



POLITECNICO DI TORINO

Department of Control and Computer Engineering

Master of Science in Computer Engineering (Software Career)

Master Thesis

# Deep Reinforcement Learning algorithms for autonomous systems

Design and implementation of a control system for autonomous  
driving task of a small robot, exploiting state-of-the-art Model-Free  
Deep Reinforcement Learning algorithms

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# Abstract

TODO (Macaluso P.): Abstract is the last thing to do

# Glossary

**RL** Reinforcement Learning. [iii](#), [iv](#), [1](#), [2](#)

# Acknowledgements

TODO (Macaluso P.): Acknowledgements must be prepared!

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# Chapter 1

## Introduction

### 1.1 Motivation

Autonomous systems, and in particular self-driving for unsupervised robots and vehicles (e.g. self-driving cars) is a topic that has attracted a lot of attention from both the research community and industry, due to its potential to radically change mobility and transport. In general, most approaches to date focus on formal logic methods, which define driving behavior in annotated geometric maps. This can be difficult to scale, as it relies heavily on an external mapping infrastructure rather than using and understanding the local scene.

In order to make autonomous driving a truly ubiquitous technology, in this thesis we focus on systems which address the ability to drive and navigate in the absence of maps and explicit rules, relying – just like humans do – on a comprehensive understanding of the immediate environment while following simple high-level directions (e.g. turn-by-turn route commands). Recent work in this area has demonstrated that this is possible on rural country roads, using GPS for coarse localization and LIDAR to understand the local scene.

Recently, Reinforcement Learning (RL) – a machine learning subfield focused on solving Markov decision process (MDP), where an agent learns to select actions in an environment in an attempt to maximize some reward function – has been shown to achieve super-human results at games such as Go or chess, to be particularly suited for simulated environments like computer games, and to be a promising methodology for simple tasks with robotic manipulators.

In this thesis, we argue that the generality of RL makes it a useful framework to apply to autonomous driving. For this reason we design and implement a control system for an autonomous driving task with a small robot, exploiting state-of-the-art model-free Deep RL algorithms and discussing possible ways to make them data efficient.

## 1.2 Structure of the thesis

The aim of this section is to describe the main structure of the thesis.

### Chapter 1 - Introduction

The current chapter contains the motivation of this work and the structure of the thesis.

### Chapter 2 - Reinforcement Learning Fundamentals

The aim of this chapter is to present a description as detailed as possible about RL state-of-the-art in order to provide the reader with useful tools to enter in this research field. **TODO (Macaluso P.): Da qui in poi questo capitolo è da fare**

### Chapter 3 - Tools and Frameworks

This chapter explains briefly what are the main tools, frameworks and languages used in the thesis. **TODO (Macaluso P.): Continue this list**

**OpenAI Gym** a framework that is proposed as toolkit for developing and comparing RL algorithms.

**Anki Cozmo** Cozmo looks like a simple toy at first sight, but it hides an infinite potential under the hood, which make it a perfect candidate for the purposes of this thesis.

### Chapter 4 - Design of the control system

### Chapter 5 - Algorithms for Autonomous Systems

### Chapter 5 - Experiments

This is the most important chapter. It shows all the results obtained during the numerous experiments with comments and speculations about them.

### Chapter 6 - Conclusions

A summary of the results obtained from experiments with a specific part dedicated to future improvements.

## 1.3 Hardware and Software

In this section I want to list all software tools and hardware used, providing a quick introduction.



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## Chapter 2

# Reinforcement Learning

Reinforcement Learning is a field of Machine Learning that is experiencing a period of great fervour in the world of research, fomented by recent progress in Deep Learning opening the doors to function approximation with Neural Network (NN) and Convolutional Neural Network (CNN). It represents the third paradigm of Machine Learning alongside supervised and unsupervised learning. The idea behind RL is that the learning process consists in a sequence of trial and error where the *agent*, the main actor in RL could discover what is positive or negative thanks to a *reward signal*, just like human beings and animals do in the real world.

