

Reinforcement Learning

Lecture 1: Foundations

Chris G. Willcocks

Durham University



1 Introduction

- definition
- examples
- comparison

2 A Brief History

- learning by trial and error
- optimal control and dynamic programming
- monte carlo tree search
- temporal difference algorithms

3 Key Concepts

- designing rewards
- action spaces
- observability
- information states
- policies
- value functions
- model
- taxonomy



Richard **Sutton** & Andrew **Barto** [5] summarise:

Definition: Reinforcement Learning

“Reinforcement learning is a computational approach to understanding and automating **goal-directed learning** and **decision making**. It is distinguished from other computational approaches by its emphasis on learning by an **agent** from direct **interaction with its environment**, without requiring exemplary supervision or complete models of the environment”



Reinforcement Learning

- Learn policies to
 - [Play Atari games](#) ▶
- Self-play
 - [AlphaGo Zero](#) ▶
- Simulation to real
 - [Control robots](#) ▶
- Surprising the creators!
 - [Four examples](#) ▶





Typical Machine Learning

- Supervisory signal (with a teacher)
 - Immediate feedback
- Learning without a teacher
 - Unsupervised (e.g. **clustering**)
- i.i.d datasets

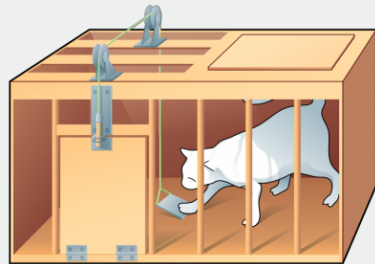
Reinforcement Learning

- Reward signal accumulated over time
 - Sparse/delayed feedback
- Not i.i.d
 - *sequential* where actions change subsequent environment

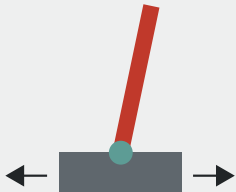
Prof. Barto gives an excellent history of the reinforcement learning field in this YouTube video [!\[\]\(5eb1325dfdc3f1cad8426726c0db51cd_img.jpg\)](#)

- Learning by **trial and error evaluation**
 - Edward L. Thorndike (1874-1949)
Behaviourism. **Law of effect, 1911:** do something satisfying, then it becomes more probable. If its discomforting it becomes less probable.

Thorndike's Puzzle Box



Cart-Pole Balancing



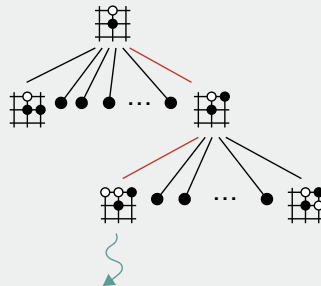
Barto et al., 1983: Neuronlike elements solve difficult learning control problems [1]

- Richard Bellman (1920-1984)
 - Optimal control theory
 - Dynamic programming, 1953
 - Breadth-first search through **state** space...
how big is the state space of Go or StarCraft? 🕒
 - The Bellman Equation

- **Monte carlo** tree search

- RL had a reputation of being slow
- Gerald Tesauro showed in the 1990s multiple MC games can focus DP onto relevant parts of the state space

MCTS in AlphaGo Zero [4]



TD Gammon, 1992



Gerald Tesauro showed a **multi-layer neural network** with **TD learning** played competitively with human experts [6]

- **Temporal difference** learning
 - Connection to how dopamine cells work in neuroscience [2]
 - Monte Carlo require playing an entire game, TD methods adjust predictions to match later, more accurate, predictions about the future before finishing the game



Designing rewards is a key challenge in reinforcement learning

Definition: Reward

A **reward** $R_t \in \mathbb{R}$ is a *scalar feedback signal*

- How well the agent is doing at step t
- Agents try to maximize cumulative reward over time into the future

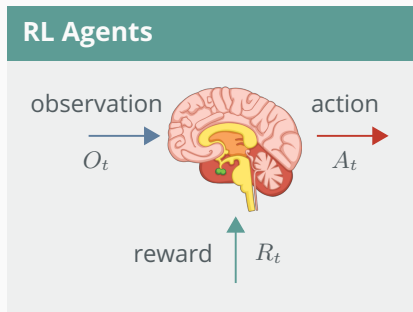
Definition: Reward hypothesis [5]

All goals and purposes can be thought of as the maximization of the expected value of the cumulative sum of a received scalar reward signal

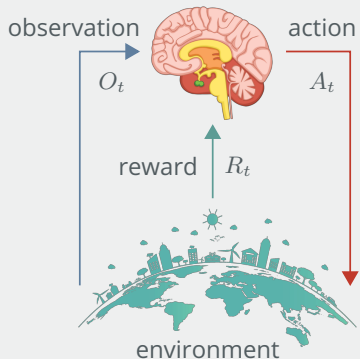
The RL challenge is to design an algorithm that chooses the action A_t given an observation O_t that maximizes (future) rewards.

