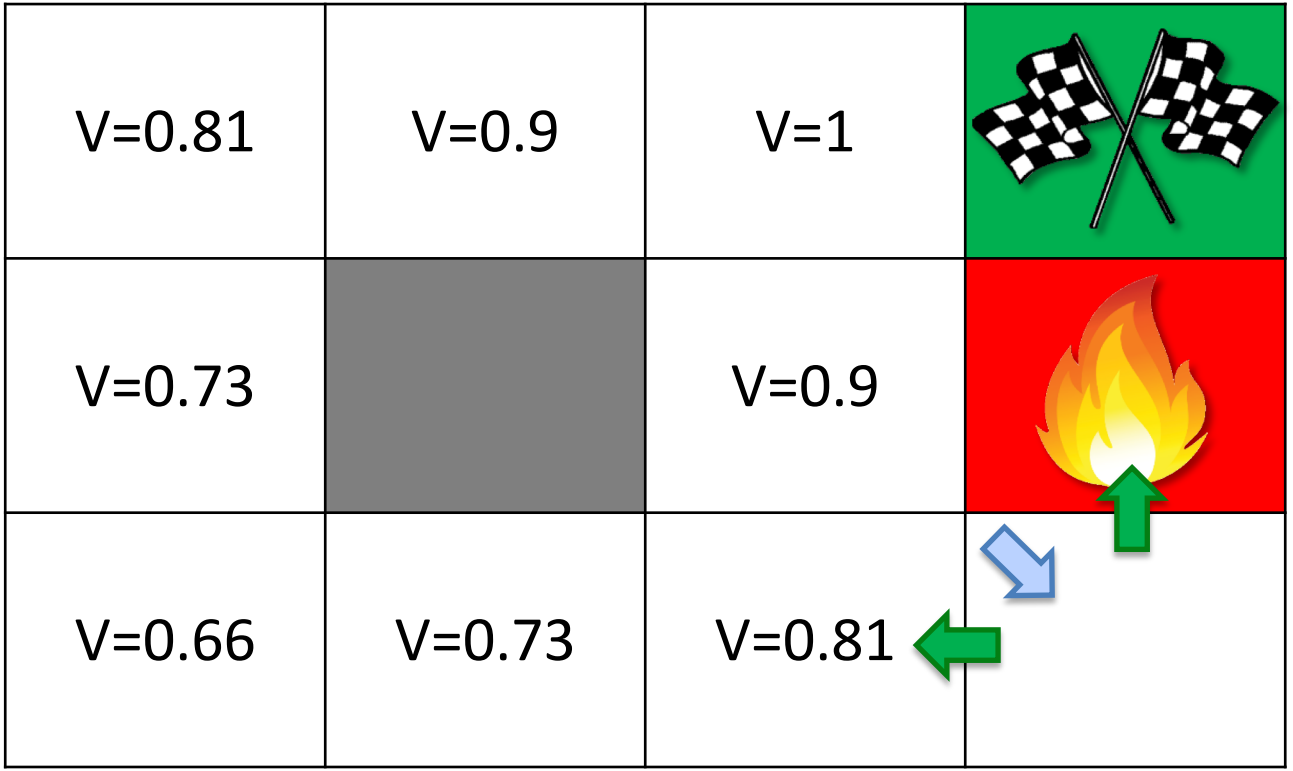

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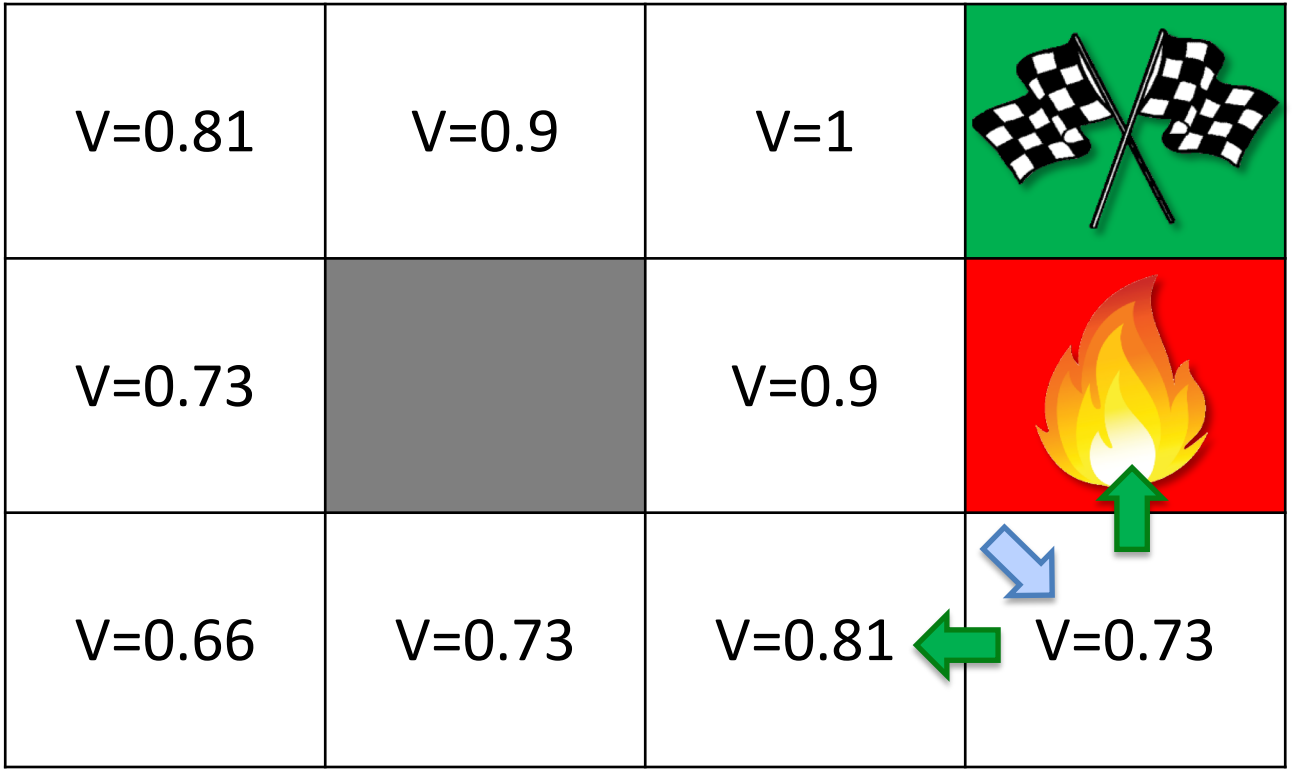
A Equação de Bellman

$$V(s) = \max_a(R(s,a) + \gamma V(s'))$$

$\gamma = 0.9$



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A Equação de Bellman

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V=0.81	V=0.9	V=1	
V=0.73		V=0.9	
V=0.66	V=0.73	V=0.81	V=0.73

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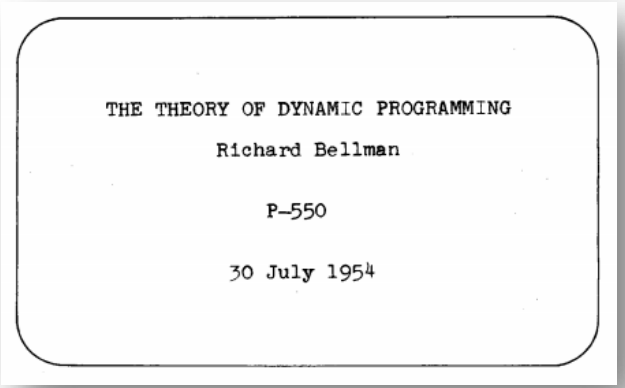
Leitura Adicional

Leitura Adicional:

The Theory of Dynamic Programming

Richard Bellman (1954)


THE THEORY OF DYNAMIC PROGRAMMING

Richard Bellman

P–550

30 July 1954

Link:

https://www.rand.org/content/dam/rand/pubs/papers/2008/P550.pdf

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O “Plano”

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A Equação de Bellman

V=0.81	V=0.9	V=1	
V=0.73		V=0.9	
V=0.66	V=0.73	V=0.81	V=0.73

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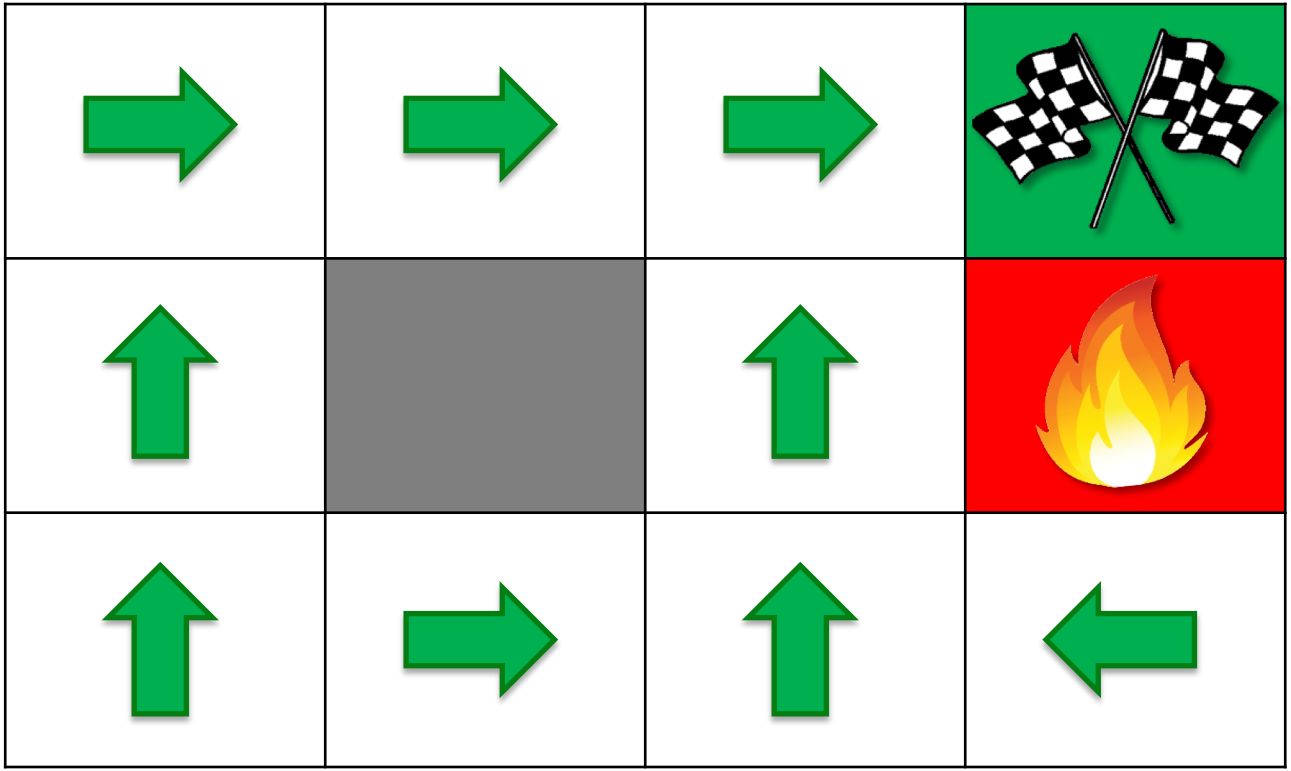
A Equação de Bellman



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Markov Decision Process (MDP)

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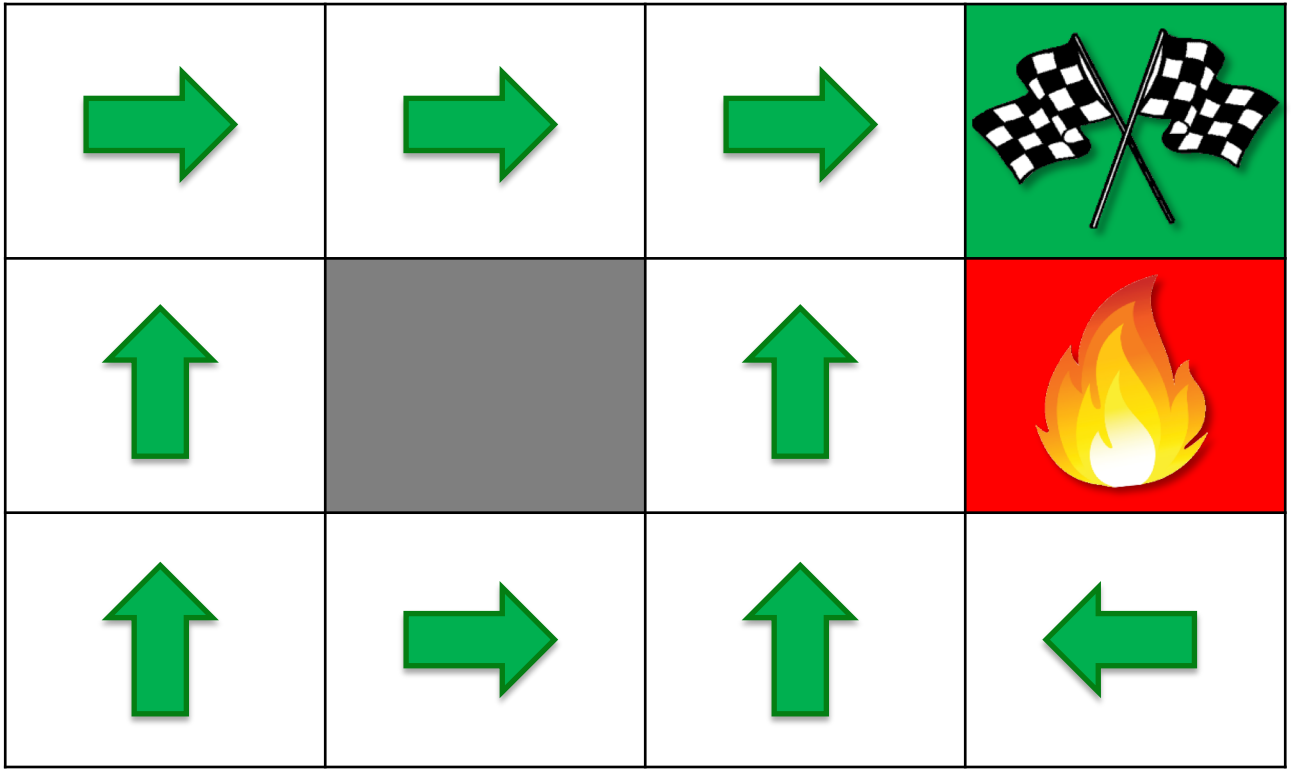
Markov Decision Process (MDP)



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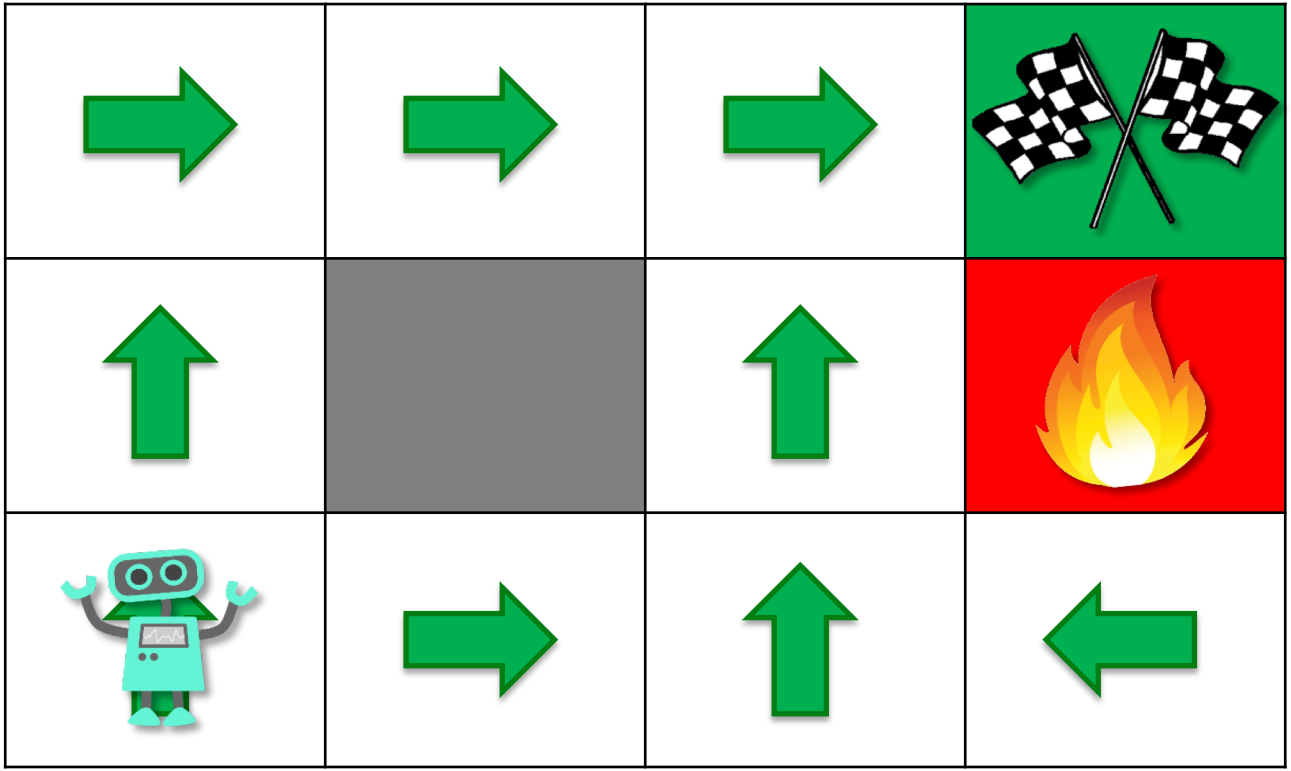

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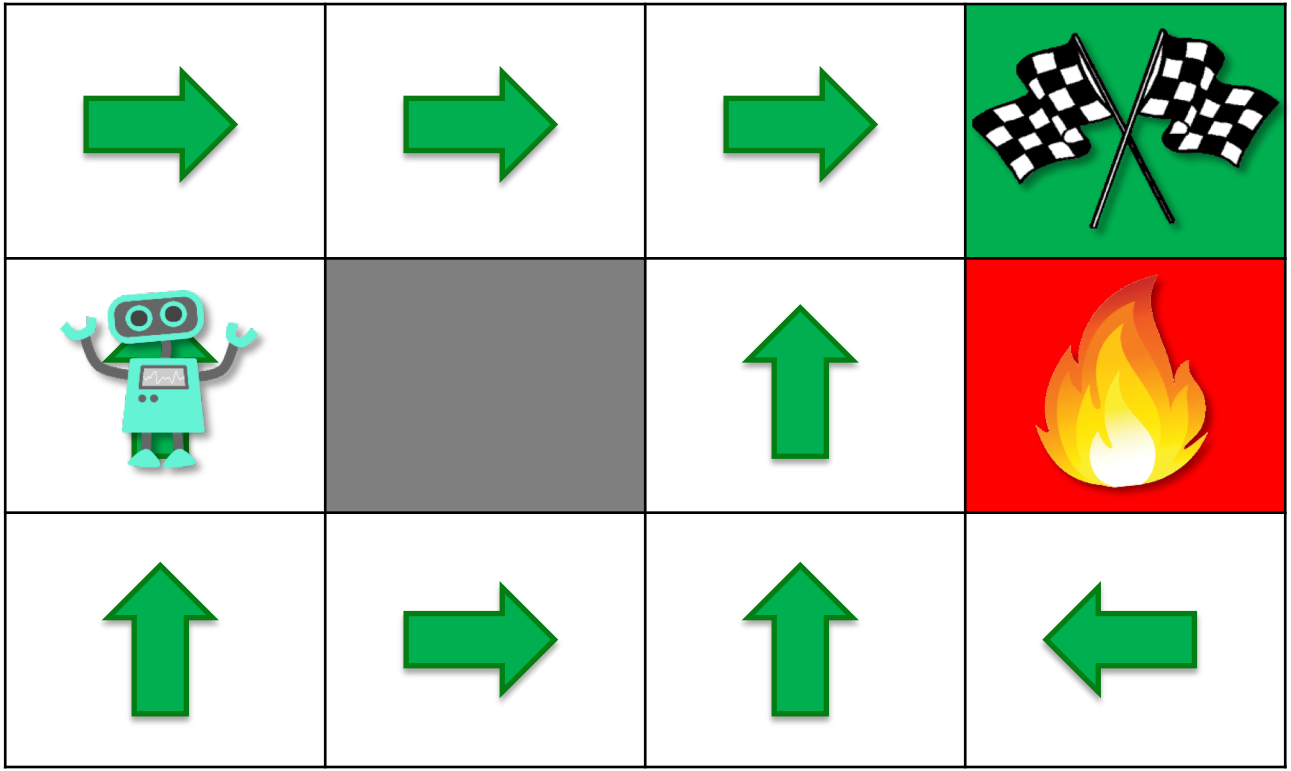
Markov Decision Process (MDP)



