Strategical languages of infinite words
Mustapha Arfi, Bedine Ould M. Lemine, Carla Selmi

To cite this version:

HAL Id: hal-00460312
https://hal.archives-ouvertes.fr/hal-00460312
Submitted on 2 Mar 2010

HAL is a multi-disciplinary open access archive for the deposit and dissemination of scientific research documents, whether they are published or not. The documents may come from teaching and research institutions in France or abroad, or from public or private research centers. L’archive ouverte pluridisciplinaire HAL, est destinée au dépôt et à la diffusion de documents scientifiques de niveau recherche, publiés ou non, émanant des établissements d’enseignement et de recherche français ou étrangers, des laboratoires publics ou privés.
Strategical languages of infinite words

M. Arfi, B. Ould M Lemine, C. Selmi *

Abstract: We deal in this paper with strategical languages of infinite words, that is those generated by a nondeterministic strategy in the sense of game theory. We first show the existence of a minimal strategy for such languages, for which we give an explicit expression. Then we characterize the family of strategical languages as that of closed ones, in the topological space of infinite words. Finally, we give a definition of a Nash equilibrium for such languages, that we illustrate with a famous example.

Keywords: Words, infinite words, formal languages, game theory, strategy, topology, Nash equilibrium.

Introduction

Game theory [6] is usually defined as a mathematical tool used to analyze strategical interaction, the game, between individuals which are called players. The games studied in this paper are supposed simultaneous, noncooperative, infinitely repeated and with a perfect knowledge of the previous moves. We will elucidate these ideas through a famous example.

In game theory, the distinction between the cooperative and noncooperative game is crucial. The Prisoner’s Dilemma [3] is an interesting example to explain these notions. It is a game involving two players where each one has two possible actions: cooperate (c) or defect (d). The game consists of simultaneous actions (called moves) of both players. It can be represented using the matrix:

<table>
<thead>
<tr>
<th></th>
<th>c</th>
<th>d</th>
</tr>
</thead>
<tbody>
<tr>
<td>c</td>
<td>(4,4)</td>
<td>(0, 5)</td>
</tr>
<tr>
<td>d</td>
<td>(5, 0)</td>
<td>(1, 1)</td>
</tr>
</tbody>
</table>

where each entry $e_{ij}$ is an ordered pair of real numbers. The two players are referred to as the row player and the column player respectively. The actions of the first player are identified with the rows of the matrix and those of the second one with the columns. If the row player chooses action $i$ and the second action $j$, the components

*LITIS EA 4108, Université du Havre, UFR Sciences et Techniques, 25 rue P. Lebon, BP 540, 76058 Le Havre Cedex, France and Université de Rouen, Département d’Informatique, Avenue de l’Université, BP 12, F-76801 St. Etienne de Rouvray Cedex, France (mustapha.arfi, blemine, carla.selmi)@litislab.eu
of the ordered pair $e_{ij}$ are the payoff received by the first and the second player respectively. It is clear that if they could play cooperatively and make a binding agreement, they would both play $c$. If the game is noncooperative, the best action for each player is $d$.

Suppose now that we consider infinite repetitions of a noncooperative base game. This game is just as noncooperative as the base one, but it allows a certain form of interaction. Suppose that each player has a perfect knowledge of the previous moves of all the others. Then his strategy may depend on these previous moves and he may coordinate it with that of his opponents. For instance, if the base game is the Prisoner’s Dilemma, grim-trigger is the strategy of cooperating in the first move and until your adversary defects, then of always defecting after the first defection of your opponent. Tit-for-tat is the strategy of playing at each step the action played by your adversary at the previous one; the initial move is free.

In this paper, we make use of infinite words to analyze the kind of games we want to model. A match of such a game is represented as an infinite word on the alphabet $A$ of moves. In this context, a strategy for player $i$ can be viewed as a relation from the set of finite words on $A$ to that of the actions of this player. The whole strategy of the game is defined as the vector composed by using the strategies of all players. We can associate to each strategy vector a language $L$ of infinite words on $A$, defined as the set of all matches that the players may make if everyone follows the strategy he decided to apply.

Nash equilibrium is one of the most important notions in game theory. The whole strategy of the game is defined as the vector composed by using the strategies of all players. Intuitively, a strategy vector is a Nash equilibrium if one player’s departure from it while the others remain faithful to it results in punishment. The idea is that once the players start playing according to such a strategy vector, then they all have a good reason to stay with it.