Recently it has known a remarkable development and interests in video games: it managed to beat world champions at the game of Go [1] and Dota with superhuman results and to master numerous Atari video games [2] from raw pixels. Decisions, actions and consequences make video games a simulated reality on which to exploit and test the power of RL algorithms. It is essential to realise that the heart of RL is the science of decision making. This fact makes it compelling and general for many research fields ranging from Engineering, Computer Science, Mathematics, Economics, to Psychology and Neuroscience.

Before discussing the results of this thesis, it is good to clarify everything that today represents the state-of-the-art in order to understand the universe behind this new paradigm better. The exploration of this field of research is the main aim of this chapter: the first section begins with the definition of the notation used and with the theoretical foundations behind RL, then in the second section it moves on to a careful discussion of the most important algorithms paying more attention to those used during the thesis project.

The elaboration of this chapter is inspired by [3] and by [4].

## 2.1 Elements of Reinforcement Learning

This thesis is written using the conventional notation of reinforcement learning where uppercase letters (e.g.  $\mathcal{A}$ ) describe sets of elements, while lowercase letters (e.g.  $a$ ) represent the specific instance of a set. Some entities are related to a specific timestep  $t$  and, for this reason, added as subscript (e.g.  $a_t$ ).

### 2.1.1 Definitions

Reinforcement Learning is a computational approach to **Sequential Decision Making**. It is useful with problems that are unsolvable with a single action but need a sequence of actions, a broader horizon, to be solved. In this context, RL algorithms learn how to improve and maximise a future reward from interactions between two main components: the *agent* and the *environment*.

The **agent** is the entity that interacts with the environment by making decisions based on what it can observe from the state of the surrounding situation. The decisions taken by the agent consist of **actions** ( $a_t$ ). The agent has no control over the environment, but actions are the only means by which it can modify and influence the environment.

Usually, the agent has a set of actions it can take, which is called **action space**. Some environments have **discrete** action spaces, where only a finite number of moves are available (e.g.  $\mathcal{A} = [\text{North}, \text{South}, \text{East}, \text{West}]$  choosing the direction to take in a bidimensional maze). On the other side, there are **continuous** action spaces where actions are vectors of real values. This distinction is fundamental to choose the algorithm to use because not all of them could be compatible with both types: according to the needs of the specific case, it may be necessary to modify the algorithm.

The **environment** represents all the things that are outside the agent. At every action received by the agent, it emits a **reward**, an essential aspect of RL, and an **observation** of the environment.

The **reward**  $r_t$  is a scalar feedback signal that defines the objective of the RL problem. This signal allows the agent to be able to distinguish positive actions from negative ones in order to reinforce and improve its behaviour. Significantly, the reward is **local**: it describes only the value of the latest action. Furthermore, actions may have long term consequences, delaying the reward. As it happens with human beings' decisions, receiving a conspicuous reward at a specific time step does not exclude the possibility to receive a small reward immediately afterwards and sometimes it may be better to sacrifice immediate reward to gain more rewards later.

In this context, many features make RL different from supervised and unsupervised learning. Firstly, there is **no supervisor**: when the agent has to decide what action to take, there is no entity that can tell him what the optimal decision is in

that specific moment. The agent receives only a reward signal which may delay compared to the moment in which it has to perform the next action. This fact led us to another significant difference: the **importance of time**. Their sequentiality links all actions taken by the agent. In this context, data are no more independent and identically distributed (i.i.d.).

The primary purpose of the agent is to **maximise** the cumulative reward called *return*.

The **return**  $g_t$  is the total discounted reward starting from timestep  $t$  defined by eq. (2.1)

$$g_t = r_{t+1} + \gamma r_{t+2} + \dots = \sum_{k=0}^{\infty} \gamma^k r_{t+k+1}, \quad \gamma \in [0,1] \quad (2.1)$$

where  $\gamma$  is a *discount factor*. Not only the fact that animal/human behaviour shows a preference for immediate rewards rather than for the future ones motivates the presence of this factor, but it is also mathematically necessary: an infinite-horizon sum of rewards may not converge to a finite value. Indeed, the return function is a *geometric series*, so, if  $\gamma \in [0,1)$ , the series converges to a finite value.