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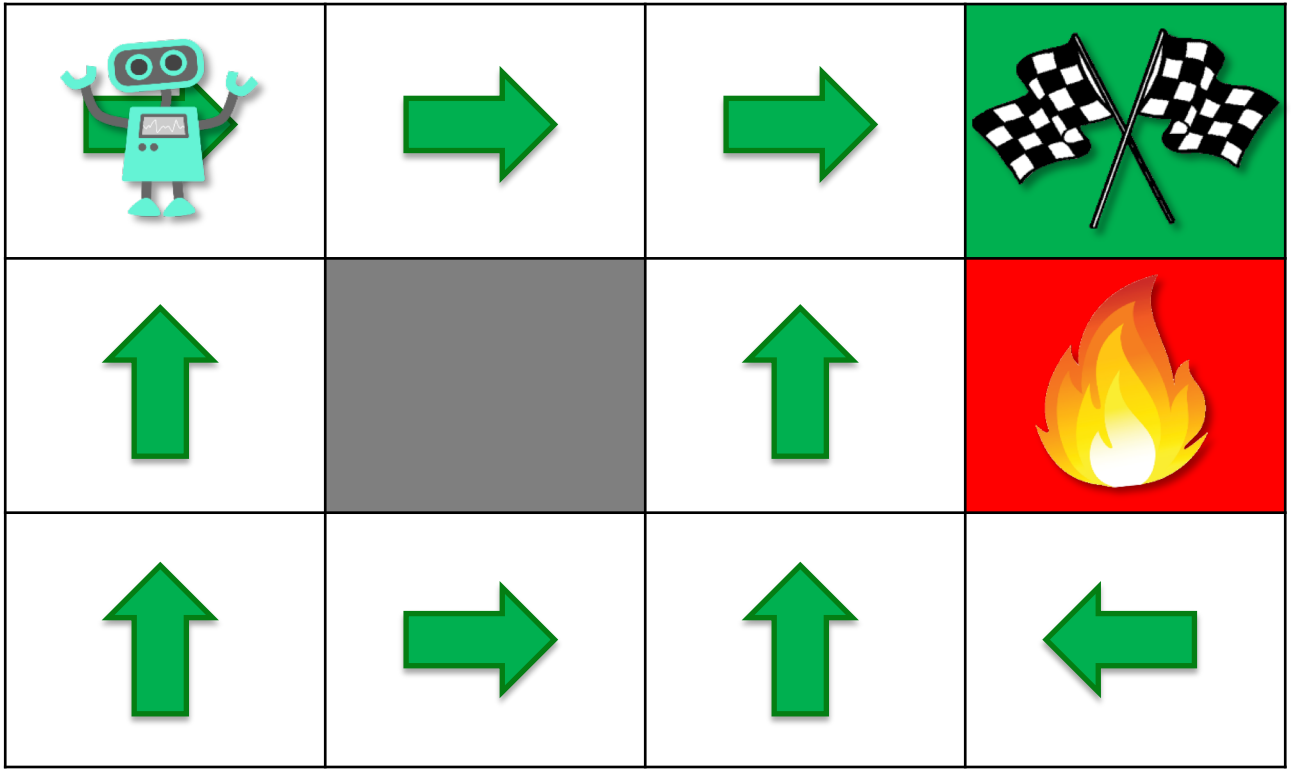
Markov Decision Process (MDP)



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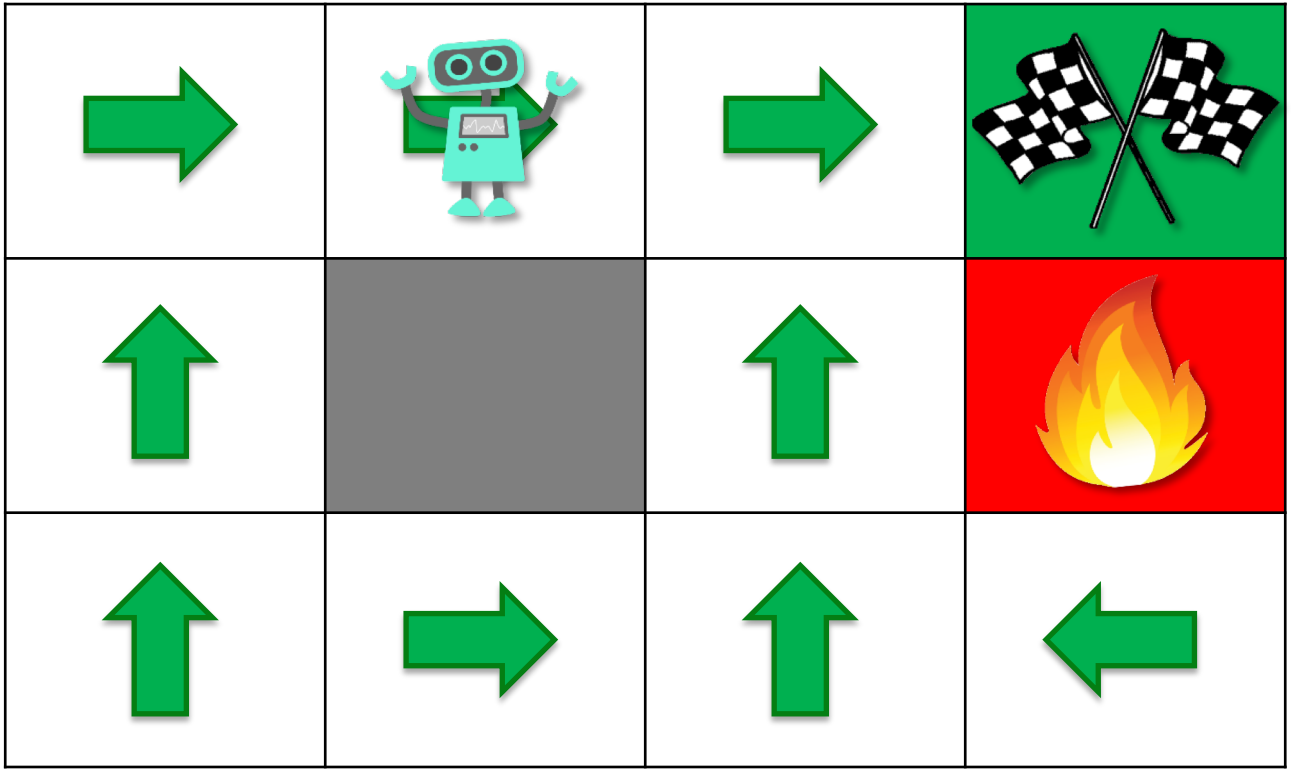

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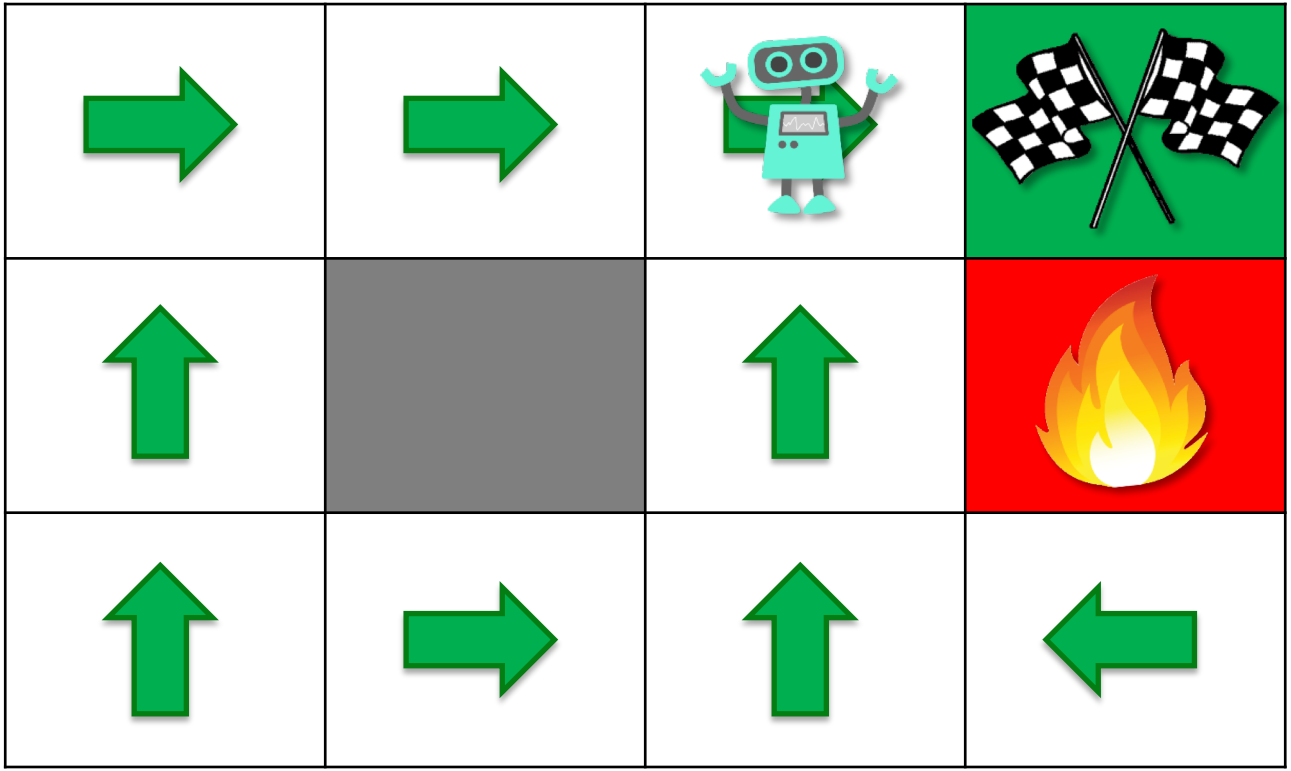

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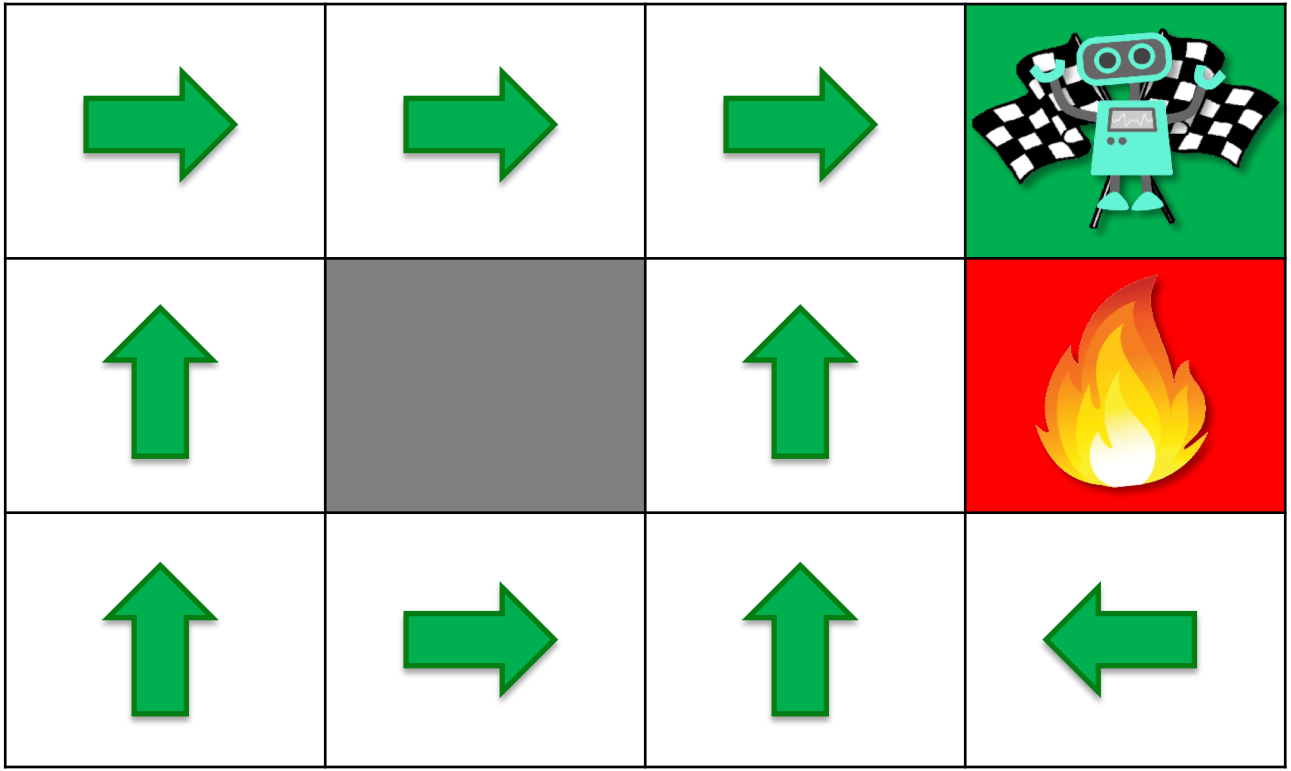

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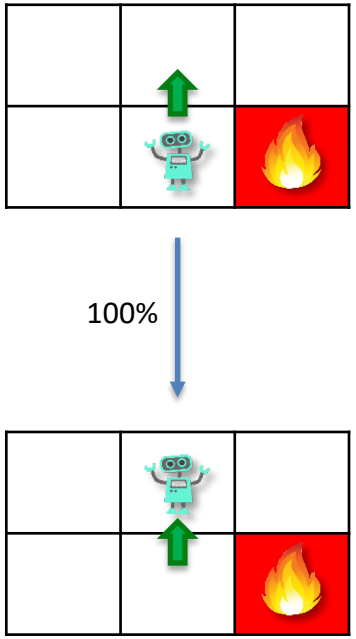
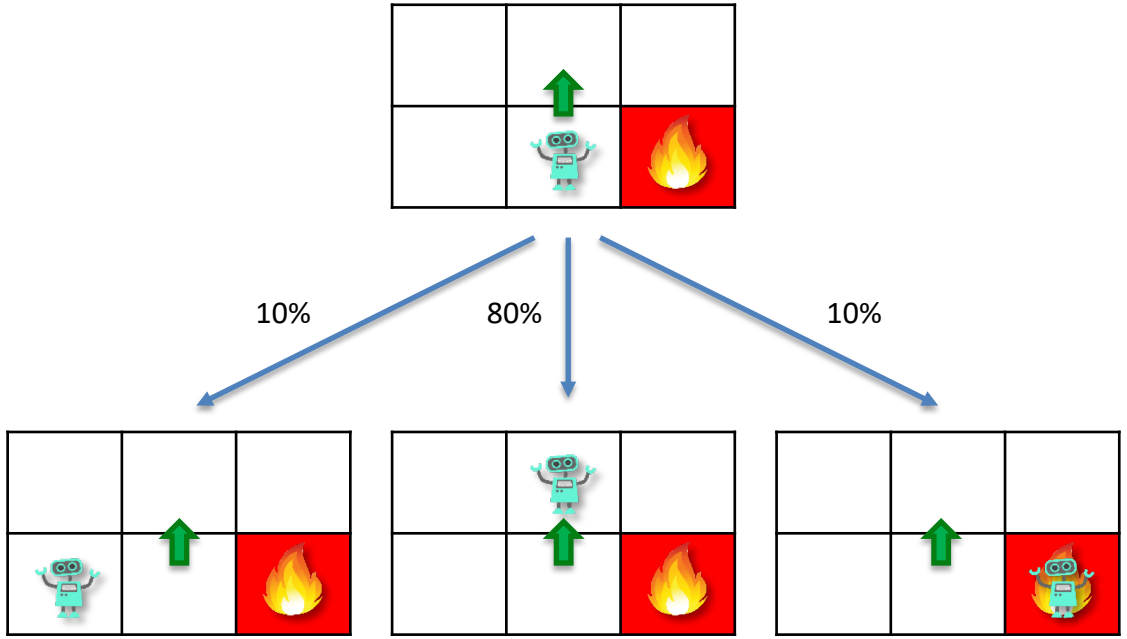
Markov Decision Process (MDP)

Busca Determinística



Busca Não-Determinística



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Markov Decision Process (MDP)

Markov Process

Markov Decision Process (MDP)

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Markov Decision Process (MDP)

Um processo estocástico possui a propriedade Markov se a distribuição de probabilidade condicional de estados futuros do processo (condicional em estados passados e presentes) depende apenas do estado presente, não da sequência de eventos que o precedeu. Um processo com essa propriedade é chamado de processo de Markov.

Wikipedia (traduzido para português)

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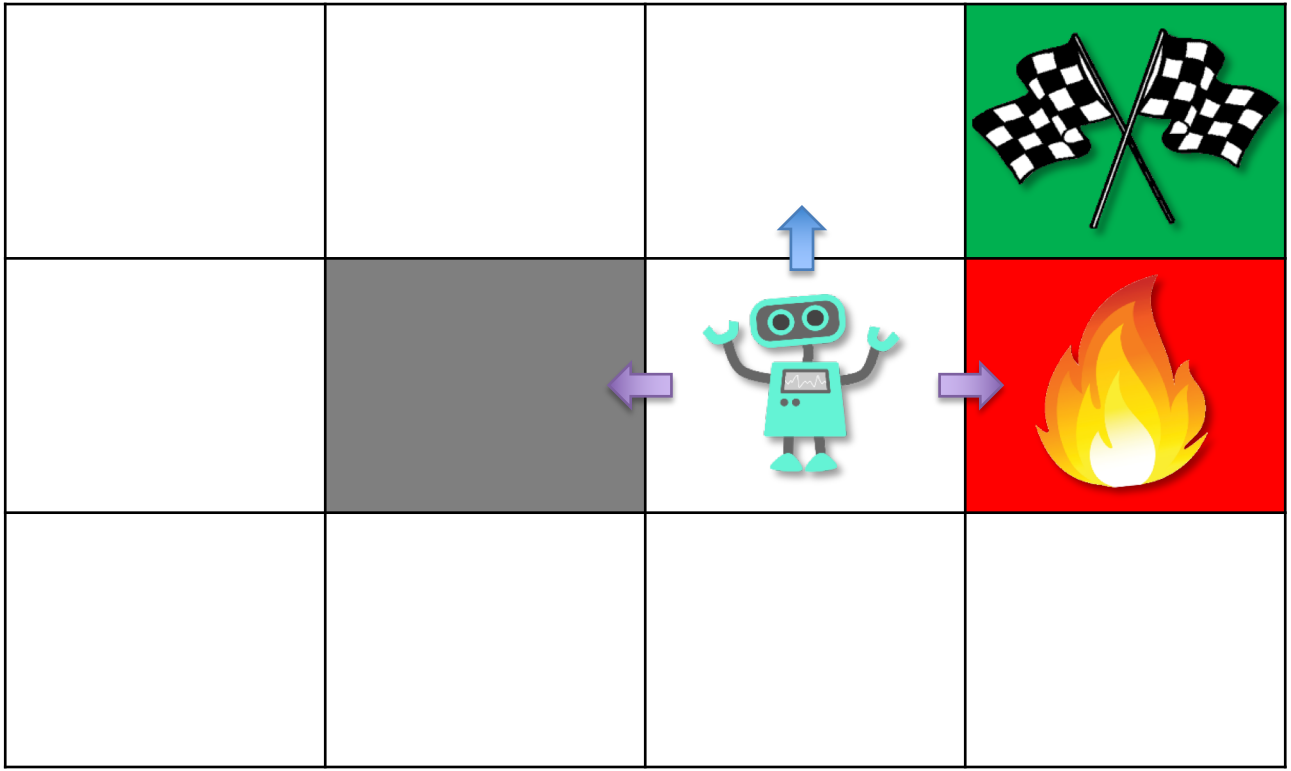
Markov Decision Process (MDP)



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Markov Decision Process (MDP)

Markov Decision Processes (MDPs – Processos de Decisão de Makov) fornecem uma estrutura matemática para modelar a tomada de decisões em situações onde os resultados são parcialmente aleatórios e parcialmente sob o controle de um tomador de decisão.

