Learning in Repeated Games

Game Theory Course:
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Introduction

- We will cover two types of learning in repeated games.
  - Fictitious Play
  - No-regret Learning
- In general Learning in Game Theory is a rich subject with many facets we will not be covering.

Fictitious Play

- Initially proposed as a method for computing Nash equilibrium.
- Each player maintains explicit belief about the other players.
  - Initialize beliefs about the opponent's strategies.
  - Each turn:
    - Play a best response to the assessed strategy of the opponent.
    - Observe the opponent's actual play and update beliefs accordingly.

Fictitious Play

Formally

- Maintain counts of opponents actions
  - For every $a \in A$ let $w(a)$ be the number of times the opponent has player action a.
  - Can be initialized to non-zero starting values.
- Assess opponent's strategy using these counts:

$$\sigma(a) = \frac{w(a)}{\sum_{a' \in A} w(a')}$$

- (pure strategy) best respond to this assessed strategy.
  - Break ties somehow.

Fictitious Play

Example using matching pennies

Round	1's action	2's action	1's beliefs	2's beliefs
0			(1.5,2)	(2,1.5)
1	T	T	(1.5,3)	(2,2.5)
2	T	H	(2.5,3)	(2,3.5)
3	T	H	(3.5,3)	(2,4.5)
4	H	H	(4.5,3)	(3,4.5)
5	H	H	(5.5,3)	(4,4.5)
6	H	H	(6.5,3)	(5,4.5)
7	H	T	(6.5,4)	(6,4.5)
⋮	⋮	⋮	⋮	⋮

Fictitious Play

Convergence

Theorem

If the empirical distribution of each player's strategies converges in fictitious play, then it converges to a Nash equilibrium.

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Theorem

Each of the following are a sufficient conditions for the empirical frequencies of play to converge in fictitious play:

- *The game is zero sum;*
- *The game is solvable by iterated elimination of strictly dominated strategies;*
- *The game is a potential game;*
- *The game is $2 \times n$ and has generic payoffs.*

No-regret Learning

Definitions

Definition (Regret)

The regret an agent experiences at time t for not having played s is $R^t(s) = \alpha^t - \alpha^t(s)$.

No-regret Learning

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Definition (No-regret learning rule)

A learning rule exhibits no regret if for any pure strategy of the agent s it holds that $Pr([\liminf R^t(s)] \leq 0) = 1$.

No-regret Learning

Regret Matching

- Example learning rule that exhibits no regret: Regret Matching.

No-regret Learning

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$$\sigma_i^{t+1}(s) = \frac{R^t(s)}{\sum_{s' \in S_i} R^t(s')},$$

where $\sigma_i^{t+1}(s)$ is the probability that agent i plays pure strategy s at time $t+1$.

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- Converges to a correlated equilibrium for finite games.