The other data emitted by the environment is the **observation** ( $o_t$ ) that is related to the **state** ( $s_t$ ). It represents a summary of information that the agent uses to select the next action, while the *state* is a function of the **history** the sequence of observation, actions and rewards at timestep  $t$  as shown in eq. (2.2).

$$h_T = o_1, r_1, a_1, \dots, a_{t-1}, o_t, r_t, \quad s_t = f(h_t) \quad (2.2)$$

The state described above is also called *agent state*  $s_t^a$ , while the private state of the environment is called *environment state*  $s_t^e$ . This distinction is useful for distinguishing **fully observable environments** where  $o_t = s_t^e = s_t^a$ , from **partially observable environments** where  $s_t^e \neq s_t^a$ . In the first case, the agent can observe the environment state directly, while in the second one, it has access to partial information about the state of the environment.

Beyond the fact that this chapter will focus on *fully observable environments*, the distinction between *state* and *observation* is often unclear and, conventionally, the input of the *agent* is composed by the *reward* and the *state* as shown in fig. 2.1 on the following page.

Furthermore, a state is called *informational state* (or *Markov state*) when it contains all data and information about its history. Formally, a state is a **Markov state** if and only if satisfies eq. (2.3).

$$\mathbb{P}[S_{t+1}|S_t] = \mathbb{P}[S_{t+1}|S_1, \dots, S_t] \quad (2.3)$$

It means that the state contains all data and information the agent needs to know to make decisions: the whole history is not useful anymore because it is inside the state. The environment state  $s_t^e$  is a Markov state.

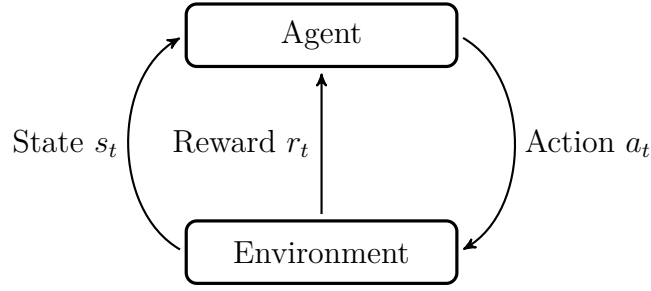


Figure 2.1. Interaction loop between Agent and Environment

### 2.1.2 The RL problem

With all the definitions shown so far it is possible to formalise the type of problems on which RL can be applied: the **MDP**, a mathematic framework to model the decision process. Its main application fields are optimization and dynamic programming.

A MDP is defined by

$$\langle \mathcal{S}, \mathcal{A}, \mathcal{P}, \mathcal{R}, \gamma \rangle$$

where  $\mathcal{S}$  is a finite set of states

$\mathcal{A}$  a finite set of actions

$\mathcal{P}$  a state transition probability matrix  $\mathcal{P}_{ss'}^a = \mathbb{P}[S_{t+1} = s' | S_t = s, A_t = a]$

$\mathcal{R}$  a reward function  $\mathcal{R}_s^a = \mathbb{E}[R_{t+1} = s' | S_t = s, A_t = a]$

$\gamma$  a discount factor such that  $\gamma \in [0,1]$

The main goal of an MDP is to select the best action to take, given a state, in order to collect the best reward.

**TODO (Macaluso P.): restart from here**

In this quick overview of the main unit of RL the components that may be compose the agent, the brain of the RL problem can not be missing: they are the *policy*, the *value function* and the *model*.

A **policy** is the core of RL because it is the representation of the agent's behaviour. It is a function that describes the mapping from state to actions. The *policy* is by  $\pi$  and it may be deterministic  $a_t = \pi(s_t)$  or stochastic  $\pi(a_t|s_t) = \mathbb{P}[a_t|s_t]$ .

A **value function** represents what is the expected reward that the agent can expect to collect in the future, starting from the current state. The reward signal represents only a local value of the reward, while the value function provides a wider view on the future reward: it can be considered as a prediction of rewards.

A **model** is composed by information about the environment. These data must not be confused with *states* and *observations*: it make possible to infer knowledge

about how the environment act and react.