More precisely, our study will be organized as follows. In Sections 1 and 2, we introduce some basic notions on words and game theory. In Section 3, we show that the same language can be generated by several strategies. We call “strategical” a language which is given by at least one strategy. Section 4 is devoted to the proof of the existence of a minimal strategy for a strategical language, for which we give an explicit description. The characterization of the family of strategical languages as that of closed sets in the topological space of infinite words is given in Section 5. Finally, in Section 6, we give a definition of a Nash equilibrium for strategical languages.

1 Words

A word is a finite sequence of elements of an alphabet $A$. We denote by $A^*$ the set of all words on $A$. The length of a word $w \in A^*$, denoted by $|w|$, is the number of letters of $A$ composing $w$. Let $a \in A$. The empty word $\epsilon$ is the only word of length zero. We denote by $|w|_a$ the number of the occurrences of $a$ in $w$. Given two words
u, v ∈ A*, we say that u is a factor of v if we have v ∈ A*uA* and that u is a prefix or a left factor of v if v ∈ uA*. An infinite word on A is an infinite sequence h of elements of A, which we will write h = h₀h₁⋯hₜ⋯. We denote by Aω the set of all infinite words on A. Given a word w ∈ A* and an infinite word h ∈ Aω, we say that w is a prefix or a left factor of h if there exists an infinite word h' ∈ Aω such that h = wh'.

If L is a subset of Aω, we denote by Prefk(L) the set of all words that are prefixes of length k of words of L. We set Pref≥k(L) = ⋃i≥k Prefi(L) and simply Pref(L) = Pref≥0(L).

Finally, the left quotient of L by a finite word w is the subset w⁻¹L of Aω defined by w⁻¹L = {h ∈ Aω|wh ∈ L}.

2 Mathematical model for games

Noncooperative games, in which moves consist of simultaneous actions of n players, can be represented by a collection of n utility functions. The values of these functions define the expected amount paid to the players. A game is a tuple G = (P, A, π) where:

- P = {1, ⋯ , n}, n ∈ IN, is the set of players.
- Ai is the set of the actions for player i.
- A = A₁ × ⋯ × An is the alphabet of the moves.
- π₁ : A → IR. is the utility function for player i.
- π = (π₁, ⋯ , πₙ) : A → IRⁿ is the utility vector.

We consider in this paper the δ-discounted infinitely repeated game of G, which we note by Gω. In such a game, we model a match h as an infinite sequence of moves which can be represented by an infinite word on the alphabet of the moves A : h = h₀h₁⋯hₜ⋯ ∈ Aω.

The utility with discounting factor δ ∈ (0, 1) of a match h for player i is defined as:

\[ \pi_δ^i(h) = (1 - δ) \sum_{k=0}^{\infty} \pi_i(h_k)δ^k. \]

Example 2.1 As concerns the Prisoner’s Dilemma game, we have P = {1, 2}, A₁ = A₂ = {c, d}, A = {c, d} × {c, d} and the utility function is defined by the matrix given in the Introduction. The infinite word h = (c, c)ω is an example of a match in which the two players cooperate infinitely.
3 Strategies and languages

A nondeterministic strategy \( \sigma \) for \( G_{\omega} \), is a relation from \( A^{*} \) into \( A_{i} \) that describes the behaviour of player \( i \) during the game. A strategy vector on \( A \) is the relation \( \sigma = (\sigma_{1}, \ldots, \sigma_{n}) : A^{*} \to A \) defined by:

\[
(a_{1}, \ldots, a_{n}) \in \sigma(w) \iff a_{i} \in \sigma_{i}(w), \forall w \in A^{*}, \forall a_{i} \in A_{i}, 1 \leq i \leq n.
\]

Let \( \Sigma \) be the set of all strategy vectors on \( A \). We consider now the map \( \gamma : \Sigma \to \mathcal{P}(A_{\omega}) \), where \( \mathcal{P}(A_{\omega}) \) denotes the set of all languages in \( A_{\omega} \), which associates to each strategy \( \sigma \in \Sigma \), the language of infinite words \( \gamma(\sigma) \) given by

\[
\gamma(\sigma) = \{ h \in A_{\omega} \mid h_{0} \in \sigma(e) \text{ and } h_{t+1} \in \sigma(h_{0} \cdots h_{t}), \forall t \geq 0 \}.
\]

We also write \( \sigma \to L \) to mean that \( L = \gamma(\sigma) \).