Wikipedia (traduzido para o português)

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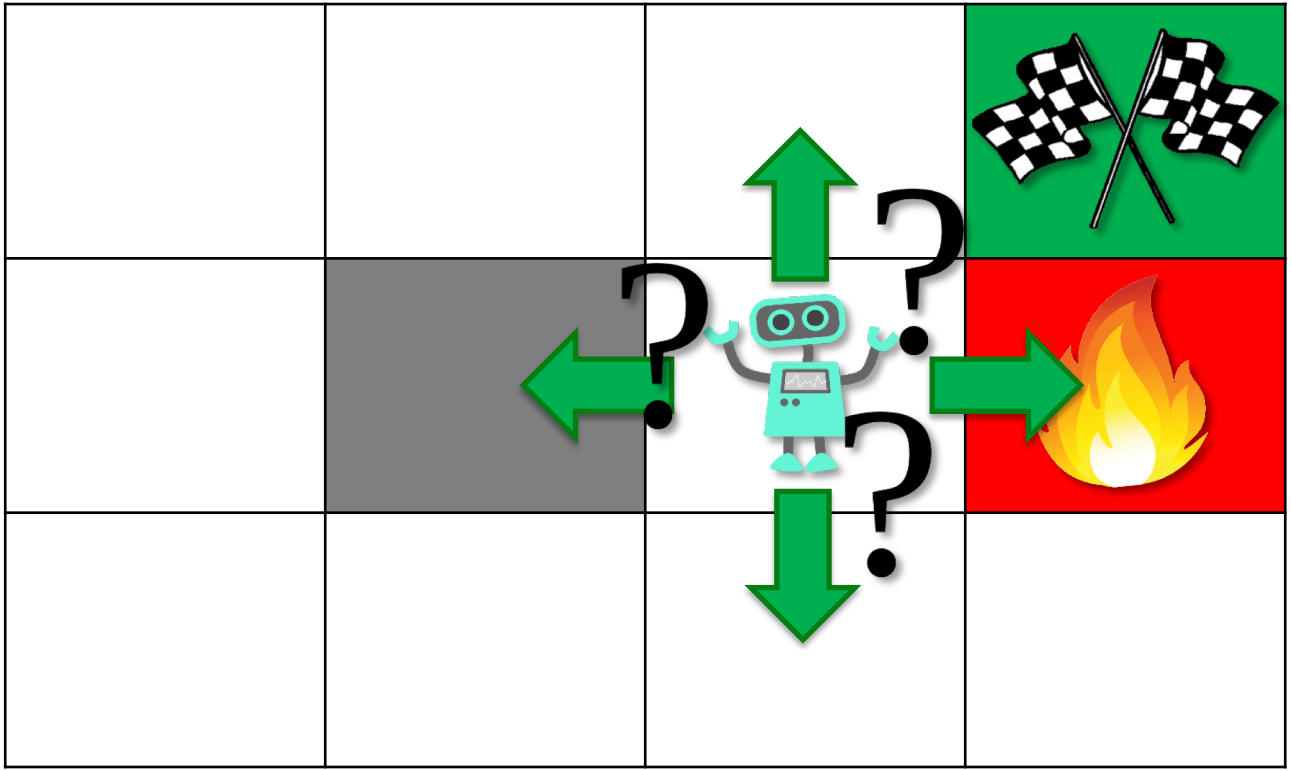
Markov Decision Process (MDP)



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Markov Decision Process (MDP)

$$V(s) = \max_{a}(R(s,a) + \gamma V(s'))$$

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Markov Decision Process (MDP)

$$V(s) = \max_{a}(R(s,a) + \gamma V(s'))$$

$s'_1 \quad s'_2 \quad s'_3$

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Markov Decision Process (MDP)

$$V(s) = \max_{a}(R(s,a) + \gamma V(s'))$$

$V(s_1')$ $V(s_2')$ $V(s_3')$

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Markov Decision Process (MDP)

$$0.8 * V(s'_1) + 0.1 * V(s'_2) + 0.1 * V(s'_3)$$

$$V(s) = \max_a (R(s,a) + \gamma V(s'))$$

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Markov Decision Process (MDP)

$$V(s) = \max_{a} \left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$

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Leitura Adicional

Leitura Adicional:

A Survey of Applications of Markov Decision Processes

D. J. White (1993)

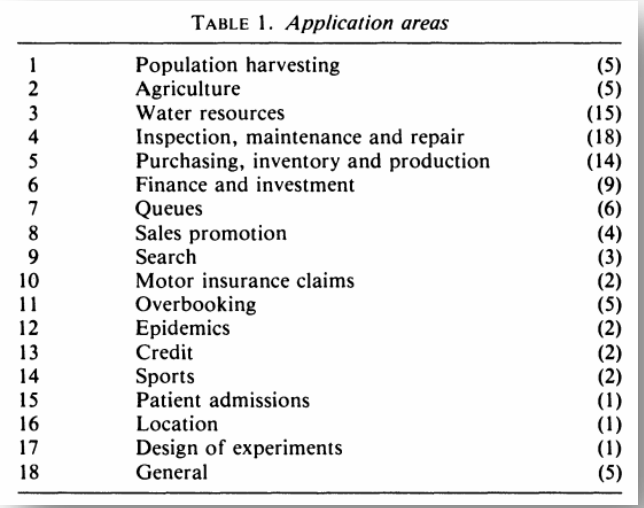

TABLE 1. *Application areas*

1	Population harvesting	(5)
2	Agriculture	(5)
3	Water resources	(15)
4	Inspection, maintenance and repair	(18)
5	Purchasing, inventory and production	(14)
6	Finance and investment	(9)
7	Queues	(6)
8	Sales promotion	(4)
9	Search	(3)
10	Motor insurance claims	(2)
11	Overbooking	(5)
12	Epidemics	(2)
13	Credit	(2)
14	Sports	(2)
15	Patient admissions	(1)
16	Location	(1)
17	Design of experiments	(1)
18	General	(5)

Link:

http://www.cs.uml.edu/ecg/uploads/AIfall14/MDPApplications3.pdf

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Política x Plano

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Política x Plano

$$V(s) = \max_{a}\left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$

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Política x Plano

V=0.81	V=0.9	V=1	
V=0.73		V=0.9	
V=0.66	V=0.73	V=0.81	V=0.73

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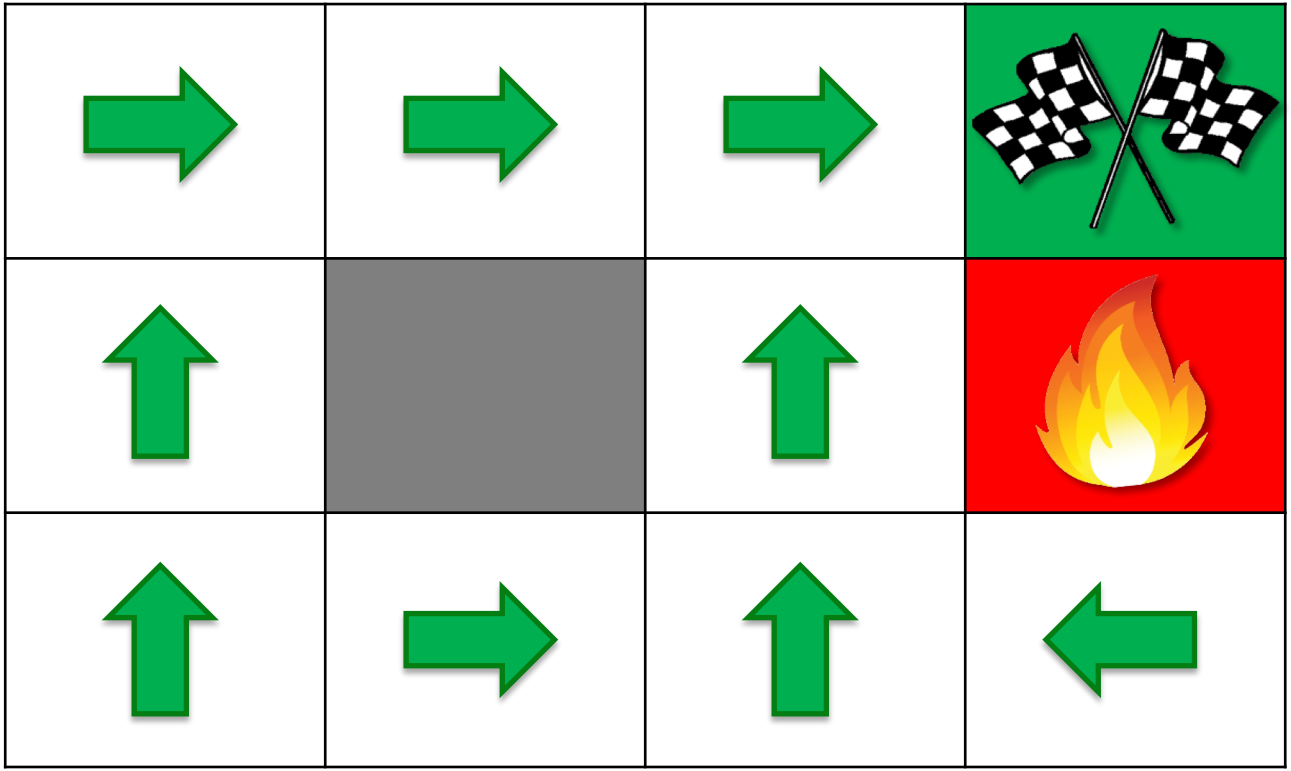
Política x Plano



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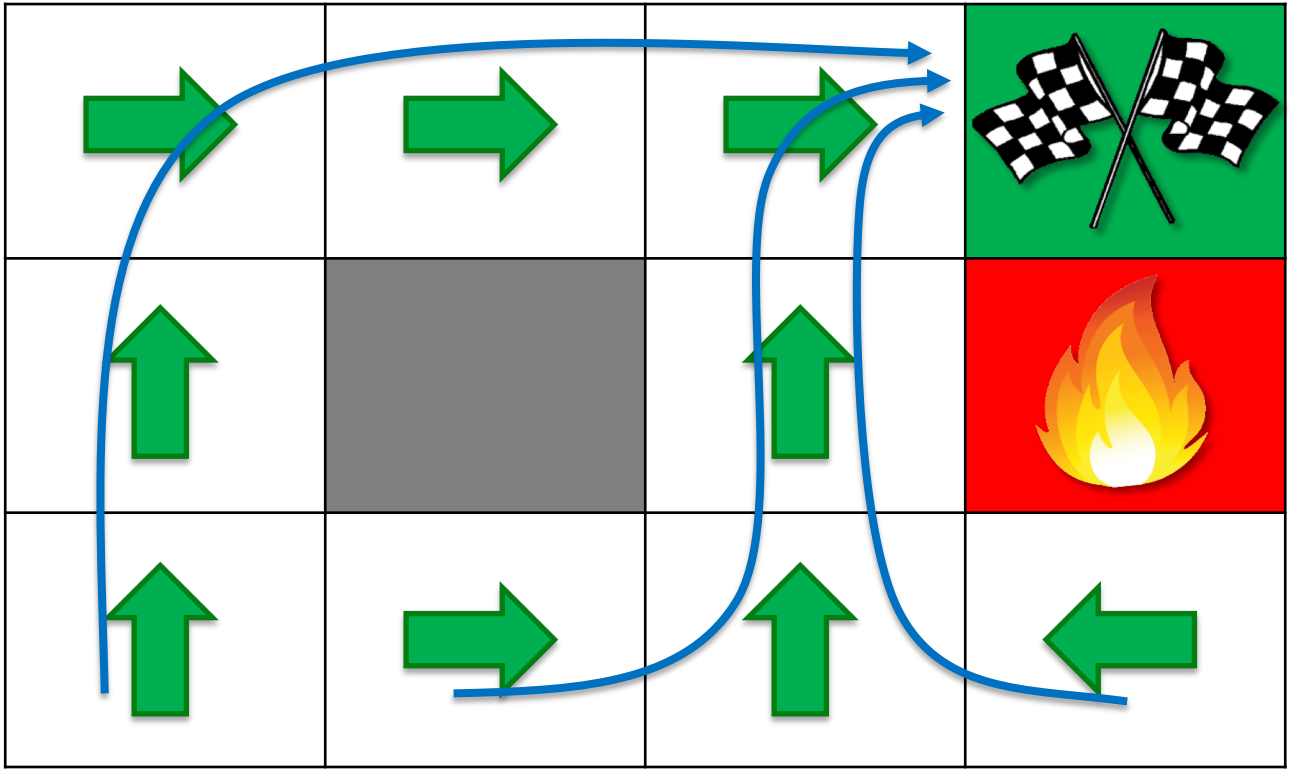
Política x Plano



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Política x Plano

V=0.71	V=0.74	V=0.86	
V=0.63		V=0.39	
V=0.55	V=0.46	V=0.36	V=0.22

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Política x Plano

V=0.81	V=0.9	V=1	
V=0.73		V=0.9	
V=0.66	V=0.73	V=0.81	V=0.73

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Política x Plano

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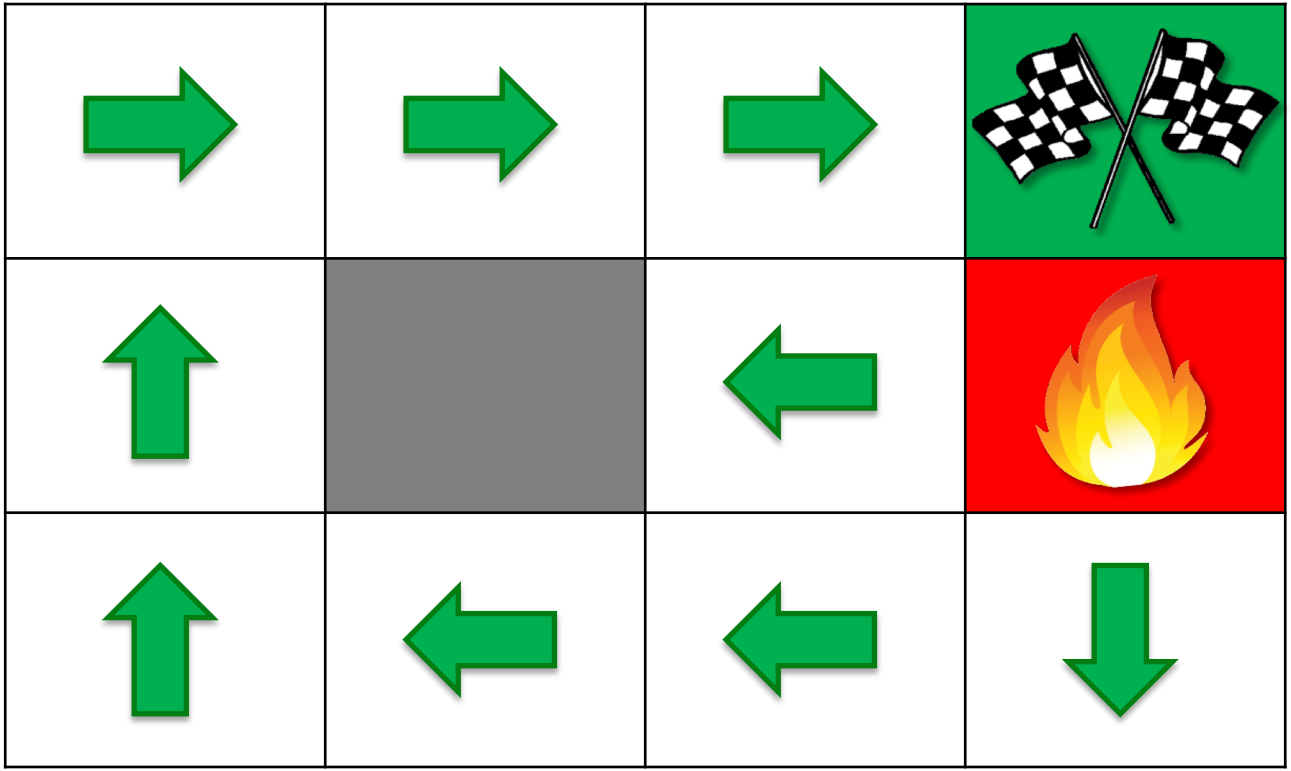
Política x Plano



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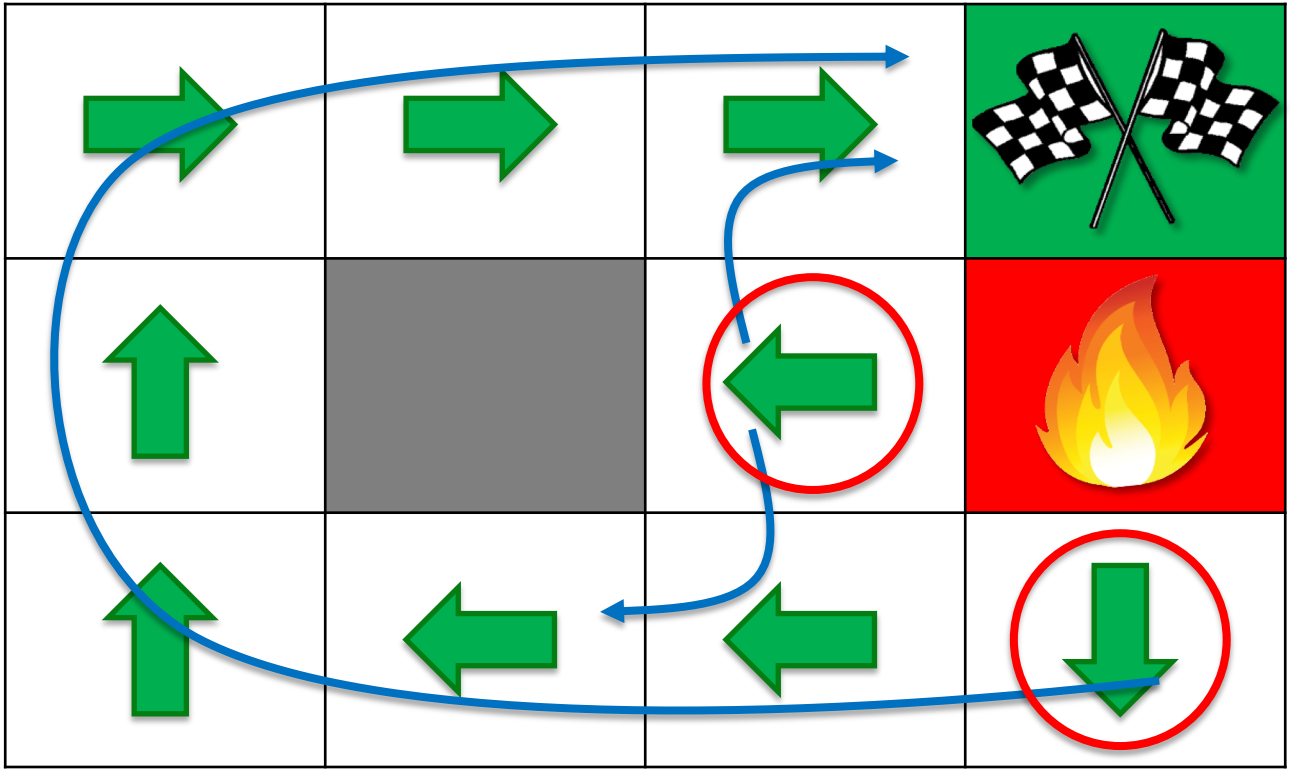
Política x Plano



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Adição de Penalidades – "Living Penalty"

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“Living Penalty”

$$V(s) = \max_{a}\left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$

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"Living Penalty"

$$V(s) = \max_{a}\left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$

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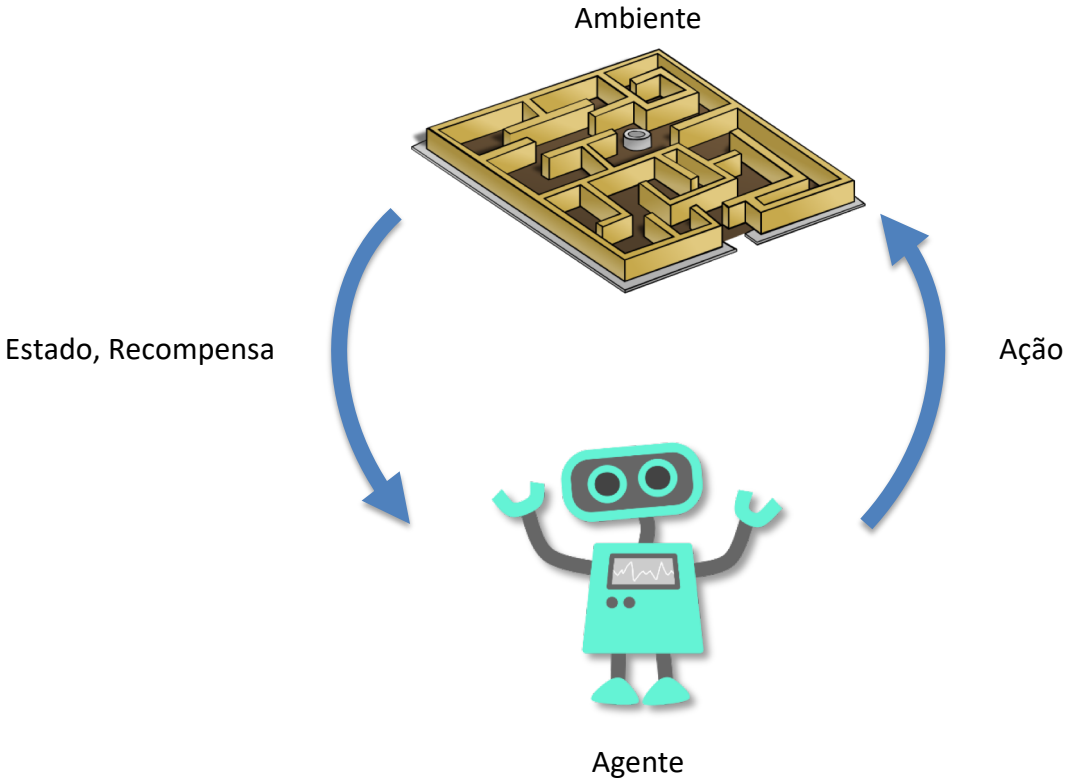
“Living Penalty”



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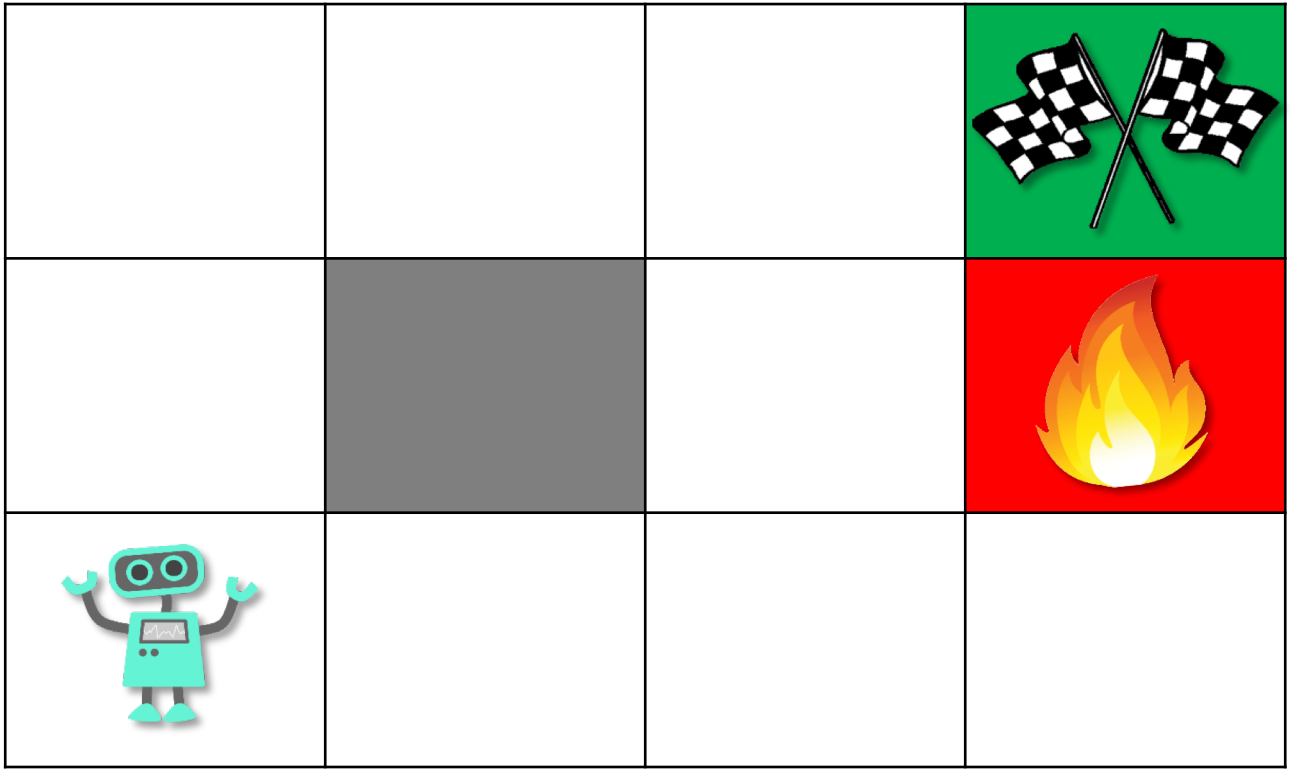

