Chapter 18
Reinforcement Learning in Robotics: A Survey

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Abstract. As most action generation problems of autonomous robots can be phrased in terms of sequential decision problems, robotics offers a tremendously important and interesting application platform for reinforcement learning. Similarly, the real-world challenges of this domain pose a major real-world check for reinforcement learning. Hence, the interplay between both disciplines can be seen as promising as the one between physics and mathematics. Nevertheless, only a fraction of the scientists working on reinforcement learning are sufficiently tied to robotics to oversee most problems encountered in this context. Thus, we will bring the most important challenges faced by robot reinforcement learning to their attention. To achieve this goal, we will attempt to survey most work that has successfully applied reinforcement learning to behavior generation for real robots. We discuss how the presented successful approaches have been made tractable despite the complexity of the domain and will study how representations or the inclusion of prior knowledge can make a significant difference. As a result, a particular focus of our chapter lies on the choice between model-based and model-free as well as between value function-based and policy search methods. As a result, we obtain a fairly complete survey of robot reinforcement learning which should allow a general reinforcement learning researcher to understand this domain.

18.1 Introduction

Robotics has a near infinite amount of interesting learning problems, a large percentage of which can be phrased as reinforcement learning problems. See Figure 18.1 for
an illustration of the wide variety of robots that have learned tasks using reinforce-
ment learning. However, robotics as a domain differs significantly from well-defined
typical reinforcement learning benchmark problems, which usually have discrete
states and actions. In contrast, many real-world problems in robotics are best repre-
sented with high-dimensional, continuous states and actions. Every single trial run
is costly and, as a result, such applications force us to focus on problems that do not
arise that frequently in classical reinforcement learning benchmark examples. In this
book chapter, we highlight the challenges faced in robot reinforcement learning and
bring many of the inherent problems of this domain to the reader’s attention.

Robotics is characterized by high dimensionality due to the many degrees of free-
dom of modern anthropomorphic robots. Experience on the real system is costly and
often hard to reproduce. However, it usually cannot be replaced by simulations, at
least for highly dynamic tasks, as even small modeling errors accumulate to sub-
stantially different dynamic behavior. Another challenge faced in robot reinforce-
ment learning is the generation of appropriate reward functions. Good rewards that
lead the systems quickly to success are needed to cope with the cost of real-world
experience but are a substantial manual contribution.

Obviously, not every reinforcement learning method is equally suitable for the
robotics domain. In fact, many of the methods that scale to more interesting tasks
are model-based (Atkeson et al, 1997; Abbeel et al, 2007) and often employ pol-
icy search rather than value function-based approaches (Gullapalli et al, 1994;
Miyamoto et al, 1996; Kohl and Stone, 2004; Tedrake et al, 2005; Peters and Schaal,
2008a,b; Kober and Peters, 2009). This stands in contrast to much of mainstream re-
inforcement (Kaelbling et al, 1996; Sutton and Barto, 1998). We attempt to give a
fairly complete overview on real robot reinforcement learning citing most original
papers while distinguishing mainly on a methodological level.

As none of the presented methods extends to robotics with ease, we discuss how
robot reinforcement learning can be made tractable. We present several approaches
to this problem such as choosing an appropriate representation for your value func-
tion or policy, incorporating prior knowledge, and transfer from simulations.

In this book chapter, we survey real robot reinforcement learning and highlight
how these approaches were able to handle the challenges posed by this setting. Less
attention is given to results that correspond only to slightly enhanced grid-worlds or
that were learned exclusively in simulation. The challenges in applying reinforce-
ment learning in robotics are discussed in Section 18.2.

Standard reinforcement learning methods suffer from the discussed challenges.
As already pointed out in the reinforcement learning review paper by Kaelbling et al
(1996) “we must give up tabula rasa learning techniques and begin to incorporate
bias that will give leverage to the learning process”. Hence, we concisely present re-
inforcement learning techniques in the context of robotics in Section 18.3. Different
approaches of making reinforcement learning tractable are treated in Sections 18.4
to 18.6. Finally in Section 18.7, we employ the example of ball-in-a-cup to highlight
which of the various approaches discussed in the book chapter have been particu-
arly helpful for us to make such a complex task tractable. In Section 18.8 we give
a conclusion and outlook on interesting problems.