**Example 3.1** We give a strategy for the Prisoner’s Dilemma game.

\[
\sigma(w) = \begin{cases} 
\{(c, c), (c, d)\} & \text{if } w \in (c, c)^{*} \\
\{(d, c), (d, d)\} & \text{if } w \in (c, c)^{*}(c, d) + (d, d)^{*} \\
\emptyset & \text{otherwise}
\end{cases}
\]

It is usually called the "grim-trigger" strategy. The language \( \gamma(\sigma) \) is described by the \( \omega \)-rational expression

\[(c, c)^{\omega} + (c, c)^{*}(c, d) + (d, d)^{\omega}.
\]

**Example 3.2** Consider the following strategy \( \sigma \) on the alphabet \( A = \{a, b\} \):

\[
\sigma(w) = \begin{cases} 
\{a, b\} & \text{if } |w|_{a} < |w|_{b} \\
b & \text{otherwise}
\end{cases}
\]

The language \( \gamma(\sigma) \) associated is

\[
\{h \in A_{\omega} \mid Pref(h) \in \{w \in A^{*} \mid |w|_{a} \leq |w|_{b}\}\}.
\]

We note that this language is not \( \omega \)-rational, in the sense of language theory.

**Proposition 3.3** The application \( \gamma \) is neither injective, nor surjective, when \( |A| > 1 \).

**Proof**: Let \( A = A_{1} \times \ldots \times A_{n} \) be the alphabet of the moves and let \( 1 \leq i \leq n \) such that \( |A_{i}| \geq 2 \). Let \( a_{j} \in A_{j}, 1 \leq j \leq n \), and let \( b_{i} \in A_{i}, b_{i} \neq a_{i} \).

1. \( \gamma \) is not injective. Consider the strategies \( \sigma \) and \( \sigma' \) defined as:

\[
\sigma(w) = \begin{cases} 
(a_{1}, \ldots, a_{n}) & \text{if } w \in (a_{1}, \ldots, a_{n})^{*} \\
\emptyset & \text{otherwise}
\end{cases}
\]

and

\[
\sigma'(w) = \begin{cases} 
(a_{1}, \ldots, a_{n}) & \text{if } w \in (a_{1}, \ldots, a_{n})^{*} \\
A & \text{otherwise}
\end{cases}
\]

Obviously \( \sigma(w) \) and \( \sigma'(w) \) lead to the same language.

4
2. \( \gamma \) is not surjective. Consider the language

\[
L = (a_1, \ldots, a_i, \ldots, a_n)^* (a_1, \ldots, b_i, \ldots, a_n) \omega, \quad a_i \neq b_i
\]

We claim that there is no strategy \( \sigma \in \Sigma \) verifying \( \sigma \rightarrow L \). Indeed, suppose such a strategy exists. We then have necessarily \( (a_1, \ldots, a_i, \ldots, a_n) \in \sigma((a_1, \ldots, a_i, \ldots, a_n) \epsilon) \forall t \geq 0 \), as a consequence of the expression of \( L \). Recall the definition of \( L \) given at the beginning:

\[
L = \{ h \in A^\omega | h_0 \in \sigma(\epsilon), \ h_{t+1} \in \sigma(h_0 \cdots h_t) \forall t \geq 0 \}.
\]

It implies that \( (a_1, \ldots, a_i, \ldots, a_n) \omega \in L \), because this word satisfies the required conditions, which leads us to a contradiction.

For a language \( L \), we note \( S(L) = \{ \sigma \in \Sigma | \sigma \rightarrow L \} \), the set of strategies generating \( L \).

**Definition 3.4** A language \( L \) is strategical if there exists a strategy \( \sigma \in \Sigma \) such that \( \sigma \rightarrow L \), that is if \( S(L) \neq \emptyset \).

4 **Minimal strategy**

We define on the set \( \Sigma \) of strategies on the alphabet \( A \) the order relation given by:

\[
\sigma \leq \sigma' \iff \sigma(w) \subset \sigma'(w), \ \forall w \in A^*.
\]

It is obvious to remark that for every family \( (\sigma_i)_{i \in I} \) of strategies of \( \Sigma \),

- \( \bigcap_{i \in I} \sigma_i \in \Sigma \);
- \( \bigcap_{i \in I} \sigma_i \subset \sigma_j, \ \forall j \in I \).