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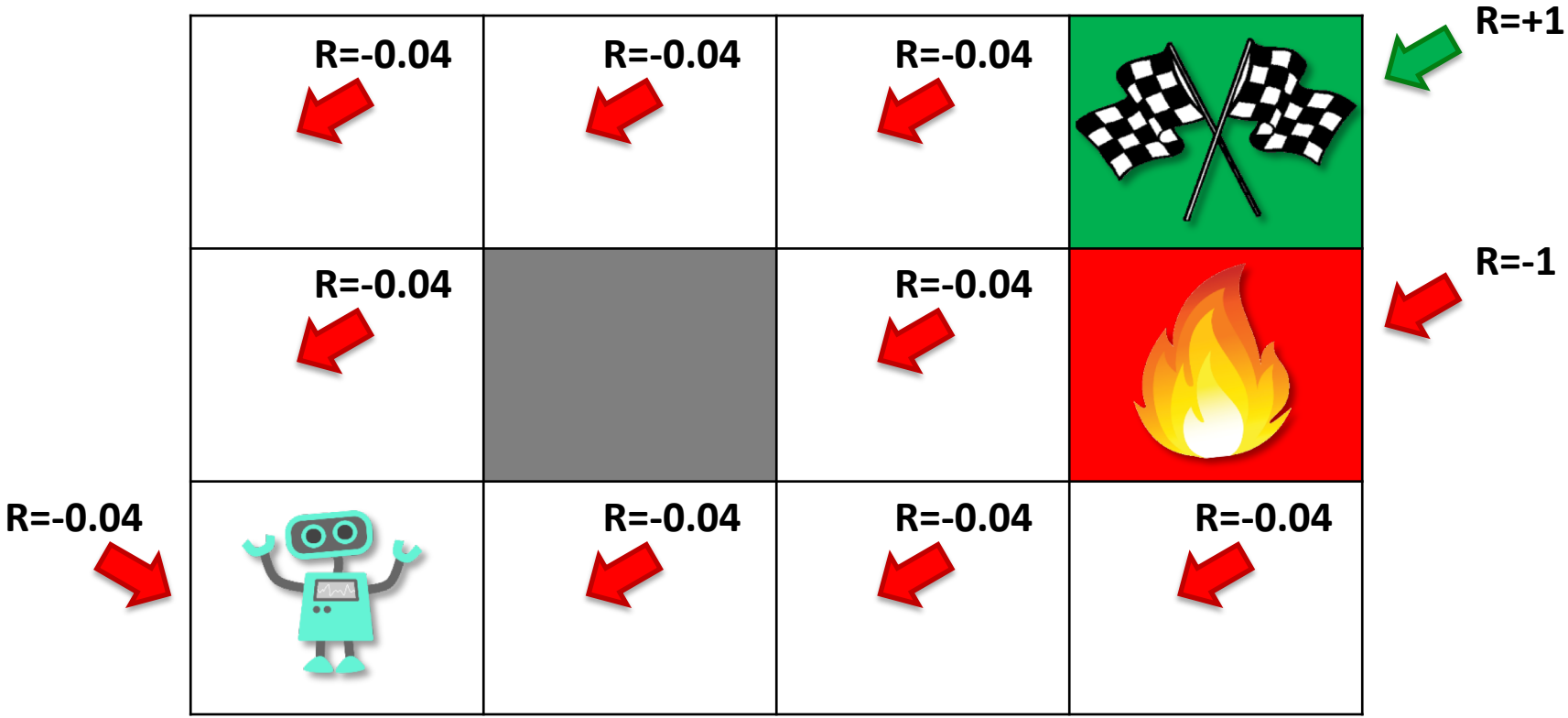
“Living Penalty”



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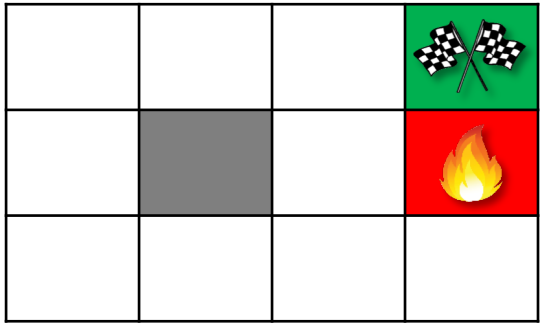
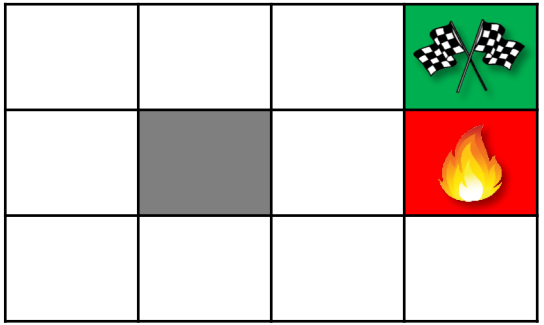
“Living Penalty”

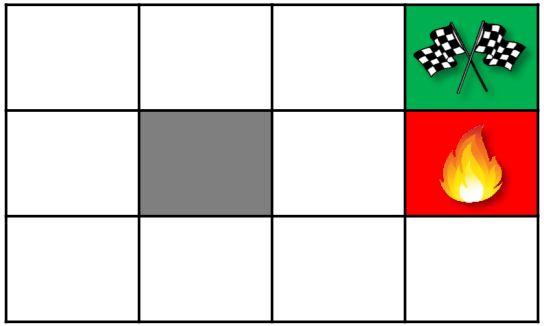
R(s)=0



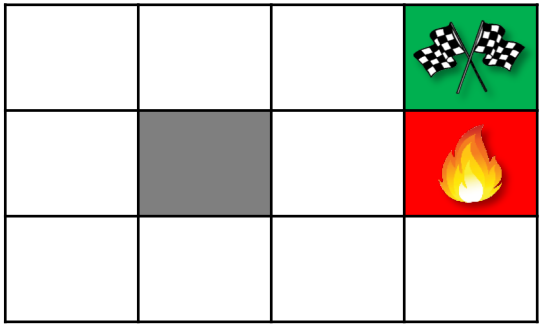
R(s)=-0.04



R(s)=-0.5



R(s)=-2.0



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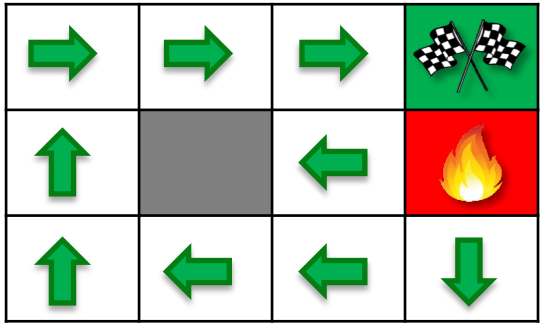
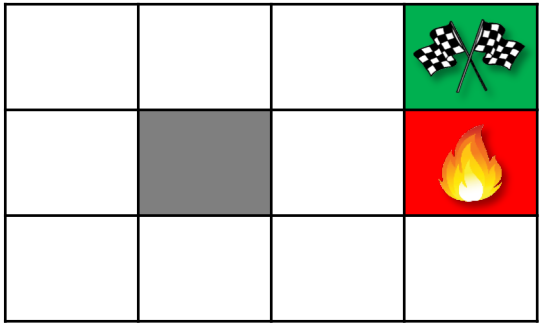
R(s)=0



R(s)=-0.04



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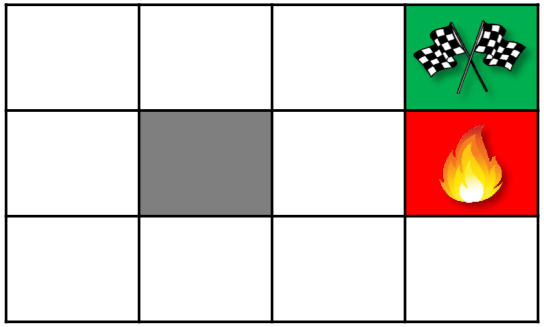

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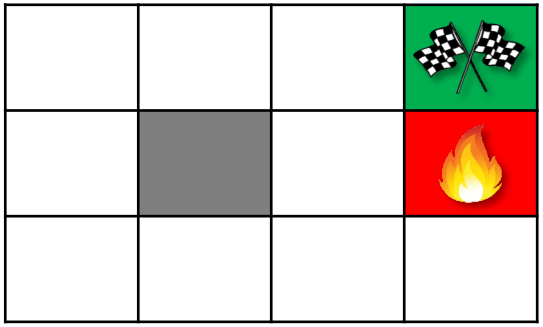

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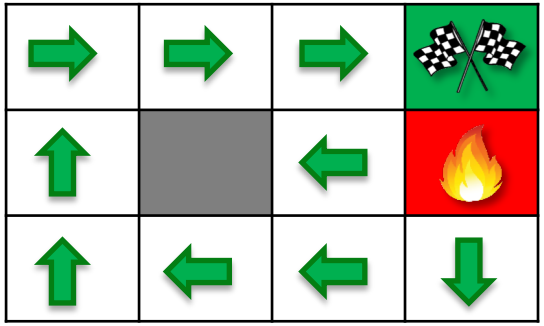
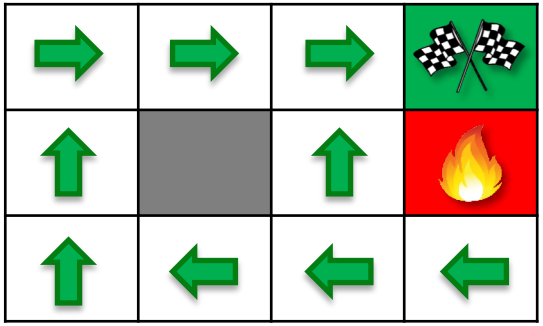
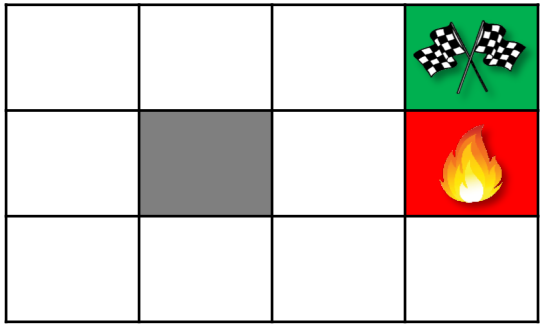


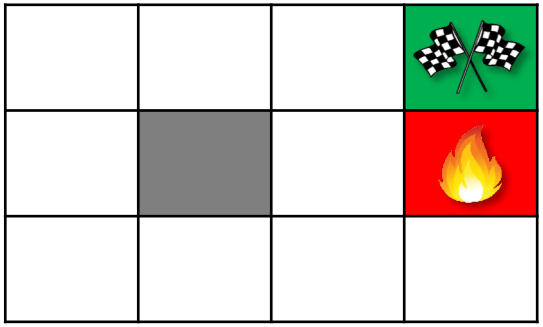
R(s)=-0.04



R(s)=-0.5



R(s)=-2.0



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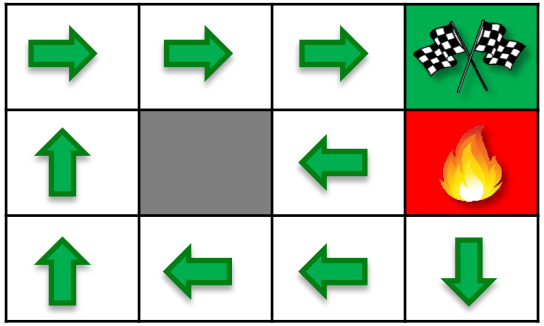

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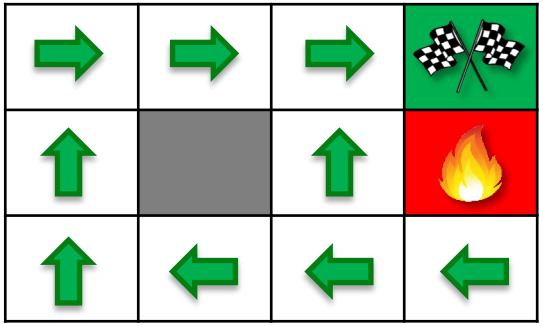
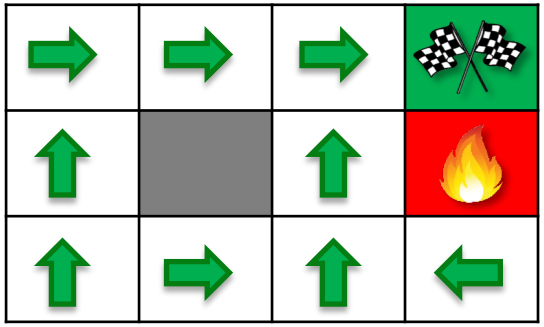
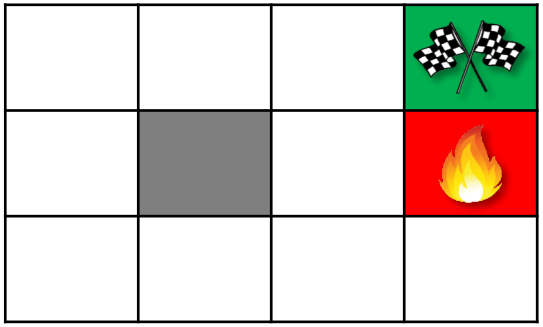


R(s)=-0.5



R(s)=-2.0



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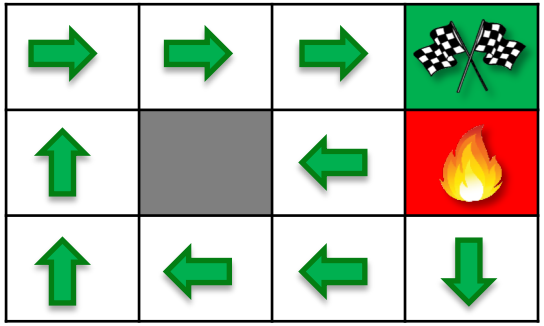
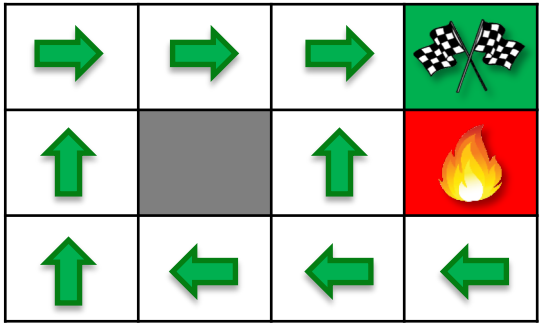
“Living Penalty”

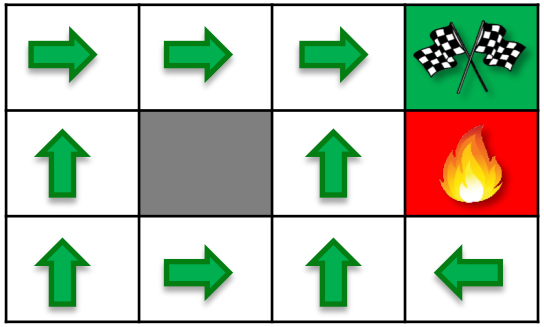
R(s)=0



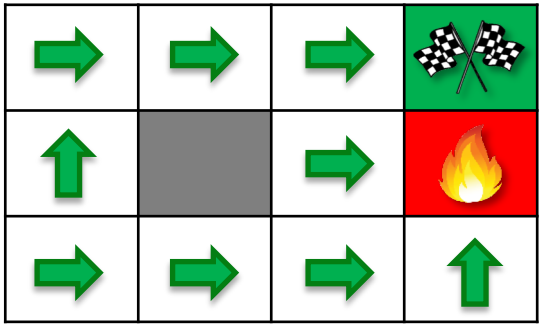
R(s)=-0.04



R(s)=-0.5



R(s)=-2.0



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Q-Learning Intuição

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Q-Learning Intuição

$$V(s) = \max_{a} \left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$

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Q-Learning Intuição

Onde está o Q?

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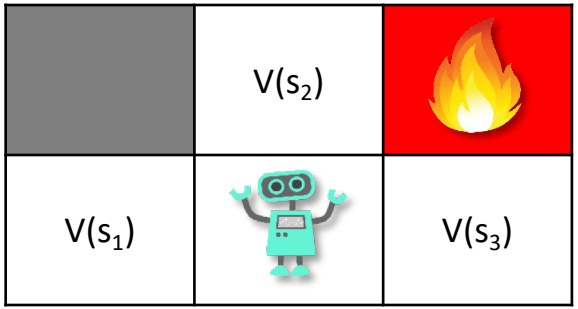

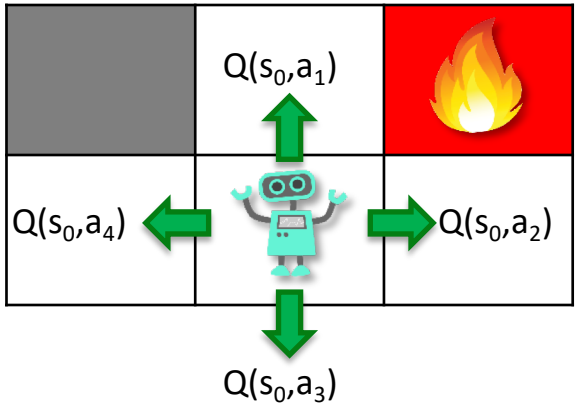

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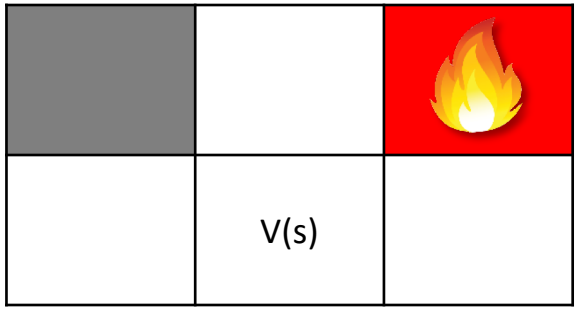

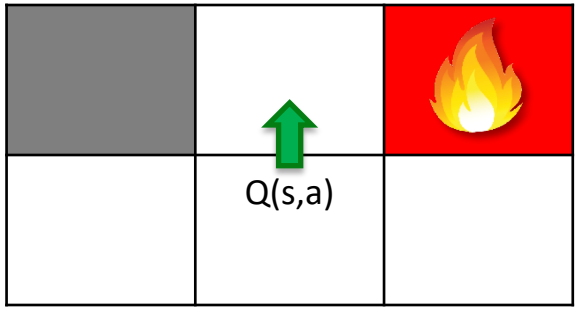

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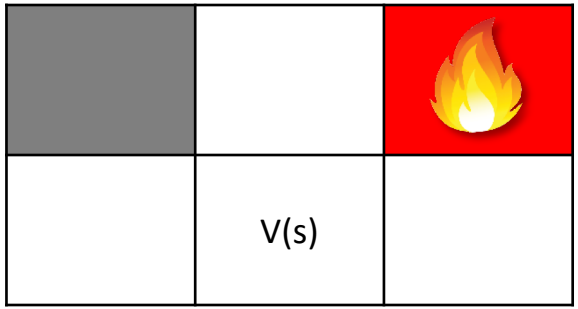