## Chapter 3

# The necessity of a Framework

### 3.1 General Concepts

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## Chapter 4

# Deep Reinforcement Learning

### 4.1 General Concepts

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Nulla non mauris vitae wisi posuere convallis. Sed eu nulla nec eros scelerisque pharetra. Nullam varius. Etiam dignissim elementum metus. Vestibulum faucibus, metus sit amet mattis rhoncus, sapien dui laoreet odio, nec ultricies nibh augue a enim. Fusce in ligula. Quisque at magna et nulla commodo consequat. Proin accumsan imperdiet sem. Nunc porta. Donec feugiat mi at justo. Phasellus facilisis ipsum quis ante. In ac elit eget ipsum pharetra faucibus. Maecenas viverra nulla in massa.

Nulla ac nisl. Nullam urna nulla, ullamcorper in, interdum sit amet, gravida ut, risus. Aenean ac enim. In luctus. Phasellus eu quam vitae turpis viverra pellentesque. Duis feugiat felis ut enim. Phasellus pharetra, sem id porttitor sodales, magna nunc aliquet nibh, nec blandit nisl mauris at pede. Suspendisse risus risus, lobortis eget, semper at, imperdiet sit amet, quam. Quisque scelerisque dapibus nibh. Nam enim. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nunc ut metus. Ut metus justo, auctor at, ultrices eu, sagittis ut, purus. Aliquam aliquam.

# Part I

## Deep Reinforcement Learning

## Chapter 5

# Key Concept of Reinforcement Learning

### 5.1 General Concepts

[5] Suspendisse vitae elit. Aliquam arcu neque, ornare in, ullamcorper quis, commodo eu, libero. Fusce sagittis erat at erat tristique mollis. Maecenas sapien libero, molestie et, lobortis in, sodales eget, dui. Morbi ultrices rutrum lorem. Nam elementum ullamcorper leo. Morbi dui. Aliquam sagittis. Nunc placerat. Pellentesque tristique sodales est. Maecenas imperdiet lacinia velit. Cras non urna. Morbi eros pede, suscipit ac, varius vel, egestas non, eros. Praesent malesuada, diam id pretium elementum, eros sem dictum tortor, vel consectetur odio sem sed wisi.

Sed feugiat. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Ut pellentesque augue sed urna. Vestibulum diam eros, fringilla et, consectetur eu, nonummy id, sapien. Nullam at lectus. In sagittis ultrices mauris. Curabitur malesuada erat sit amet massa. Fusce blandit. Aliquam erat volutpat. Aliquam euismod. Aenean vel lectus. Nunc imperdiet justo nec dolor.

Etiam euismod. Fusce facilisis lacinia dui. Suspendisse potenti. In mi erat, cursus id, nonummy sed, ullamcorper eget, sapien. Praesent pretium, magna in eleifend egestas, pede pede pretium lorem, quis consectetur tortor sapien facilisis magna. Mauris quis magna varius nulla scelerisque imperdiet. Aliquam non quam. Aliquam porttitor quam a lacus. Praesent vel arcu ut tortor cursus volutpat. In vitae pede quis diam bibendum placerat. Fusce elementum convallis neque. Sed dolor orci, scelerisque ac, dapibus nec, ultricies ut, mi. Duis nec dui quis leo sagittis commodo.

Aliquam lectus. Vivamus leo. Quisque ornare tellus ullamcorper nulla. Mauris porttitor pharetra tortor. Sed fringilla justo sed mauris. Mauris tellus. Sed non leo. Nullam elementum, magna in cursus sodales, augue est scelerisque sapien, venenatis congue nulla arcu et pede. Ut suscipit enim vel sapien. Donec congue.

Maecenas urna mi, suscipit in, placerat ut, vestibulum ut, massa. Fusce ultrices nulla et nisl.