Actions can be:

- **Discrete** – for example Go and chess
- **Continuous** – controlling voltage of a robot



RL Agents



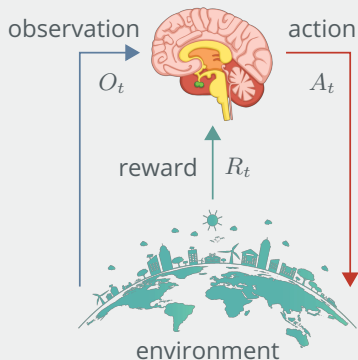
At step t , the agent:

- Executes an **action** A_t

and also (without control):

- **Observes** O_t the environment
- Receives a **reward** R_t

RL Agents



The **environment** has a state S_t^e

- Typically not used
- Not all visible to the agent

The **agent** has a state S_t^a

- Summarises relevant observations
- Its any function of history $S_t^a = f(H_t)$

Definition: Full observability

This is where:

$$O_t = S_t^a = S_t^e,$$

unlike **partial observability** where $S_t^a \neq S_t^e$



With the **Markov property**, we can throw away the history and just use the agents state:

Definition: Markov property

A state S_t is **Markov** if and only if

$$P(S_{t+1} | S_t) = P(S_{t+1} | S_1, S_2, \dots, S_t)$$

- For example, a **chess board**
 - We don't need to know how the game was played up to this point
- The state fully characterises the distribution over future events:

$$H_{1:t} \rightarrow S_t \rightarrow H_{t+1:\infty}$$

Agent component 1 :

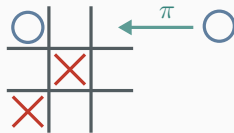
Definition: Policy

A **policy** is how the agent picks its actions. A policy π can be either **deterministic**, where:

$$a = \pi(s),$$

or it can be **stochastic**, where:

$$a \sim \pi(a|s).$$

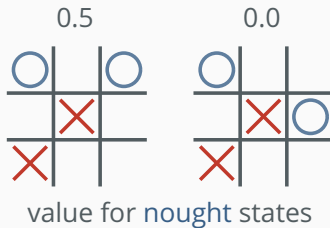


Agent component 2:

Definition: Value function

The **value function** is the prediction of expected total **future** rewards:

$$v_{\pi}(s) = \mathbb{E}_{\pi}[R_t + \gamma R_{t+1} + \gamma^2 R_{t+2} + \dots | S_t = s]$$



Agent component 3 :

Definition: Model

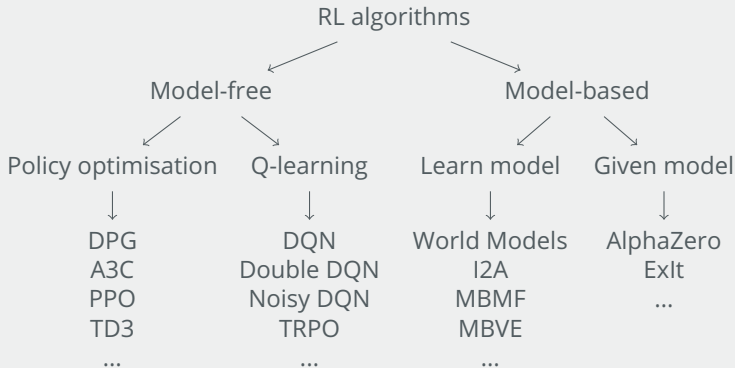
The **model** predicts what the environment will do next. It models the joint distribution of the new state and reward:

$$p(s', r | s, a) = P(S_t = s', R_t = r | S_{t-1} = s, A_{t-1} = a).$$

The model is optional (**model-based** vs **model-free** learning)



Taxonomy of reinforcement learning algorithms




This figure does not capture overlap, for example between policy optimisation and Q-learning algorithms



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