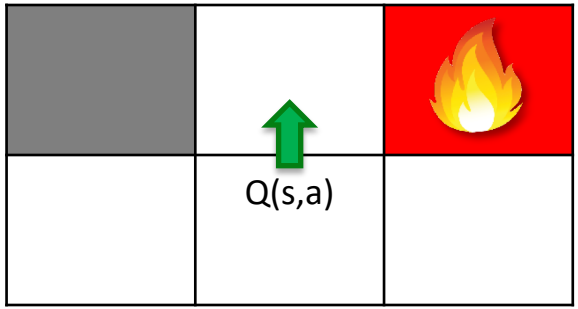

$$V(s) = \max_a \left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$

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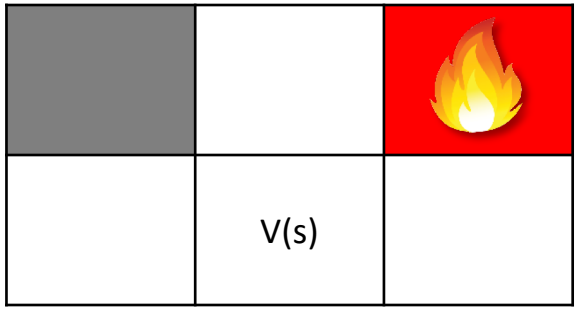
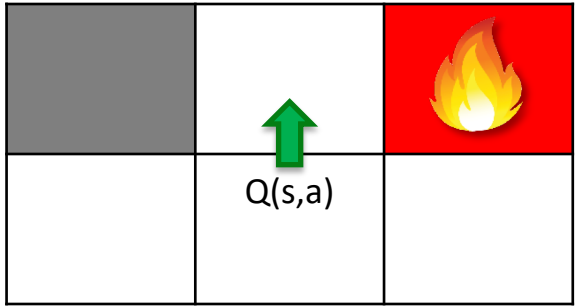
Q-Learning Intuição



$$V(s) = \max_a \left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$



$$Q(s,a) =$$

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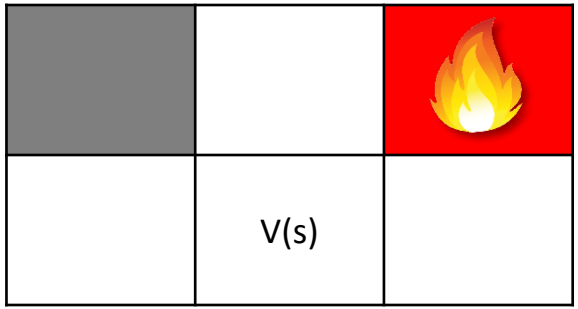
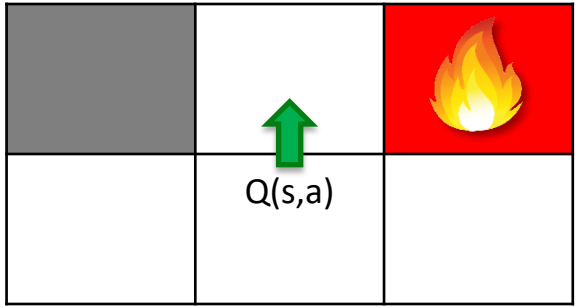


$$V(s) = \max_a \left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$



$$Q(s,a) = R(s,a) +$$

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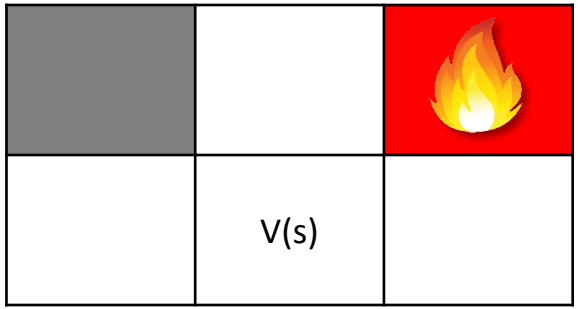
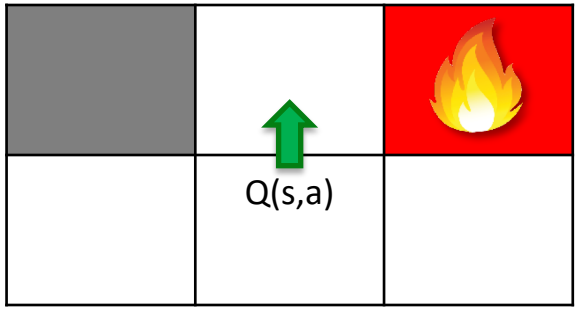


$$V(s) = \max_a \left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$



$$Q(s,a) = R(s,a) + \gamma \sum_{s'} \left(P(s,a,s')V(s') \right)$$

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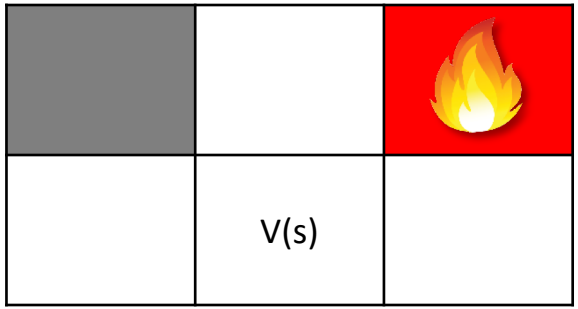
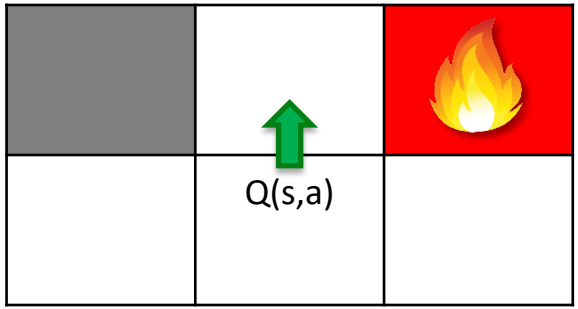
Q-Learning Intuição





$$V(s) = \max_a \left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$

$$Q(s,a) = R(s,a) + \gamma \sum_{s'} \left(P(s,a,s')V(s') \right)$$

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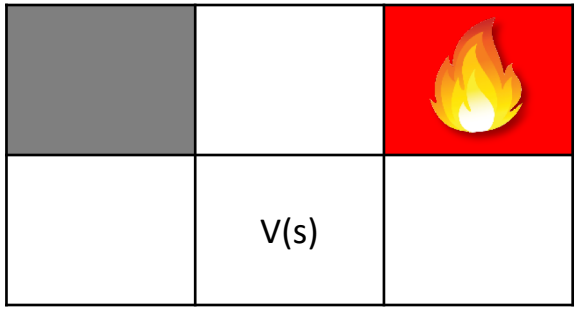
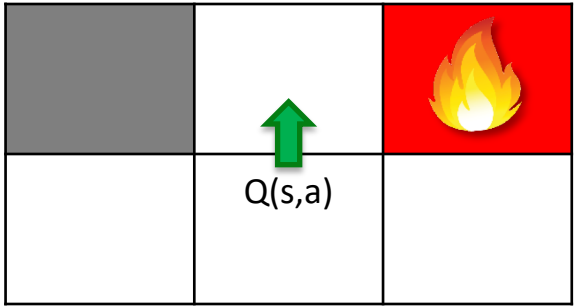
Q-Learning Intuição



$$V(s) = \max_a \left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$



$$Q(s,a) = R(s,a) + \gamma \sum_{s'} \left(P(s,a,s')V(s') \right)$$

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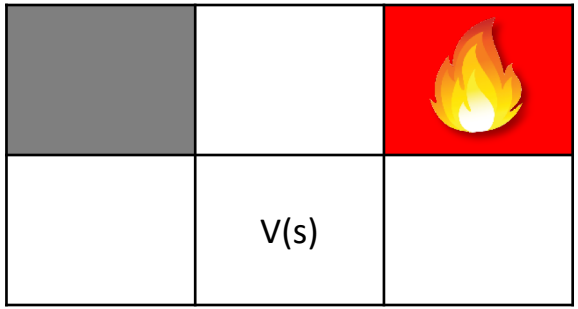
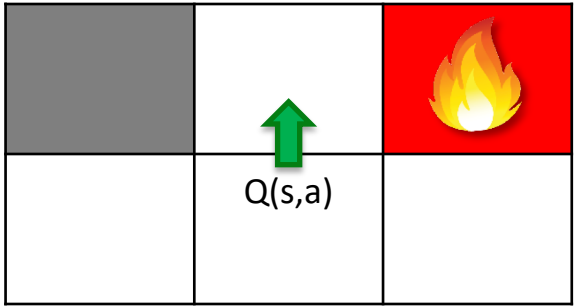
Q-Learning Intuição





$$V(s) = \max_a \left(R(s,a) + \gamma \sum_{s'} P(s,a,s')V(s') \right)$$

$$Q(s,a) = R(s,a) + \gamma \sum_{s'} \left(P(s,a,s')V(s') \right)$$

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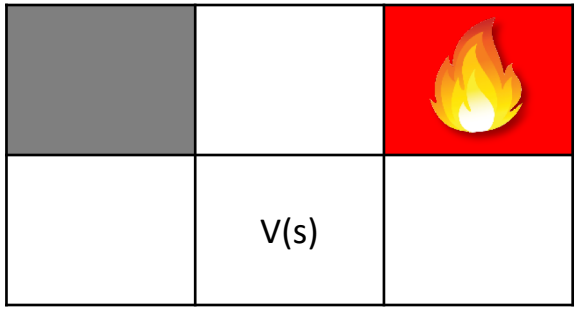
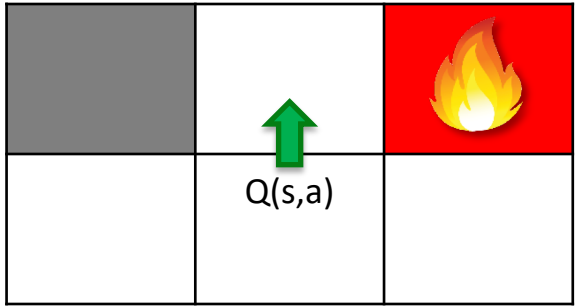
Q-Learning Intuição



$$V(s) = \max_a \left(R(s,a) + \gamma \sum_{s'} P(s,a,s') V(s') \right)$$



$$Q(s,a) = R(s,a) + \gamma \sum_{s'} \left(P(s,a,s') \max_{a'} Q(s',a') \right)$$

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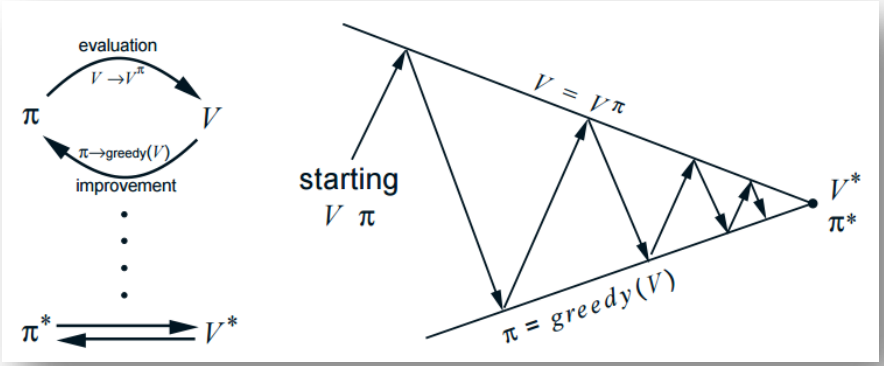
Leitura Adicional

Leitura Adicional:

Markov Decision Processes: Concepts and Algorithms

Martijn van Otterlo (2009)



Link:

https://pdfs.semanticscholar.org/968b/ab782e52faf0f7957ca0f38b9e9078454afe.pdf

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Diferença Temporal

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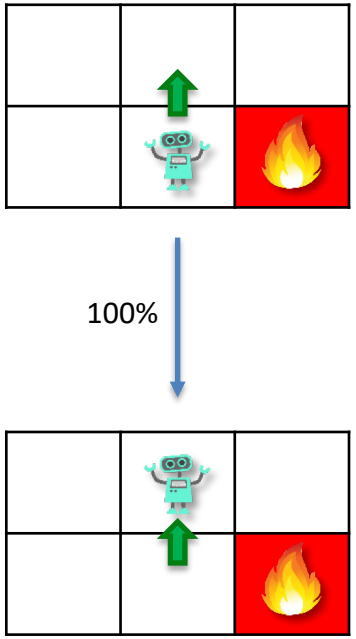
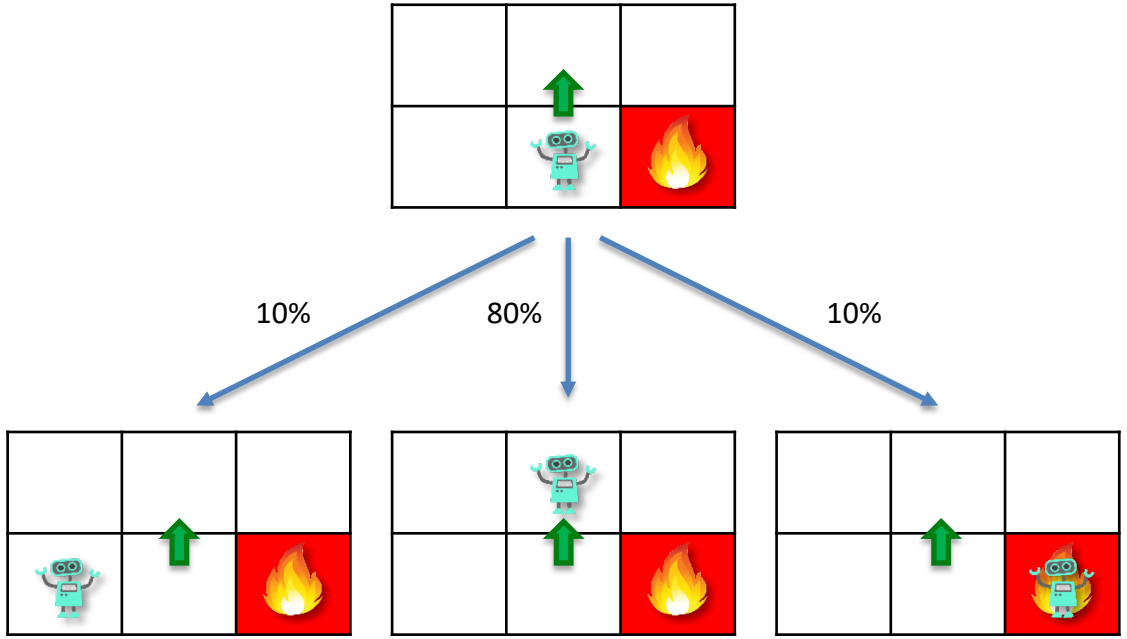
Diferença Temporal

Busca Determinística



Busca Não-Determinística



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Diferença Temporal

V=0.81	V=0.9	V=1	
V=0.73		V=0.9	
V=0.66	V=0.73	V=0.81	V=0.73

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Diferença Temporal

V=0.71	V=0.74	V=0.86	
V=0.63		V=0.39	
V=0.55	V=0.46	V=0.36	V=0.22

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Diferença Temporal

$$Q(s,a) = R(s,a) + \gamma \sum_{s'} \left(P(s,a,s') \max_{a'} Q(s',a') \right)$$

$$Q(s,a) = R(s,a) + \gamma \max_{a'} Q(s',a')$$

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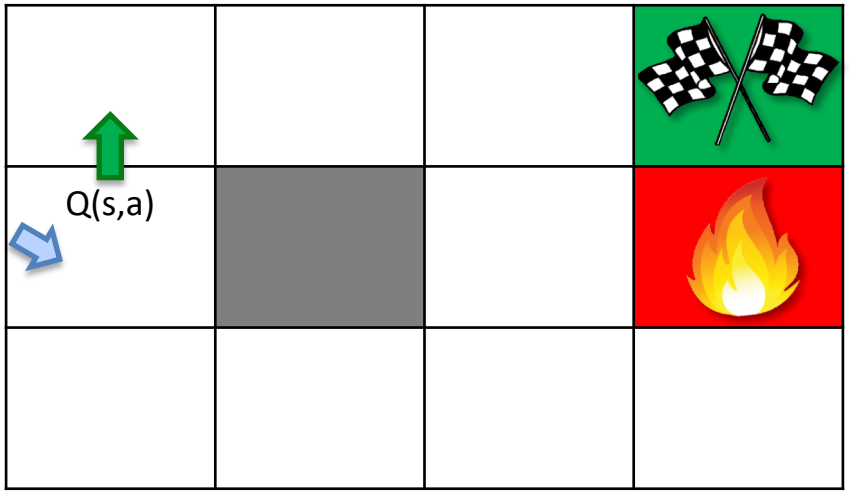
Diferença Temporal



Antes:

$$Q(s,a)$$

Depois:

$$R(s,a) + \gamma \max_{a'} Q(s',a')$$

$$TD(a,s) = \overbrace{R(s,a) + \gamma \max_{a'} Q(s',a')}^{} - \overbrace{Q(s,a)}^{}$$

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Diferença Temporal

$$TD(a,s) = R(s,a) + \gamma \max_{a'} Q(s',a') - Q(s,a)$$

$$Q(s,a) = Q(s,a) + \alpha TD(a,s)$$

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Diferença Temporal

$$TD(a,s) = R(s,a) + \gamma \max_{a'} Q(s',a') - Q_{t-1}(s,a)$$

$$Q_t(s,a) = Q_{t-1}(s,a) + \alpha TD_t(a,s)$$

$$Q_t(s,a) = Q_{t-1}(s,a) + \alpha \left(R(s,a) + \gamma \max_{a'} Q(s',a') - Q_{t-1}(s,a) \right)$$

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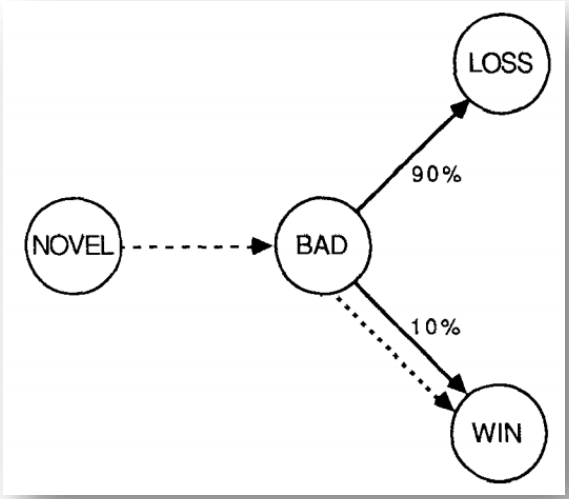
Leitura Adicional

Leitura Adicional:

Learning to Predict by the Methods of Temporal Differences

Richard Sutton (1988)



Link:

https://link.springer.com/article/10.1007/BF00115009

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Conteúdo

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Conteúdo

O que você aprenderá nessa seção:

- Intuição Deep Q-Learning (Aprendizagem)
- Intuição Deep Q-Learning (Ação)
- Experiência de Replay
- Políticas de Seleção de Ações

- Anexo 1: Redes Neurais Artificiais

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Intuição Deep Q-Learning

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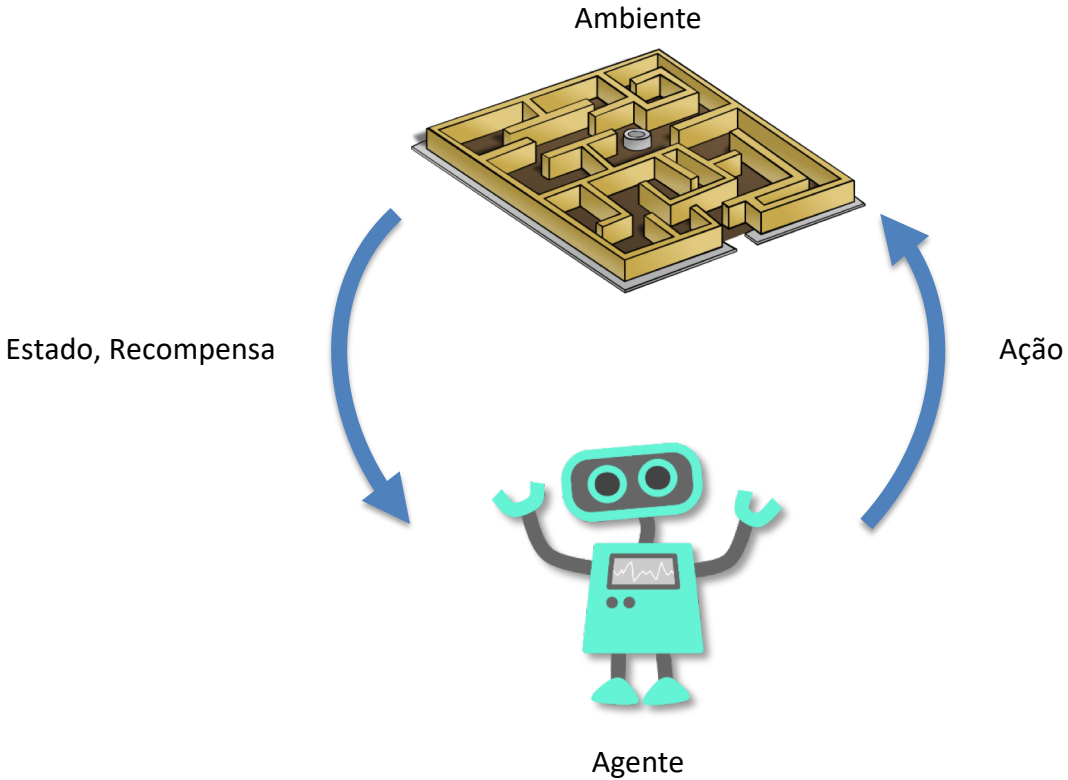
Intuição Deep Q-Learning