Etiam ac leo a risus tristique nonummy. Donec dignissim tincidunt nulla. Vestibulum rhoncus molestie odio. Sed lobortis, justo et pretium lobortis, mauris turpis condimentum augue, nec ultricies nibh arcu pretium enim. Nunc purus neque, placerat id, imperdiet sed, pellentesque nec, nisl. Vestibulum imperdiet neque non sem accumsan laoreet. In hac habitasse platea dictumst. Etiam condimentum facilisis libero. Suspendisse in elit quis nisl aliquam dapibus. Pellentesque auctor sapien. Sed egestas sapien nec lectus. Pellentesque vel dui vel neque bibendum viverra. Aliquam porttitor nisl nec pede. Proin mattis libero vel turpis. Donec rutrum mauris et libero. Proin euismod porta felis. Nam lobortis, metus quis elementum commodo, nunc lectus elementum mauris, eget vulputate ligula tellus eu neque. Vivamus eu dolor.

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Nulla mattis luctus nulla. Duis commodo velit at leo. Aliquam vulputate magna et leo. Nam vestibulum ullamcorper leo. Vestibulum condimentum rutrum mauris. Donec id mauris. Morbi molestie justo et pede. Vivamus eget turpis sed nisl cursus tempor. Curabitur mollis sapien condimentum nunc. In wisi nisl, malesuada at, dignissim sit amet, lobortis in, odio. Aenean consequat arcu a ante. Pellentesque porta elit sit amet orci. Etiam at turpis nec elit ultricies imperdiet. Nulla facilisi. In hac habitasse platea dictumst. Suspendisse viverra aliquam risus. Nullam pede justo, molestie nonummy, scelerisque eu, facilisis vel, arcu.

Curabitur tellus magna, porttitor a, commodo a, commodo in, tortor. Donec interdum. Praesent scelerisque. Maecenas posuere sodales odio. Vivamus metus lacus, varius quis, imperdiet quis, rhoncus a, turpis. Etiam ligula arcu, elementum a, venenatis quis, sollicitudin sed, metus. Donec nunc pede, tincidunt in, venenatis vitae, faucibus vel, nibh. Pellentesque wisi. Nullam malesuada. Morbi ut tellus ut pede tincidunt porta. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam congue neque id dolor.

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Nulla ac nisl. Nullam urna nulla, ullamcorper in, interdum sit amet, gravida ut, risus. Aenean ac enim. In luctus. Phasellus eu quam vitae turpis viverra pellentesque. Duis feugiat felis ut enim. Phasellus pharetra, sem id porttitor sodales, magna nunc aliquet nibh, nec blandit nisl mauris at pede. Suspendisse risus risus, lobortis eget, semper at, imperdiet sit amet, quam. Quisque scelerisque dapibus nibh. Nam enim. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nunc ut metus. Ut metus justo, auctor at, ultrices eu, sagittis ut, purus. Aliquam aliquam.



## Chapter 6

# The necessity of a Framework

### 6.1 General Concepts

Suspendisse vitae elit. Aliquam arcu neque, ornare in, ullamcorper quis, commodo eu, libero. Fusce sagittis erat at erat tristique mollis. Maecenas sapien libero, molestie et, lobortis in, sodales eget, dui. Morbi ultrices rutrum lorem. Nam elementum ullamcorper leo. Morbi dui. Aliquam sagittis. Nunc placerat. Pellentesque tristique sodales est. Maecenas imperdiet lacinia velit. Cras non urna. Morbi eros pede, suscipit ac, varius vel, egestas non, eros. Praesent malesuada, diam id pretium elementum, eros sem dictum tortor, vel consectetur odio sem sed wisi.

Sed feugiat. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Ut pellentesque augue sed urna. Vestibulum diam eros, fringilla et, consectetur eu, nonummy id, sapien. Nullam at lectus. In sagittis ultrices mauris. Curabitur malesuada erat sit amet massa. Fusce blandit. Aliquam erat volutpat. Aliquam euismod. Aenean vel lectus. Nunc imperdiet justo nec dolor.

