

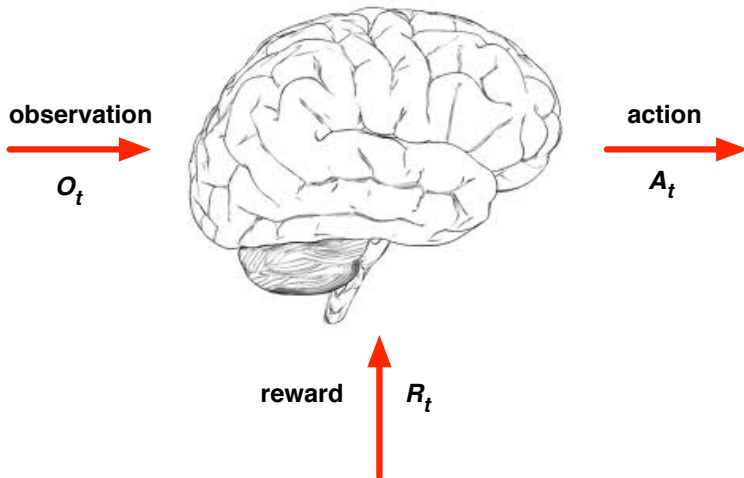
Lecture 1: Introduction to Reinforcement Learning

David Silver

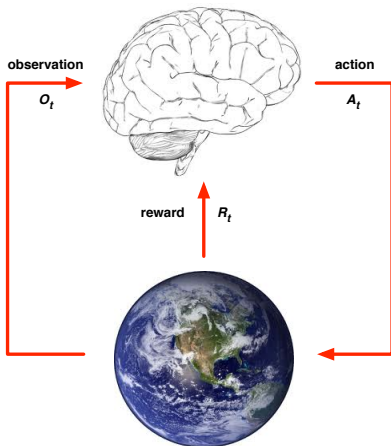
Sequential Decision Making

- Goal: *select actions to maximise total future reward*
- Actions may have long term consequences
- Reward may be delayed
- It may be better to sacrifice immediate reward to gain more long-term reward
- Examples:
 - A financial investment (may take months to mature)
 - Refuelling a helicopter (might prevent a crash in several hours)
 - Blocking opponent moves (might help winning chances many moves from now)

Agent and Environment



Agent and Environment



- At each step t the agent:
 - Executes action A_t
 - Receives observation O_t
 - Receives scalar reward R_t
- The environment:
 - Receives action A_t
 - Emits observation O_{t+1}
 - Emits scalar reward R_{t+1}
- t increments at env. step

History and State

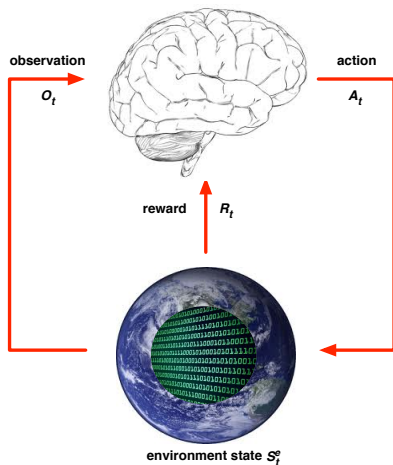
- The **history** is the sequence of observations, actions, rewards

$$H_t = O_1, R_1, A_1, \dots, A_{t-1}, O_t, R_t$$

- i.e. all observable variables up to time t
- i.e. the sensorimotor stream of a robot or embodied agent
- What happens next depends on the history:
 - The agent selects actions
 - The environment selects observations/rewards
- **State** is the information used to determine what happens next
- Formally, state is a function of the history:

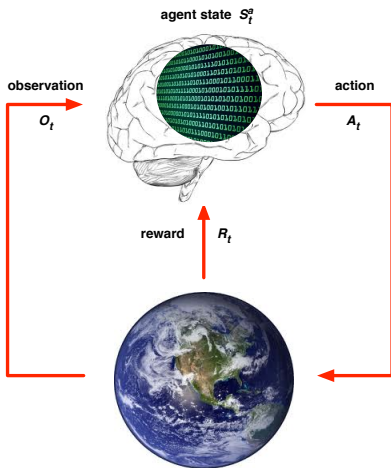
$$S_t = f(H_t)$$

Environment State



- The **environment state** S_t^e is the environment's private representation
- i.e. whatever data the environment uses to pick the next observation/reward
- The environment state is **not usually visible to the agent**
- Even if S_t^e is visible, it may contain irrelevant information

Agent State



- The **agent state** S_t^a is the agent's internal representation
- i.e. whatever information the agent uses to pick the next action
- i.e. it is the information used by reinforcement learning algorithms
- It can be any function of history:

$$S_t^a = f(H_t)$$

Information State

An **information state** (a.k.a. **Markov state**) contains all useful information from the history.

Definition

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

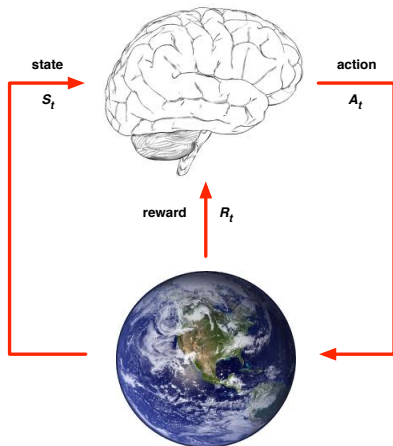
$$\mathbb{P}[S_{t+1} \mid S_t] = \mathbb{P}[S_{t+1} \mid S_1, \dots, S_t]$$

- “The future is independent of the past given the present”

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

- Once the state is known, the history may be thrown away
- i.e. **The state is a sufficient statistic of the future**
- The environment state S_t^e is Markov
- The history H_t is Markov

Fully Observable Environments



Full observability: agent **directly** observes environment state

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

- Agent state = environment state = information state
- Formally, this is a **Markov decision process** (MDP)
- (Next lecture and the majority of this course)

Partially Observable Environments

- **Partial observability**: agent **indirectly** observes environment:
 - A robot with camera vision isn't told its absolute location
 - A trading agent only observes current prices
 - A poker playing agent only observes public cards
- Now agent state \neq environment state
- Formally this is a **partially observable Markov decision process** (POMDP)
- Agent must construct its own state representation S_t^a , e.g.
 - Complete history: $S_t^a = H_t$
 - **Beliefs** of environment state: $S_t^a = (\mathbb{P}[S_t^e = s^1], \dots, \mathbb{P}[S_t^e = s^n])$
 - Recurrent neural network: $S_t^a = \sigma(S_{t-1}^a W_s + O_t W_o)$