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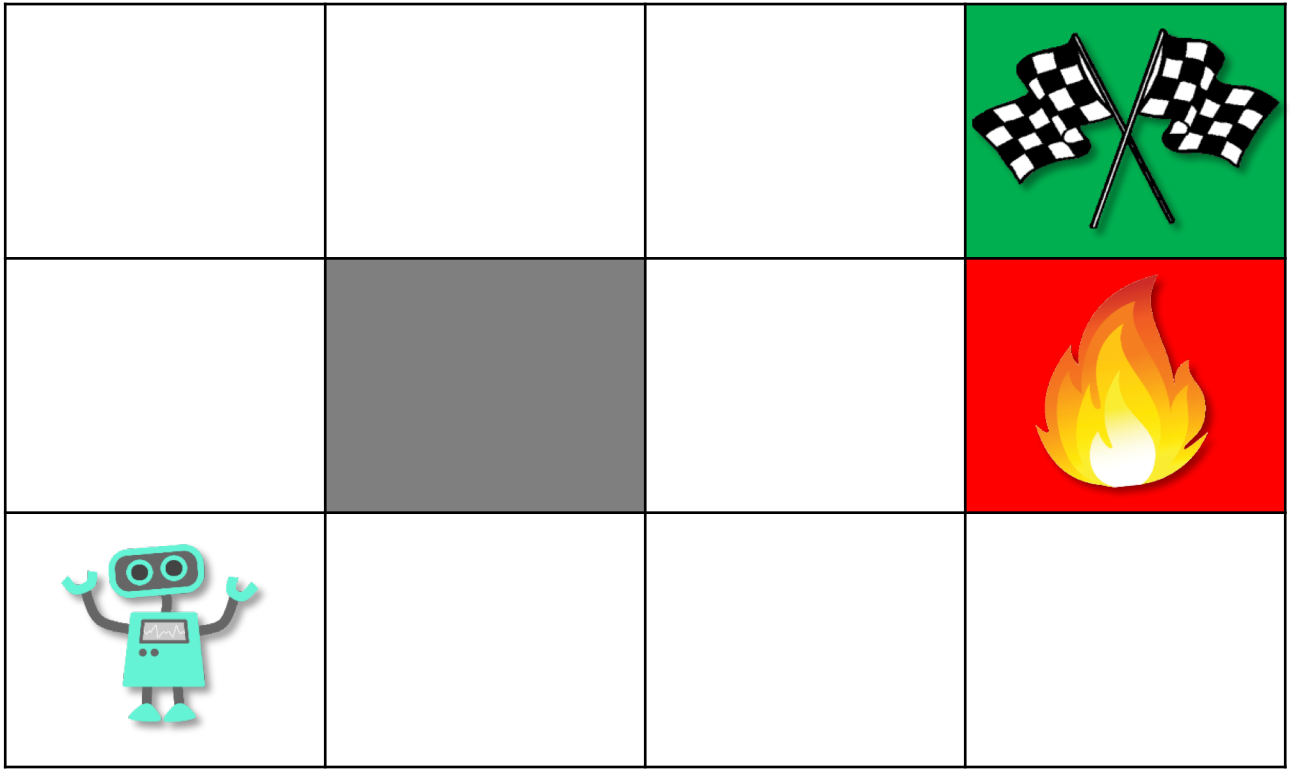
Intuição Deep Q-Learning



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Intuição Deep Q-Learning

V=0.71	V=0.74	V=0.86	
V=0.63		V=0.39	
V=0.55	V=0.46	V=0.36	V=0.22

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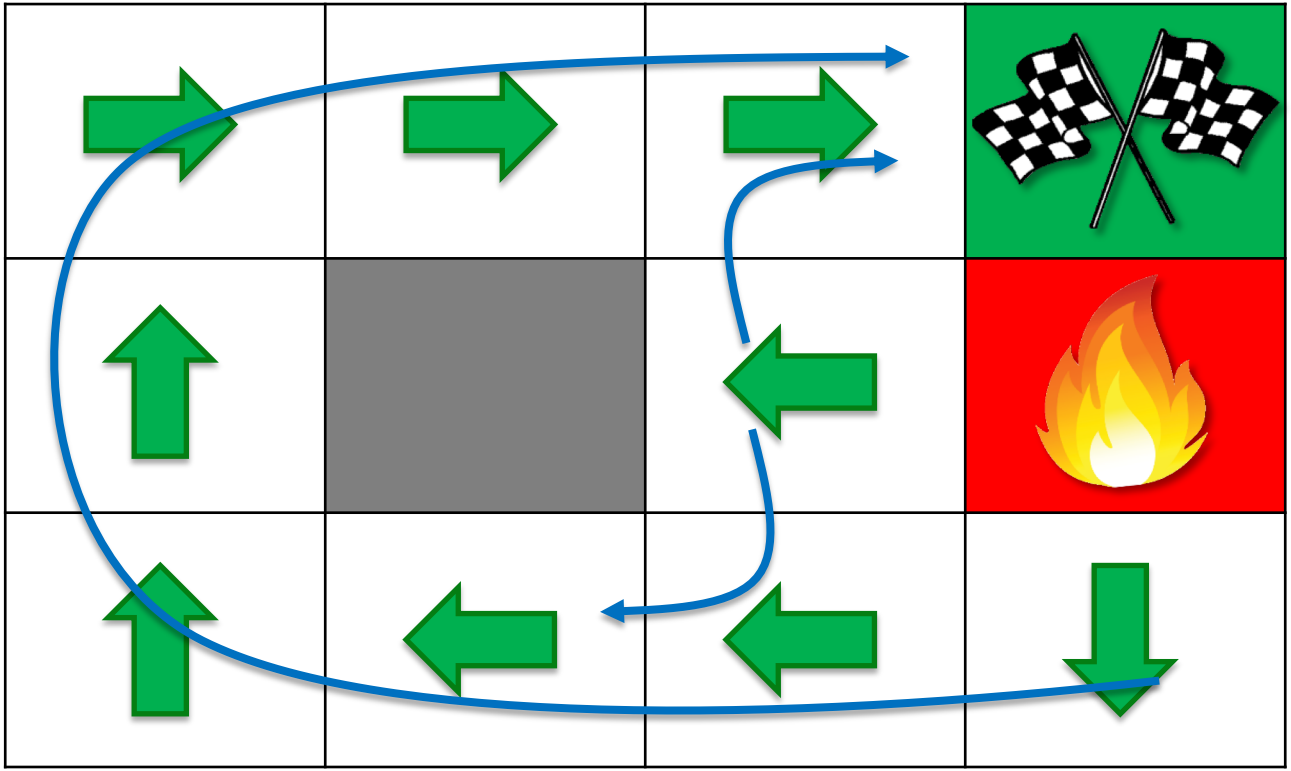
Intuição Deep Q-Learning



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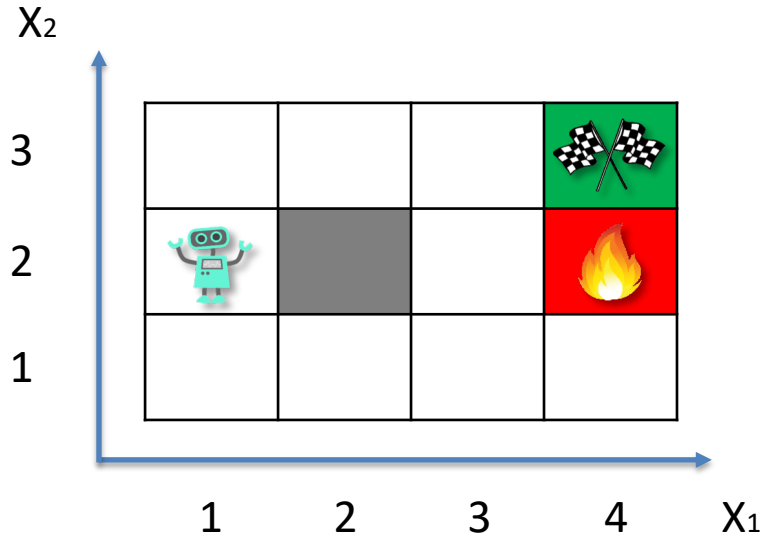
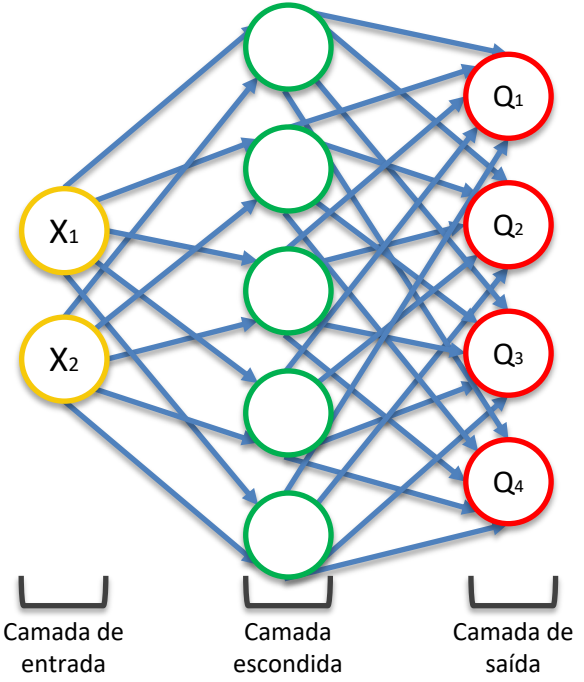
Intuição Deep Q-Learning





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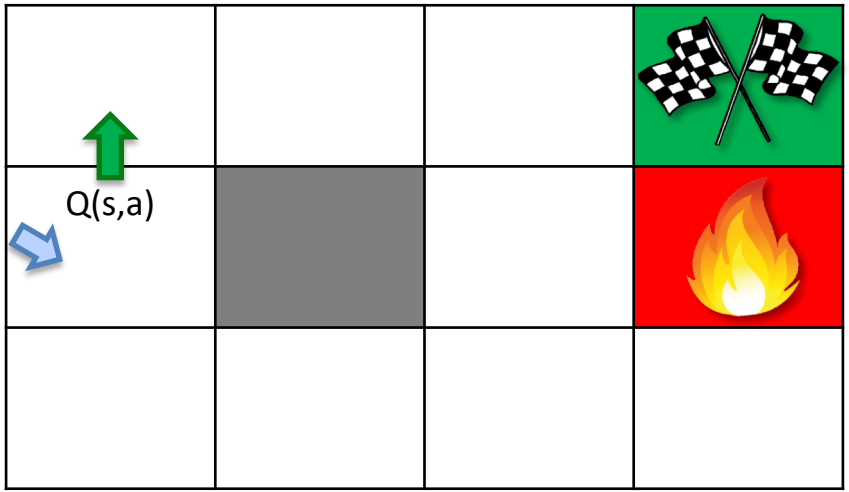
Intuição Deep Q-Learning



Antes:

$Q(s,a)$

Depois:

$R(s,a) + \gamma \max_{a'} Q(s',a')$

$$TD(a,s) = R(s,a) + \gamma \max_{a'} Q(s',a') - Q(s,a)$$

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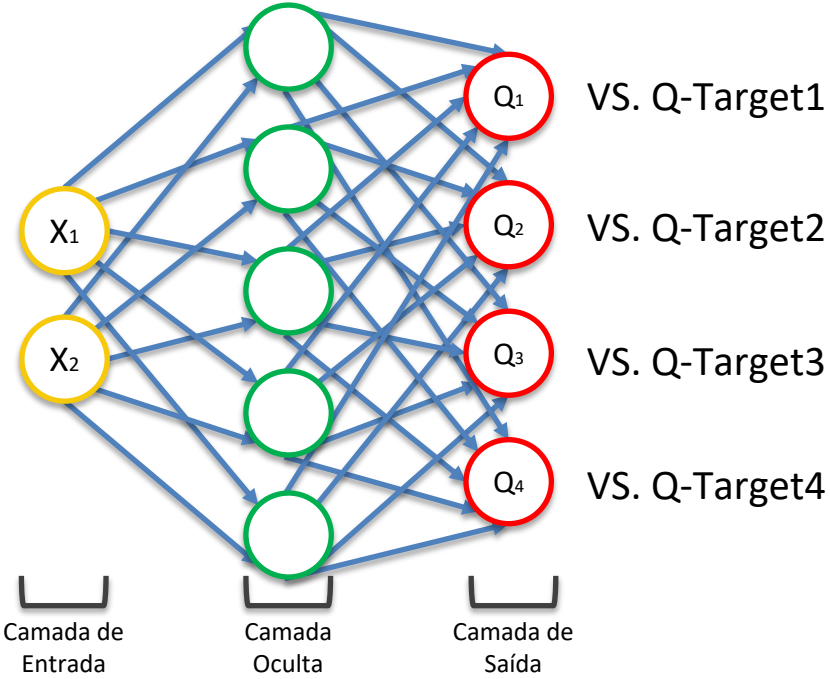
Intuição Deep Q-Learning

Aprendizagem:



$$L = \sum (Q\text{-}Target\ - Q)^2$$

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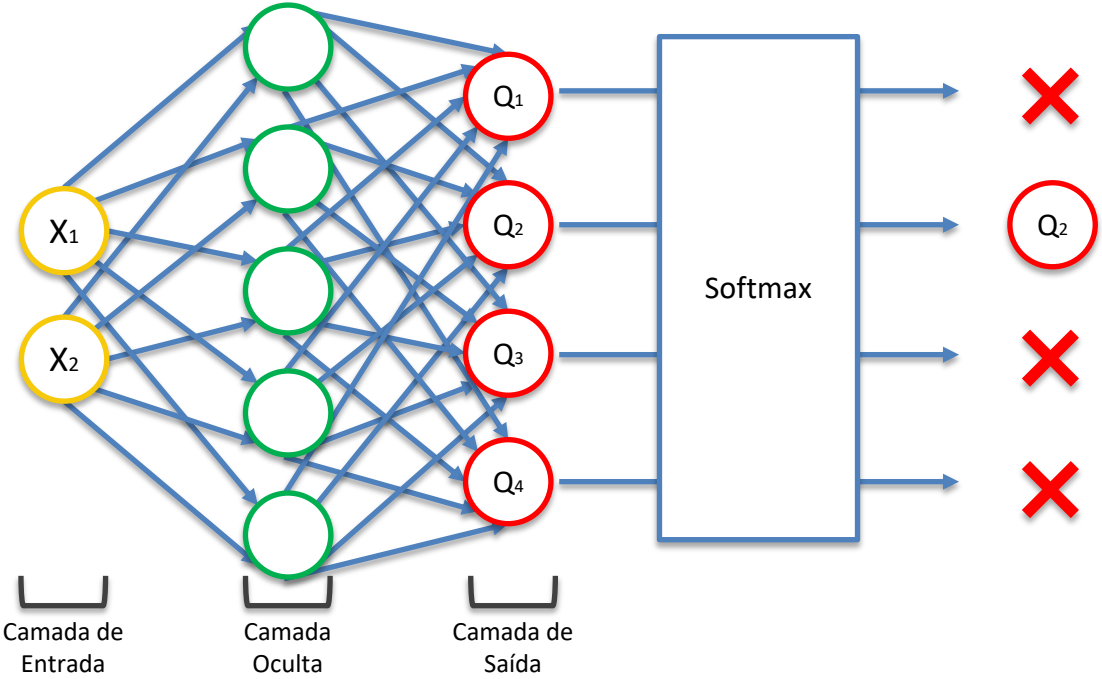
Ações:



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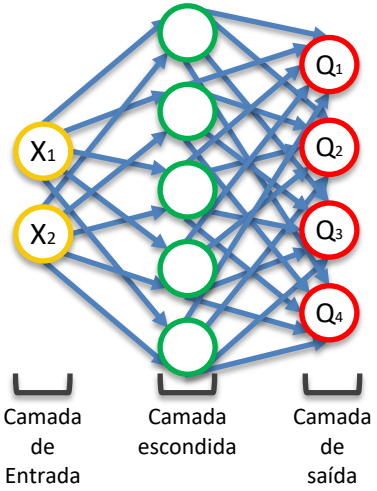
Intuição Deep Q-Learning



Aprendizagem:

VS. Q-Target1

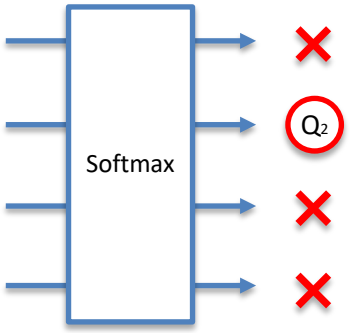
VS. Q-Target2

VS. Q-Target3

VS. Q-Target4

$$L = \sum (Q\text{–}Target\ - Q)^2$$

Ações:



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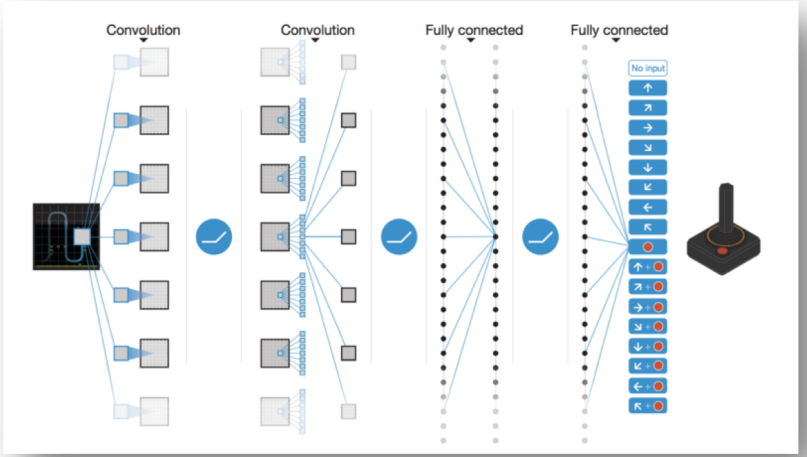
Leitura Adicional

Leitura Adicional:

Simple Reinforcement Learning with Tensorflow (Part 4)

Arthur Juliani (2016)



Link:

https://medium.com/@awjuliani/simple-reinforcement-learning-with-tensorflow-part-4-deep-q-networks-and-beyond-8438a3e2b8df

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Experiência de Replay

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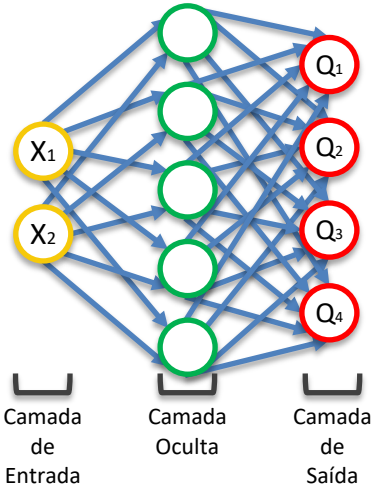
Experiência de Replay



Aprendizagem:

VS. Q-Target1

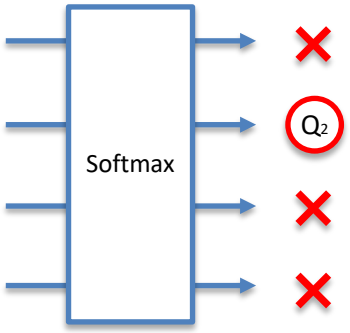
VS. Q-Target2

VS. Q-Target3

VS. Q-Target4

$$L = \sum (Q\text{–}Target\ - Q)^2$$

Ação:



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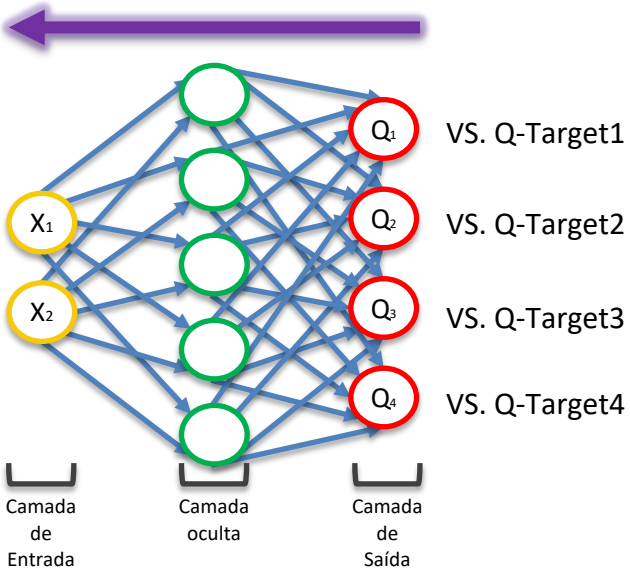
Experiência de Replay



$$L = \sum (Q\text{-}Target\ - Q)^2$$

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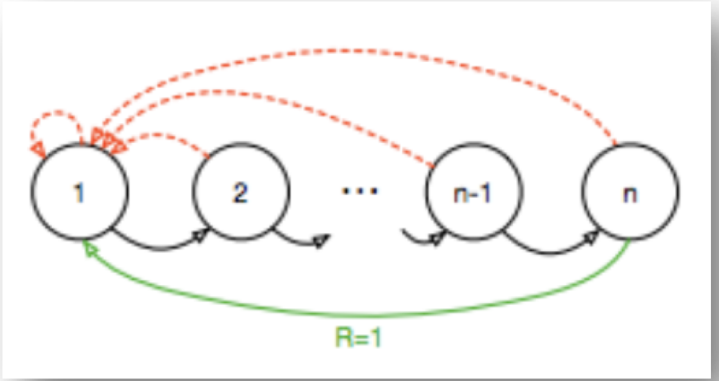
Leitura Adicional

Leitura Adicional:

Prioritized Experience Replay

Tom Schaul et al.,
Google DeepMind (2016)



Link:

https://arxiv.org/pdf/1511.05952.pdf

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Política de Seleção de Ações

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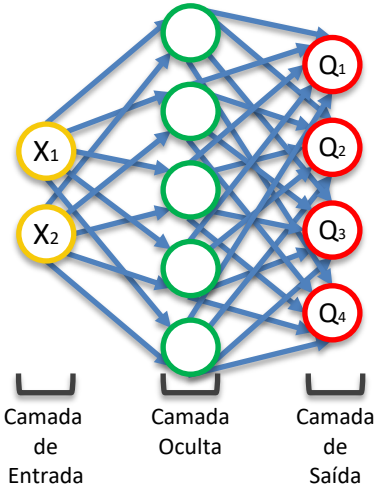
Política de Seleção de Ações



Aprendizagem:

VS. Q-Target1

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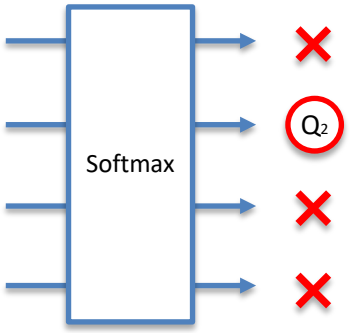
Ações:



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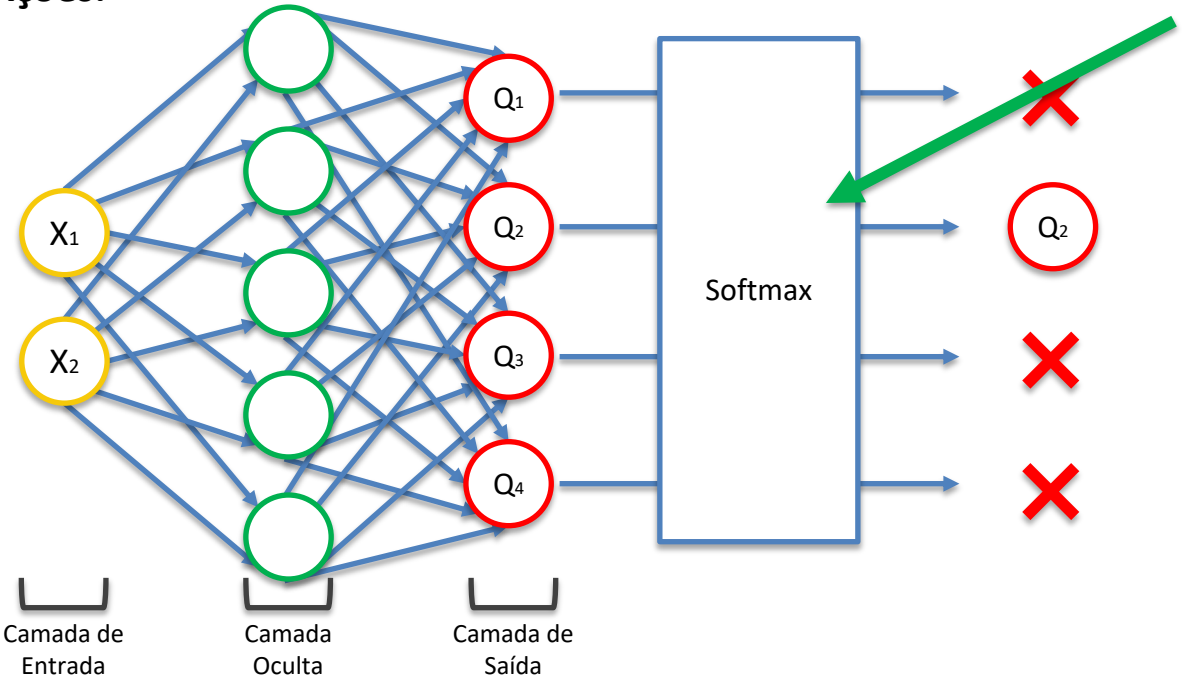
Política de Seleção de Ações

Ações:



Seleção de Ação:

- ε-greedy
- ε-soft (1-ε)
- Softmax

Exploration
vs
Exploitation

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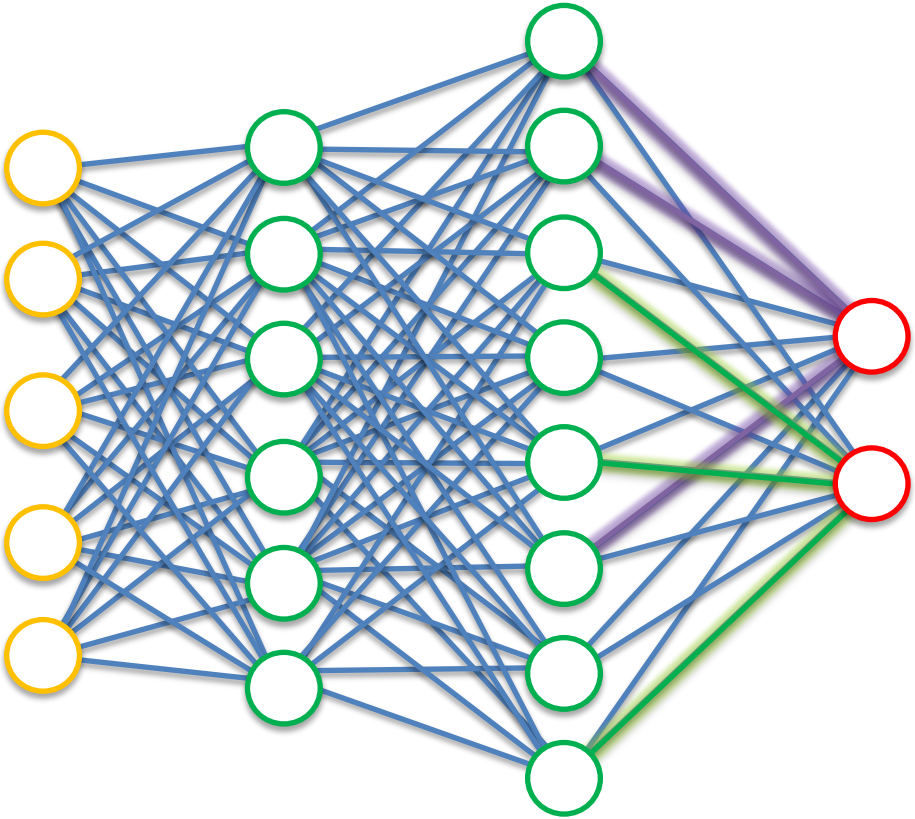
Política de Seleção de Ações

Flattening



Cachorro 0.95

Gato 0.05

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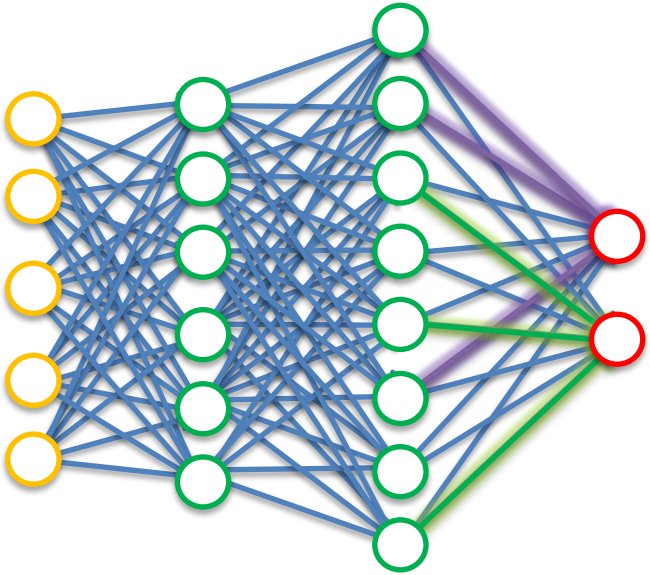
Política de Seleção de Ações

Flattening



$$f_j(z) = \frac{e^{z_j}}{\sum_k e^{z_k}}$$

Cachorro → z_1 → 0.95

Gato → z_2 → 0.05

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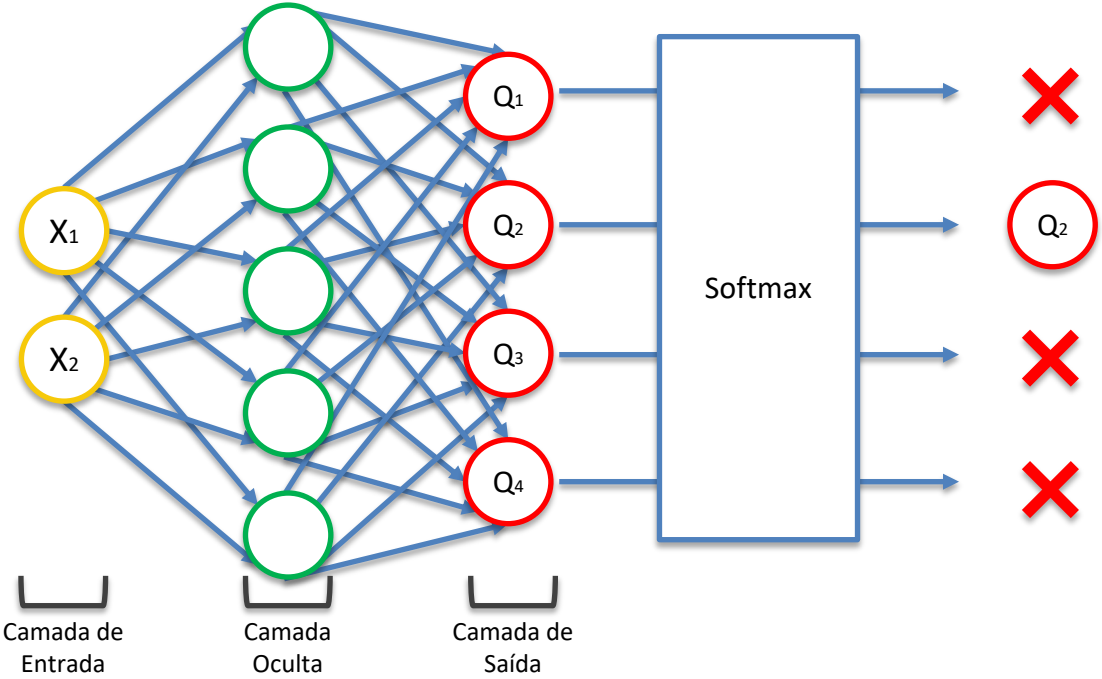
Política de Seleção de Ações

Ações:



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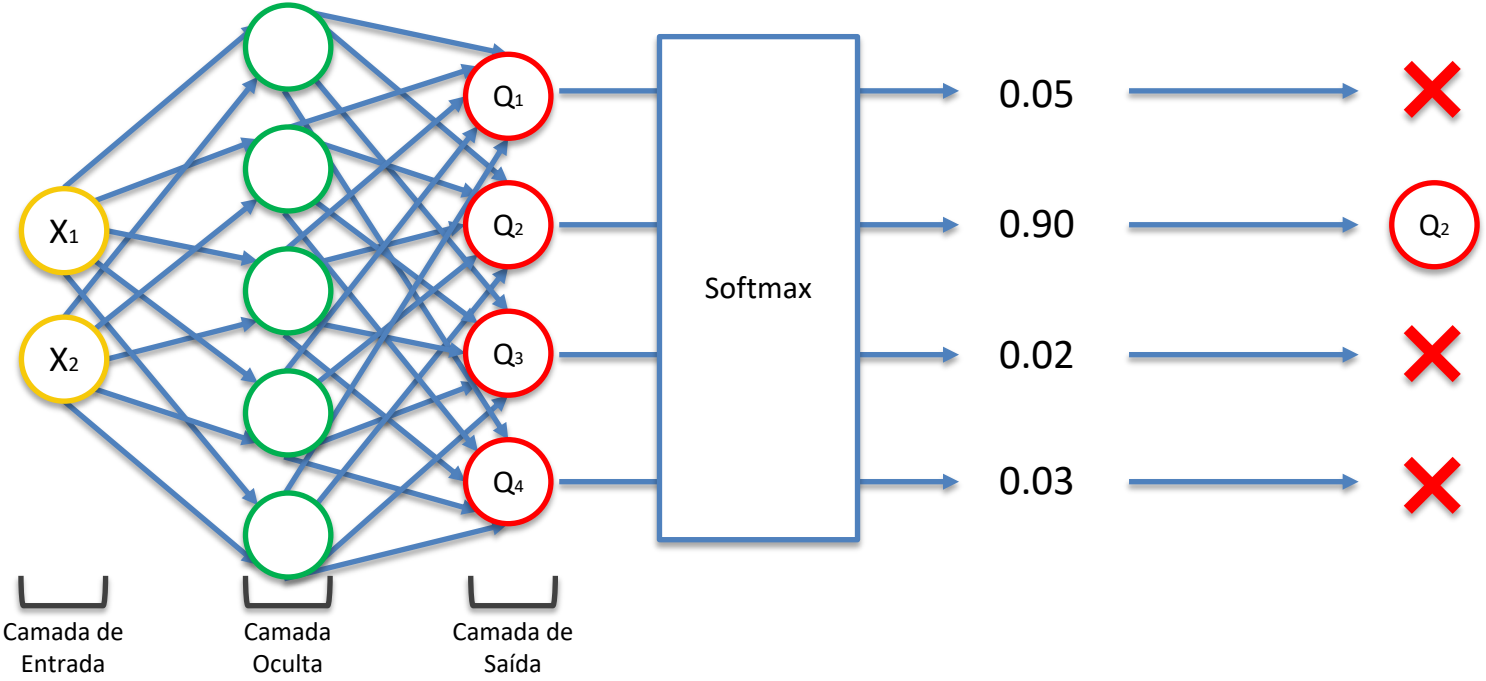

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Política de Seleção de Ações

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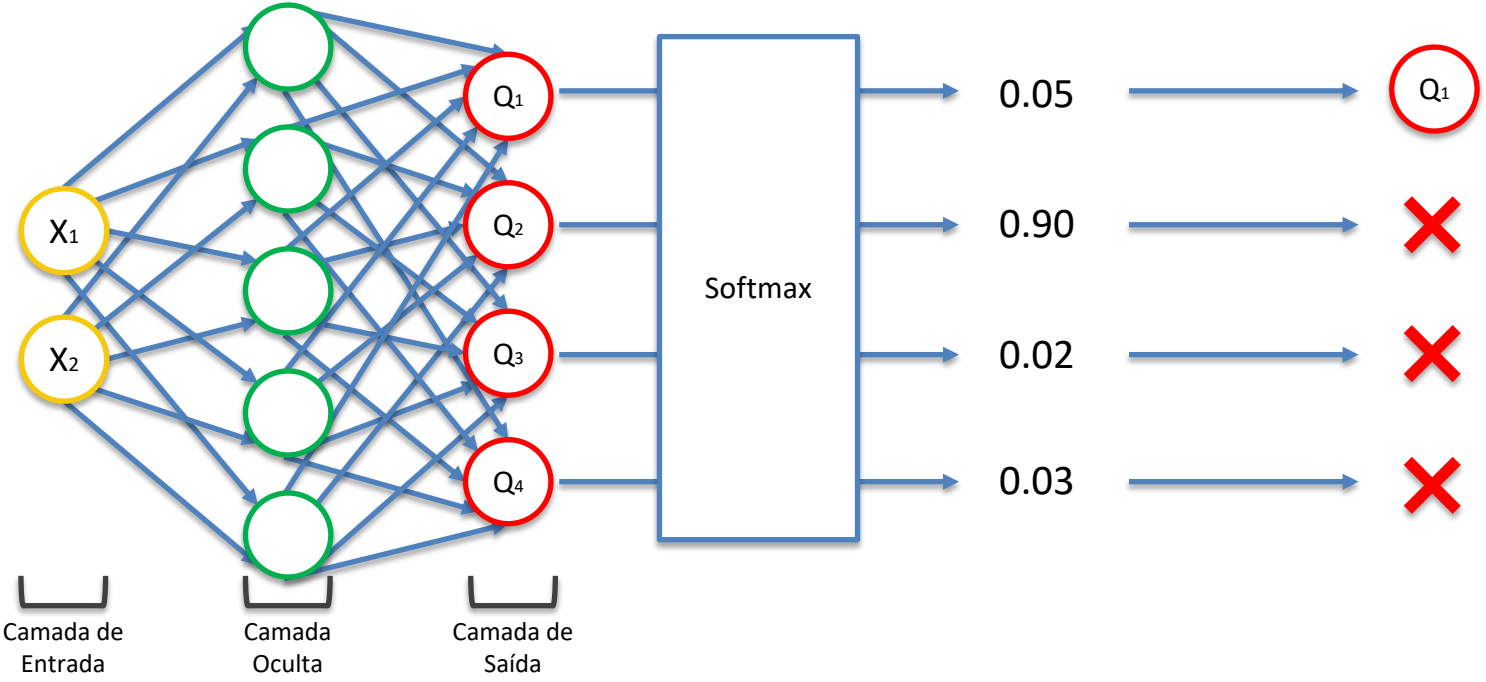

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Política de Seleção de Ações

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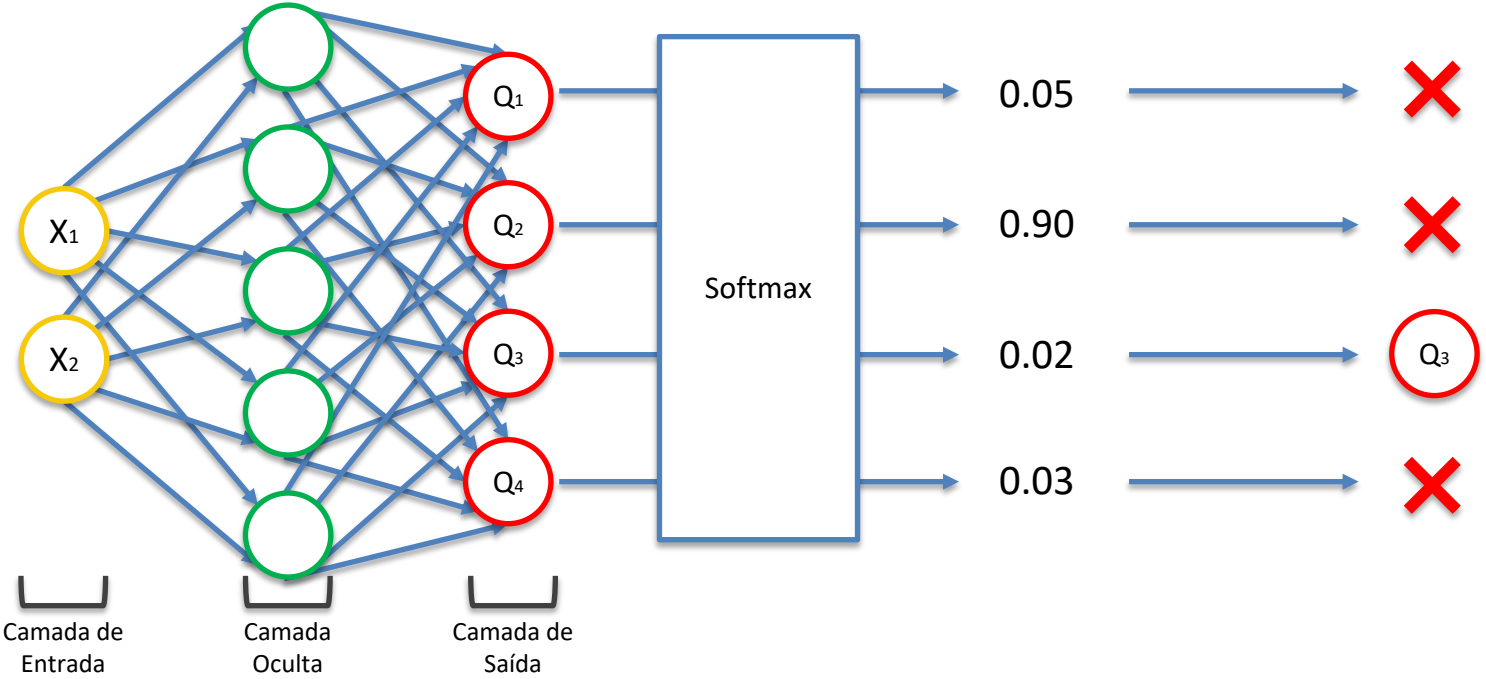

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Política de Seleção de Ações

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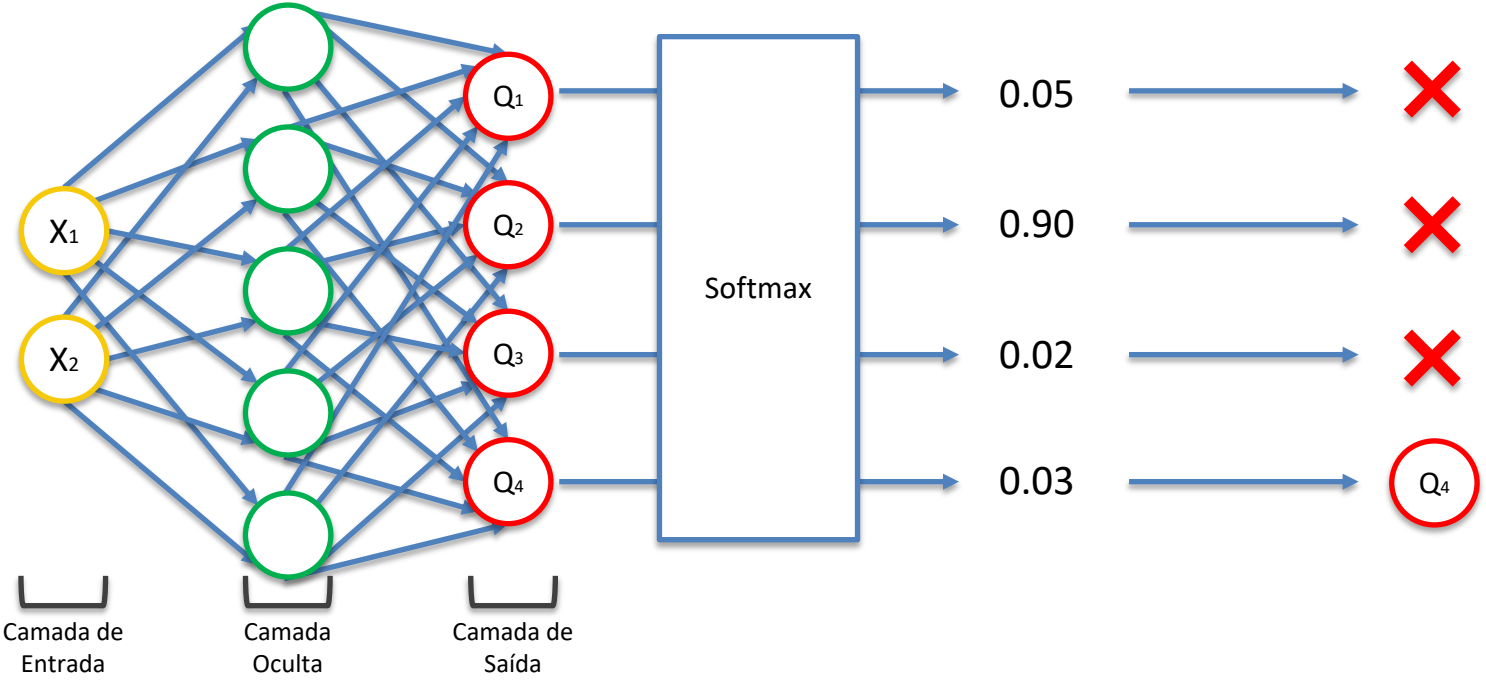