Etiam euismod. Fusce facilisis lacinia dui. Suspendisse potenti. In mi erat, cursus id, nonummy sed, ullamcorper eget, sapien. Praesent pretium, magna in eleifend egestas, pede pede pretium lorem, quis consectetur tortor sapien facilisis magna. Mauris quis magna varius nulla scelerisque imperdiet. Aliquam non quam. Aliquam porttitor quam a lacus. Praesent vel arcu ut tortor cursus volutpat. In vitae pede quis diam bibendum placerat. Fusce elementum convallis neque. Sed dolor orci, scelerisque ac, dapibus nec, ultricies ut, mi. Duis nec dui quis leo sagittis commodo.

Aliquam lectus. Vivamus leo. Quisque ornare tellus ullamcorper nulla. Mauris porttitor pharetra tortor. Sed fringilla justo sed mauris. Mauris tellus. Sed non leo. Nullam elementum, magna in cursus sodales, augue est scelerisque sapien, venenatis congue nulla arcu et pede. Ut suscipit enim vel sapien. Donec congue. Maecenas urna mi, suscipit in, placerat ut, vestibulum ut, massa. Fusce ultrices nulla et nisl.

Etiam ac leo a risus tristique nonummy. Donec dignissim tincidunt nulla. Vestibulum rhoncus molestie odio. Sed lobortis, justo et pretium lobortis, mauris turpis condimentum augue, nec ultricies nibh arcu pretium enim. Nunc purus neque, placerat id, imperdiet sed, pellentesque nec, nisl. Vestibulum imperdiet neque non sem accumsan laoreet. In hac habitasse platea dictumst. Etiam condimentum facilisis libero. Suspendisse in elit quis nisl aliquam dapibus. Pellentesque auctor sapien. Sed egestas sapien nec lectus. Pellentesque vel dui vel neque bibendum viverra. Aliquam porttitor nisl nec pede. Proin mattis libero vel turpis. Donec rutrum mauris et libero. Proin euismod porta felis. Nam lobortis, metus quis elementum commodo, nunc lectus elementum mauris, eget vulputate ligula tellus eu neque. Vivamus eu dolor.

Nulla in ipsum. Praesent eros nulla, congue vitae, euismod ut, commodo a, wisi. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Aenean nonummy magna non leo. Sed felis erat, ullamcorper in, dictum non, ultricies ut, lectus. Proin vel arcu a odio lobortis euismod. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Proin ut est. Aliquam odio. Pellentesque massa turpis, cursus eu, euismod nec, tempor congue, nulla. Duis viverra gravida mauris. Cras tincidunt. Curabitur eros ligula, varius ut, pulvinar in, cursus faucibus, augue.

Nulla mattis luctus nulla. Duis commodo velit at leo. Aliquam vulputate magna et leo. Nam vestibulum ullamcorper leo. Vestibulum condimentum rutrum mauris. Donec id mauris. Morbi molestie justo et pede. Vivamus eget turpis sed nisl cursus tempor. Curabitur mollis sapien condimentum nunc. In wisi nisl, malesuada at, dignissim sit amet, lobortis in, odio. Aenean consequat arcu a ante. Pellentesque porta elit sit amet orci. Etiam at turpis nec elit ultricies imperdiet. Nulla facilisi. In hac habitasse platea dictumst. Suspendisse viverra aliquam risus. Nullam pede justo, molestie nonummy, scelerisque eu, facilisis vel, arcu.

Curabitur tellus magna, porttitor a, commodo a, commodo in, tortor. Donec interdum. Praesent scelerisque. Maecenas posuere sodales odio. Vivamus metus lacus, varius quis, imperdiet quis, rhoncus a, turpis. Etiam ligula arcu, elementum a, venenatis quis, sollicitudin sed, metus. Donec nunc pede, tincidunt in, venenatis vitae, faucibus vel, nibh. Pellentesque wisi. Nullam malesuada. Morbi ut tellus ut pede tincidunt porta. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam congue neque id dolor.

Donec et nisl at wisi luctus bibendum. Nam interdum tellus ac libero. Sed sem justo, laoreet vitae, fringilla at, adipiscing ut, nibh. Maecenas non sem quis tortor eleifend fermentum. Etiam id tortor ac mauris porta vulputate. Integer porta neque vitae massa. Maecenas tempus libero a libero posuere dictum. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Aenean quis mauris sed elit commodo placerat. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Vivamus rhoncus tincidunt libero. Etiam elementum pretium justo. Vivamus est. Morbi a tellus eget pede tristique

commodo. Nulla nisl. Vestibulum sed nisl eu sapien cursus rutrum.

