

# 1 OR 3: Chapter 14 - Stochastic games

## 1.1 Recap

In the [previous chapter](#):

- We considered games of incomplete information;
- Discussed some basic utility theory;
- Considered the principal agent game.

In this chapter we will take a look at a more general type of random game.

## 1.2 Stochastic games

### 1.2.1 Definition of a stochastic game

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A stochastic game is defined by:

- $X$  a set of states with a stage game defined for each state;
  - A set of strategies  $S_i(x)$  for each player for each state  $x \in X$ ;
  - A set of rewards dependant on the state and the actions of the other players:  $u_i(x, s_1, s_2)$ ;
  - A set of probabilities of transitioning to a future state:  $\pi(x'|x, s_1, s_2)$ ;
  - Each stage game is played at a set of discrete times  $t$ .
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We will make some simplifying assumptions in this course:

1. The length of the game is not known (infinite horizon);
2. The rewards and transition probabilities are not dependent;
3. We will only consider strategies called **Markov strategies**.

### 1.2.2 Definition of a Markov strategy

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A strategy is call a **Markov strategy** if the behaviour dictated is not time dependent.

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### 1.2.3 Example

Consider the following game with  $X = \{x, y\}$ :

- $S_1(x) = \{a, b\}$  and  $S_2(x) = \{c, d\}$ ;
- $S_1(y) = \{e\}$  and  $S_2(y) = \{f\}$ ;

We have the stage game corresponding to state  $x$ :

$$\begin{pmatrix} (8, 4) & (5, 3) \\ (1, 5) & (2, 6) \end{pmatrix}$$

The stage game corresponding to state  $y$ :

$$((0, 0))$$

The transition probabilities corresponding to state  $x$ :

$$\begin{pmatrix} (.5, .5) & (1, 0) \\ (1, 0) & (1, 0) \end{pmatrix}$$

The transition probabilities corresponding to state  $y$ :

$$((0, 0))$$

A concise way of representing all this is shown in Figure 1.

We see that the Nash equilibrium for the stage game corresponding to  $x$  is  $(a, c)$  however as soon as the players play that strategy profile they will go to state  $y$  which is an absorbing state at which players gain no further utility.

To calculate utilities for players in infinite horizon stochastic games we use a discount rate. Thus without loss of generality if the game is in state  $x$  and we assume that both players are playing  $\sigma_i^*$  then player 1 would be attempting to maximise future payoffs:

$$U_1(r, s) = \left( u_1(x, r, s) + \delta \sum_{x' \in X} \pi(x'|x, r, s) U_1^*(x') \right)$$

where  $U_1^*$  denotes the expected utility to player 1 when both players are playing the Nash strategy profile.

Thus a Nash equilibrium satisfies:

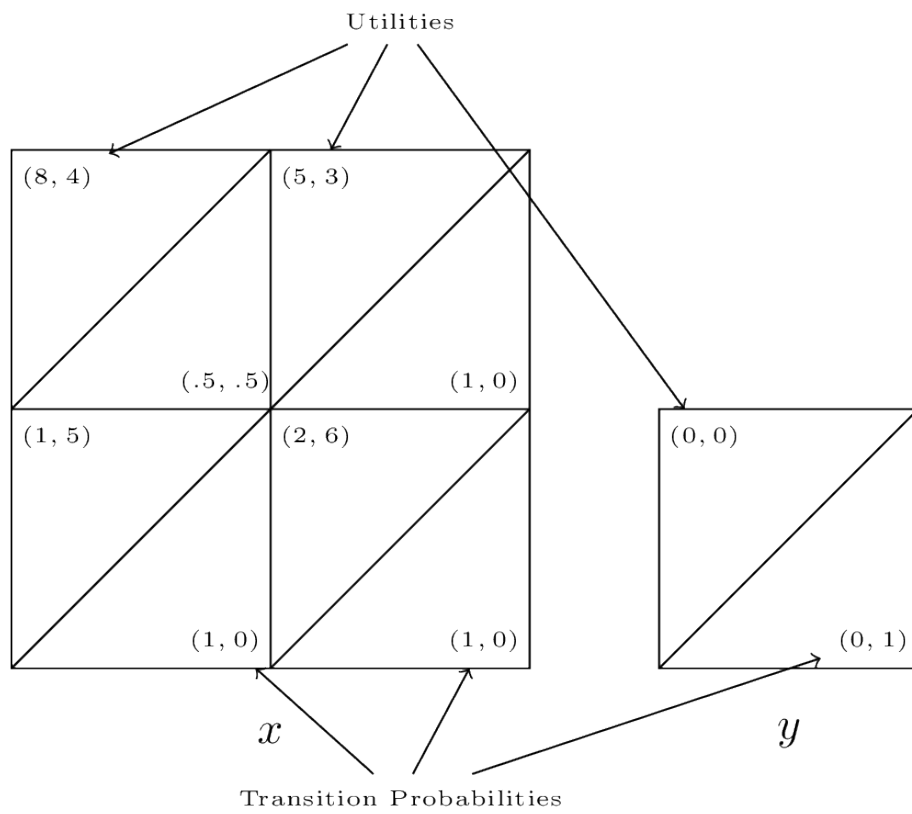


Figure 1: A simple stochastic game.

$$U_1^*(x) = \max_{r \in S_1(x)} (u_i(x, r, s^*) + \delta \sum_{x' \in X} \pi(x'|x, r, s^*) U_1^*(x'))$$

$$U_2^*(x) = \max_{s \in S_2(x)} (u_i(x, r^*, s) + \delta \sum_{x' \in X} \pi(x'|x, r^*, s) U_1^*(x'))$$

Solving these equations is not straightforward. We will take a look at one approach by solving the example we have above.

### 1.3 Finding equilibria in stochastic games

Let us find a Nash equilibrium for the game considered above with  $\delta = 2/3$ .

State  $y$  gives no value to either player so we only need to consider state  $x$ . Let the future gains to player 1 in state  $x$  be  $u$ , and the future gains to player 2 in state  $x$  be  $v$ . Thus the players are facing the following game:

$$\begin{pmatrix} (8 + \frac{1}{3}v, 4 + \frac{1}{3}u) & (5 + \frac{2}{3}v, 3 + \frac{2}{3}u) \\ (1 + \frac{2}{3}v, 5 + \frac{2}{3}u) & (2 + \frac{2}{3}v, 6 + \frac{2}{3}u) \end{pmatrix}$$

We consider each strategy pair and state the condition for Nash equilibrium:

1.  $(a, c)$ :  $v \leq 21$  and  $u \leq 3$ .
2.  $(a, d)$ :  $u \geq 3$ .
3.  $(b, c)$ :  $v \geq 21$  and  $5 \geq 6$ .
4.  $(b, d)$ :  $5 \geq 2$ .

Now consider the implications of each of those profiles being an equilibrium:

1.  $8 + v/3 = v \Rightarrow v = 12$  and  $4 + u/3 = u \Rightarrow u = 6$  which contradicts the corresponding inequality.
2.  $3 + 2u/3 = u \Rightarrow u = 9$ .
3. The second inequality cannot hold.
4. The inequality cannot hold.

Thus the unique Markov strategy Nash equilibria is  $(a, d)$  **which is not the stage Nash equilibria!**