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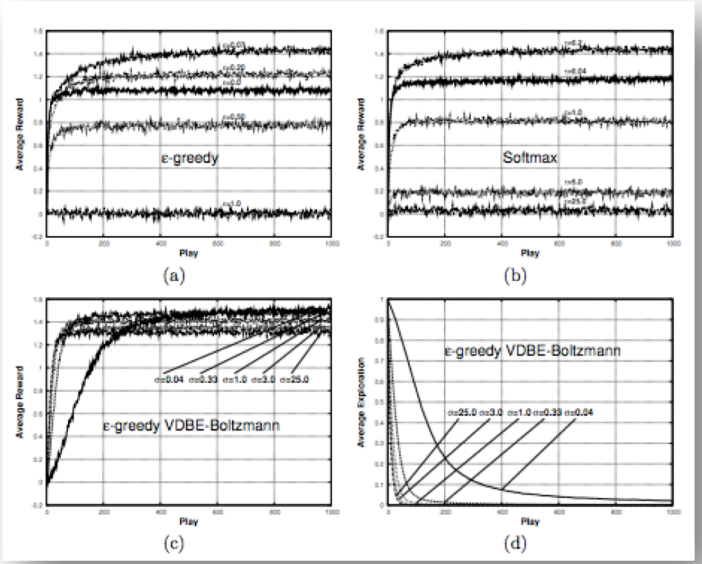
Leitura Adicional

Leitura Adicional:

Adaptive ε-greedy Exploration in Reinforcement Learning Based on Value Differences

Michel Tokic (2010)

Link:



http://tokic.com/www/tokicm/publikationen/papers/AdaptiveEpsilonGreedyExploration.pdf

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Conteúdo

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Conteúdo

O que você aprenderá nessa seção:

- Construção de um carro autônomo!
- Ambiente contendo o mapa
- IA para controlar o carro no mapa com Deep Q-Learning (PyTorch)
- Configuração do Ambiente

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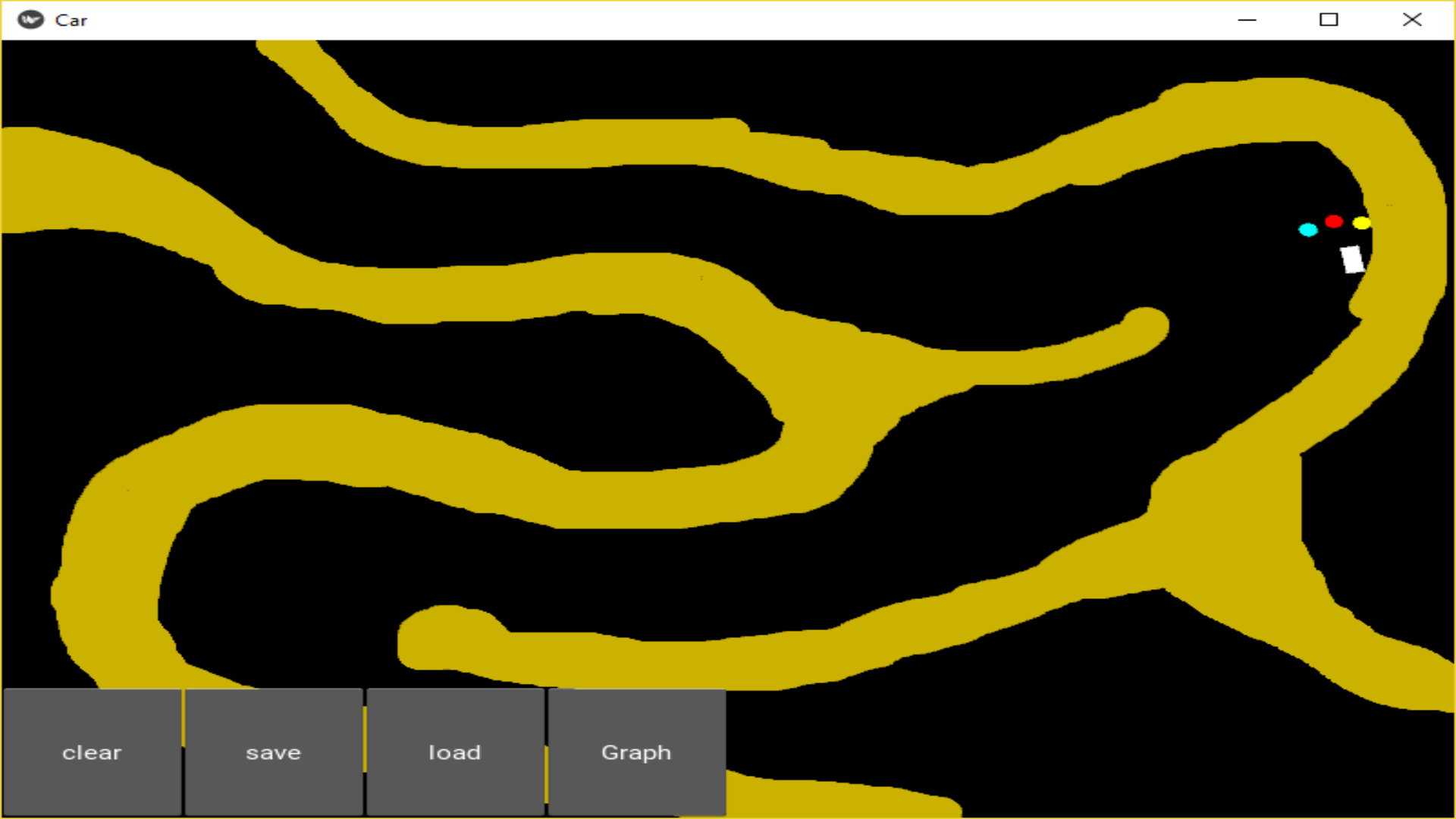
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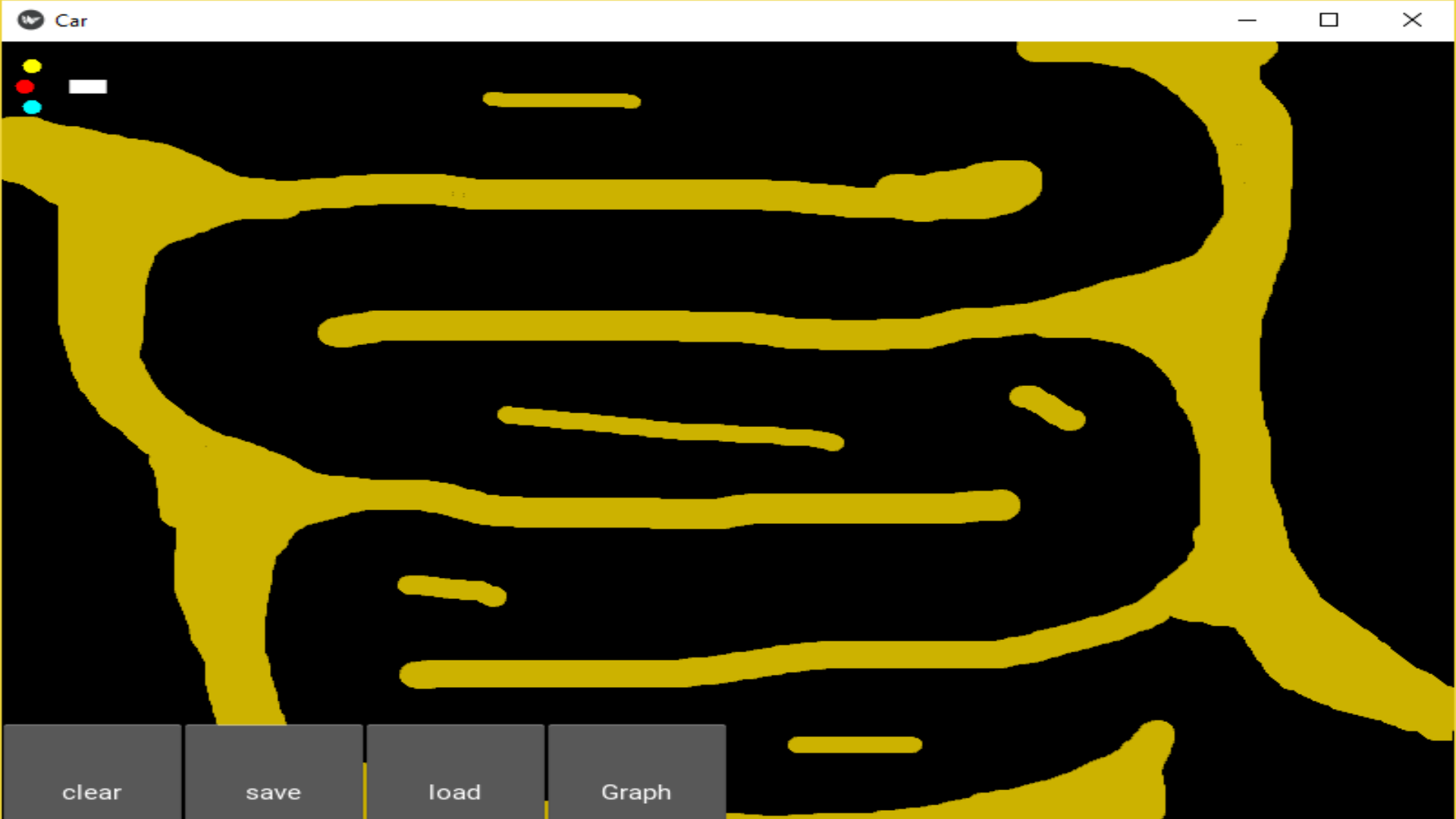
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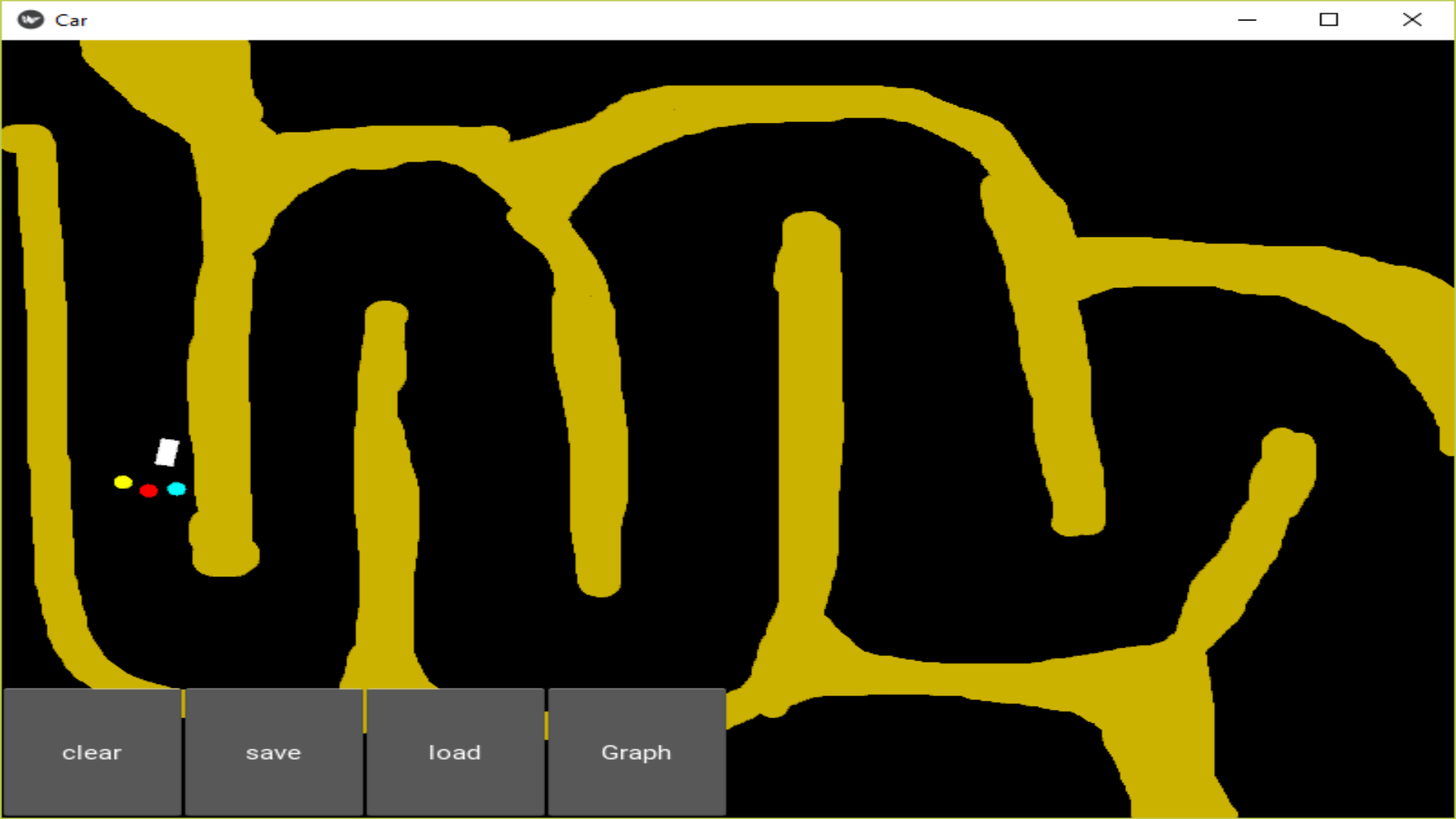
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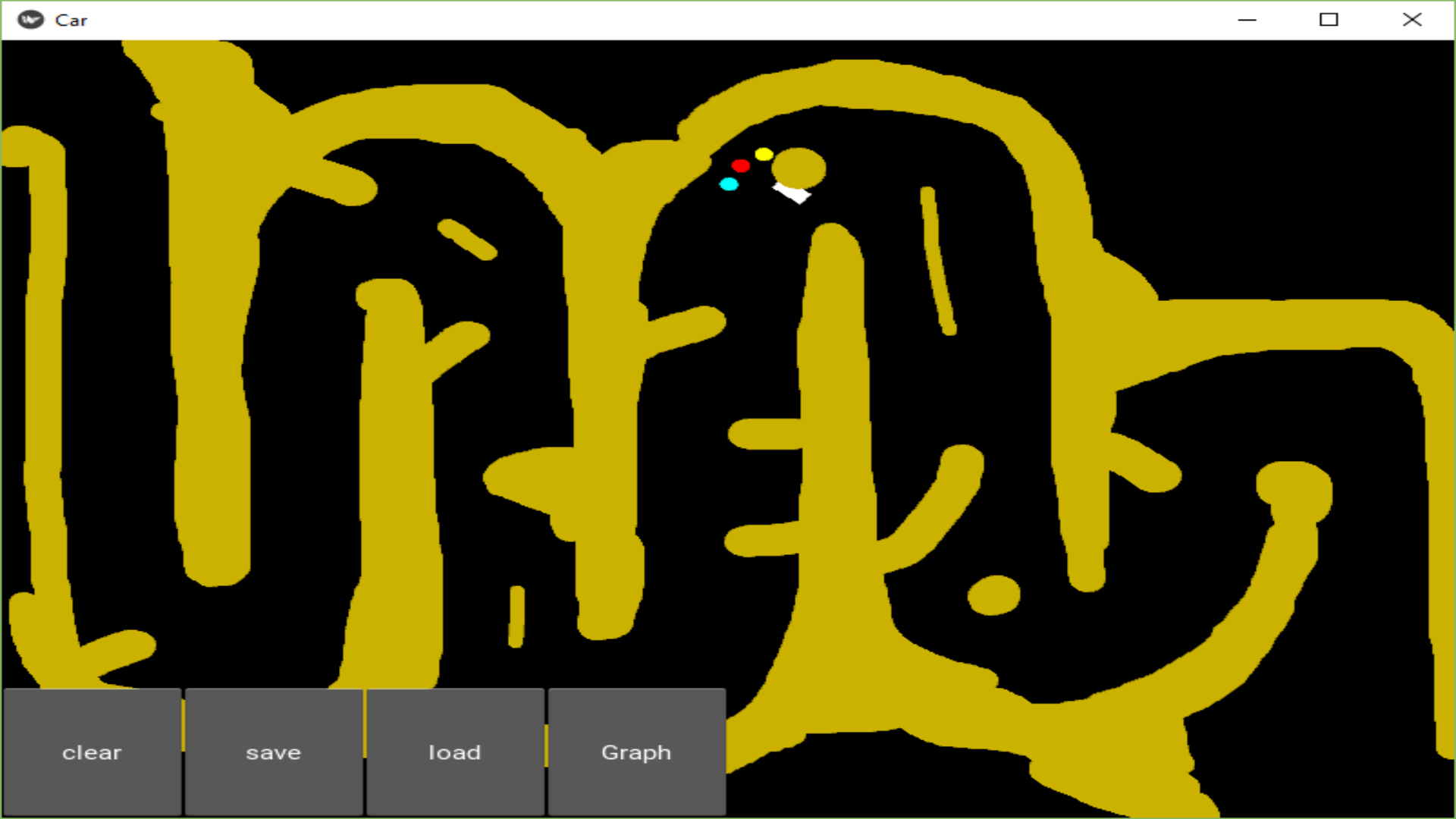
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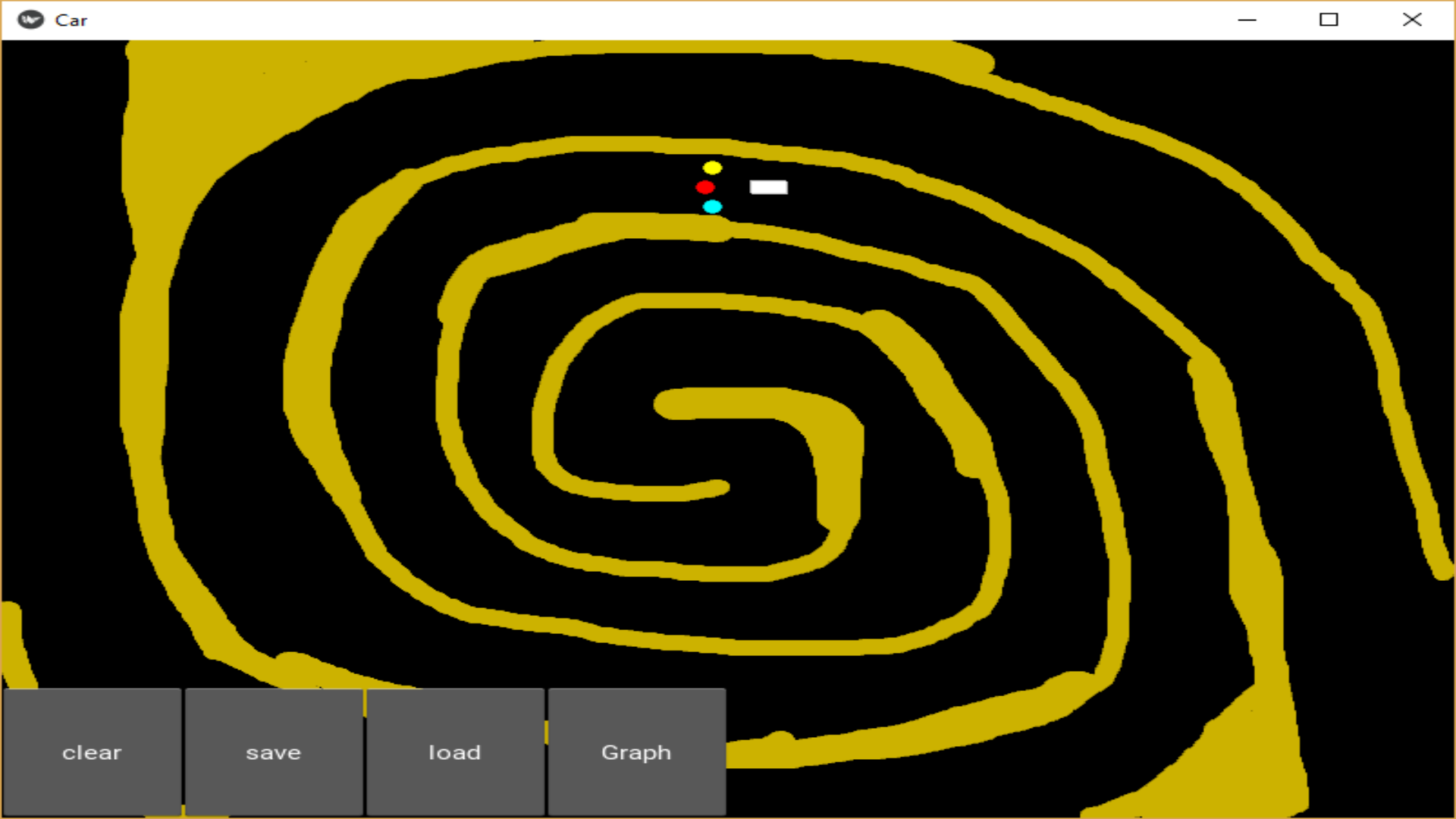
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