Nulla non mauris vitae wisi posuere convallis. Sed eu nulla nec eros scelerisque pharetra. Nullam varius. Etiam dignissim elementum metus. Vestibulum faucibus, metus sit amet mattis rhoncus, sapien dui laoreet odio, nec ultricies nibh augue a enim. Fusce in ligula. Quisque at magna et nulla commodo consequat. Proin accumsan imperdiet sem. Nunc porta. Donec feugiat mi at justo. Phasellus facilisis ipsum quis ante. In ac elit eget ipsum pharetra faucibus. Maecenas viverra nulla in massa.

Nulla ac nisl. Nullam urna nulla, ullamcorper in, interdum sit amet, gravida ut, risus. Aenean ac enim. In luctus. Phasellus eu quam vitae turpis viverra pellentesque. Duis feugiat felis ut enim. Phasellus pharetra, sem id porttitor sodales, magna nunc aliquet nibh, nec blandit nisl mauris at pede. Suspendisse risus risus, lobortis eget, semper at, imperdiet sit amet, quam. Quisque scelerisque dapibus nibh. Nam enim. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nunc ut metus. Ut metus justo, auctor at, ultrices eu, sagittis ut, purus. Aliquam aliquam.

# Chapter 7

## Deep Reinforcement Learning

### 7.1 General Concepts

Suspendisse vitae elit. Aliquam arcu neque, ornare in, ullamcorper quis, commodo eu, libero. Fusce sagittis erat at erat tristique mollis. Maecenas sapien libero, molestie et, lobortis in, sodales eget, dui. Morbi ultrices rutrum lorem. Nam elementum ullamcorper leo. Morbi dui. Aliquam sagittis. Nunc placerat. Pellentesque tristique sodales est. Maecenas imperdiet lacinia velit. Cras non urna. Morbi eros pede, suscipit ac, varius vel, egestas non, eros. Praesent malesuada, diam id pretium elementum, eros sem dictum tortor, vel consectetur odio sem sed wisi.

Sed feugiat. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Ut pellentesque augue sed urna. Vestibulum diam eros, fringilla et, consectetur eu, nonummy id, sapien. Nullam at lectus. In sagittis ultrices mauris. Curabitur malesuada erat sit amet massa. Fusce blandit. Aliquam erat volutpat. Aliquam euismod. Aenean vel lectus. Nunc imperdiet justo nec dolor.

Etiam euismod. Fusce facilisis lacinia dui. Suspendisse potenti. In mi erat, cursus id, nonummy sed, ullamcorper eget, sapien. Praesent pretium, magna in eleifend egestas, pede pede pretium lorem, quis consectetur tortor sapien facilisis magna. Mauris quis magna varius nulla scelerisque imperdiet. Aliquam non quam. Aliquam porttitor quam a lacus. Praesent vel arcu ut tortor cursus volutpat. In vitae pede quis diam bibendum placerat. Fusce elementum convallis neque. Sed dolor orci, scelerisque ac, dapibus nec, ultricies ut, mi. Duis nec dui quis leo sagittis commodo.

Aliquam lectus. Vivamus leo. Quisque ornare tellus ullamcorper nulla. Mauris porttitor pharetra tortor. Sed fringilla justo sed mauris. Mauris tellus. Sed non leo. Nullam elementum, magna in cursus sodales, augue est scelerisque sapien, venenatis congue nulla arcu et pede. Ut suscipit enim vel sapien. Donec congue. Maecenas urna mi, suscipit in, placerat ut, vestibulum ut, massa. Fusce ultrices nulla et nisl.

Etiam ac leo a risus tristique nonummy. Donec dignissim tincidunt nulla. Vestibulum rhoncus molestie odio. Sed lobortis, justo et pretium lobortis, mauris turpis condimentum augue, nec ultricies nibh arcu pretium enim. Nunc purus neque, placerat id, imperdiet sed, pellentesque nec, nisl. Vestibulum imperdiet neque non sem accumsan laoreet. In hac habitasse platea dictumst. Etiam condimentum facilisis libero. Suspendisse in elit quis nisl aliquam dapibus. Pellentesque auctor sapien. Sed egestas sapien nec lectus. Pellentesque vel dui vel neque bibendum viverra. Aliquam porttitor nisl nec pede. Proin mattis libero vel turpis. Donec rutrum mauris et libero. Proin euismod porta felis. Nam lobortis, metus quis elementum commodo, nunc lectus elementum mauris, eget vulputate ligula tellus eu neque. Vivamus eu dolor.

Nulla in ipsum. Praesent eros nulla, congue vitae, euismod ut, commodo a, wisi. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Aenean nonummy magna non leo. Sed felis erat, ullamcorper in, dictum non, ultricies ut, lectus. Proin vel arcu a odio lobortis euismod. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Proin ut est. Aliquam odio. Pellentesque massa turpis, cursus eu, euismod nec, tempor congue, nulla. Duis viverra gravida mauris. Cras tincidunt. Curabitur eros ligula, varius ut, pulvinar in, cursus faucibus, augue.

Nulla mattis luctus nulla. Duis commodo velit at leo. Aliquam vulputate magna et leo. Nam vestibulum ullamcorper leo. Vestibulum condimentum rutrum mauris. Donec id mauris. Morbi molestie justo et pede. Vivamus eget turpis sed nisl cursus tempor. Curabitur mollis sapien condimentum nunc. In wisi nisl, malesuada at, dignissim sit amet, lobortis in, odio. Aenean consequat arcu a ante. Pellentesque porta elit sit amet orci. Etiam at turpis nec elit ultricies imperdiet. Nulla facilisi. In hac habitasse platea dictumst. Suspendisse viverra aliquam risus. Nullam pede justo, molestie nonummy, scelerisque eu, facilisis vel, arcu.

Curabitur tellus magna, porttitor a, commodo a, commodo in, tortor. Donec interdum. Praesent scelerisque. Maecenas posuere sodales odio. Vivamus metus lacus, varius quis, imperdiet quis, rhoncus a, turpis. Etiam ligula arcu, elementum a, venenatis quis, sollicitudin sed, metus. Donec nunc pede, tincidunt in, venenatis vitae, faucibus vel, nibh. Pellentesque wisi. Nullam malesuada. Morbi ut tellus ut pede tincidunt porta. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Etiam congue neque id dolor.

Donec et nisl at wisi luctus bibendum. Nam interdum tellus ac libero. Sed sem justo, laoreet vitae, fringilla at, adipiscing ut, nibh. Maecenas non sem quis tortor eleifend fermentum. Etiam id tortor ac mauris porta vulputate. Integer porta neque vitae massa. Maecenas tempus libero a libero posuere dictum. Vestibulum ante ipsum primis in faucibus orci luctus et ultrices posuere cubilia Curae; Aenean quis mauris sed elit commodo placerat. Class aptent taciti sociosqu ad litora torquent per conubia nostra, per inceptos hymenaeos. Vivamus rhoncus tincidunt libero. Etiam elementum pretium justo. Vivamus est. Morbi a tellus eget pede tristique

commodo. Nulla nisl. Vestibulum sed nisl eu sapien cursus rutrum.

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Nulla ac nisl. Nullam urna nulla, ullamcorper in, interdum sit amet, gravida ut, risus. Aenean ac enim. In luctus. Phasellus eu quam vitae turpis viverra pellentesque. Duis feugiat felis ut enim. Phasellus pharetra, sem id porttitor sodales, magna nunc aliquet nibh, nec blandit nisl mauris at pede. Suspendisse risus risus, lobortis eget, semper at, imperdiet sit amet, quam. Quisque scelerisque dapibus nibh. Nam enim. Lorem ipsum dolor sit amet, consectetur adipiscing elit. Nunc ut metus. Ut metus justo, auctor at, ultrices eu, sagittis ut, purus. Aliquam aliquam.

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