Among all the strategies giving a strategical language \( L \), we consider a particular one:

\[
\sigma_L = \bigcap_{\sigma \in S(L)} \sigma.
\]

We have the following result.

**Proposition 4.1** If \( L \) is a strategical language, then \( \sigma_L \) is the smallest strategy giving \( L \). It will be called the minimal strategy of \( L \).

**Proof**: It suffices to show that \( \gamma(\sigma_L) = L \). It will then be obvious that \( \sigma_L \) is the smallest one. We obtain successively:
\[\gamma(\sigma_L) = \{ h \in A^\omega \mid h_0 \in \sigma_L(\epsilon) \text{ and } h_{t+1} \in \sigma_L(h_0 \ldots h_t), \forall t \geq 0 \}\]
\[= \{ h \in A^\omega \mid h_0 \in \bigcap_{\sigma \in S(L)} \sigma(\epsilon) \text{ and } h_{t+1} \in \bigcap_{\sigma \in S(L)} \sigma(h_0 \ldots h_t), \forall t \geq 0 \}\]
\[= \{ h \in A^\omega \mid h_0 \in \sigma(\epsilon) \text{ and } h_{t+1} \in \sigma(h_0 \ldots h_t), \forall t \geq 0, \forall \sigma \in S(L) \}\]
\[= \bigcap_{\sigma \in S(L)} \gamma(\sigma)\]
\[= \bigcap_{\sigma \in S(L)} L = L.\]

Consider now the particular strategy \(\hat{\sigma}_L\) defined as follows:
\[\hat{\sigma}_L : \ A^* \rightarrow A \]
\[w \mapsto \text{Pref}(w^{-1}L).\]

**Proposition 4.2** For every language \(L \subset A^\omega\), we have \(L \subset \gamma(\hat{\sigma}_L)\).

**Proof:** Let \(h = h_0 \ldots h_t \ldots \in L\). We have successively:
\[\hat{\sigma}_L(h) = \text{Pref}_1(\epsilon^{-1}L) = \hat{\sigma}_L(\epsilon),\]
\[h_{t+1} \in \text{Pref}_1((h_0 \ldots h_t)^{-1}h) \subset \text{Pref}_1((h_0 \ldots h_t)^{-1}L), \forall t \geq 0.\]
Thus, \(h \in \gamma(\hat{\sigma}_L)\).

To characterize strategic languages of \(A^\omega\), we introduce a new operator. For all subsets \(X \subset A^\omega\), let
\[\overline{X} = \{ u \in A^\omega \mid u \text{ has infinitely many prefixes in } X \}.\]

**Example 4.3** We give the value of \(\overline{X}\) for some simple sets \(X \subset A^*\).
1. If \(X = a^*b\) then \(\overline{X} = \emptyset\).
2. If \(X = (ab)^+\) then \(\overline{X} = (ab)^{\omega}\).
3. If \(X = (a+b)^*b\) then \(\overline{X} = (a^*b)^{\omega}\)

**Theorem 4.4** \(L\) is strategic if and only if \(L = \overline{\text{Pref}(L)}\).

**Proof:** We first prove that condition is necessary. The inclusion \(L \subset \overline{\text{Pref}(L)}\) always holds.
Let now \(h \in \overline{\text{Pref}(L)}\), then \(h\) has infinitely many prefixes in \(\text{Pref}(L) = \{ w \in A^* \mid \exists x \in A^\omega : wx \in L \}\). This implies that: \(\forall n \geq 0, \exists t_n \geq n, \exists x \in A^\omega\) such that \(h_0 \ldots h_{t_n}x \in L\). We know that there exists a strategy \(\sigma\) such that \(L = \gamma(\sigma)\). Thus, \(L = \{ h \in A^\omega \mid h_0 \in \sigma(\epsilon) \text{ and } h_{t+1} \in \sigma(h_0 \ldots h_t), \forall t \geq 0 \}\). Hence: \(\forall n \geq 0, \exists t_n \geq n\) such that \(h_0 \in \sigma(\epsilon)\) and \(h_{t+1} \in \sigma(h_0 \ldots h_t)\) \(\forall i, 0 \leq i \leq t_n\). This implies \(h_0 \in \sigma(\epsilon)\) and \(h_{t+1} \in \sigma(h_0 \ldots h_t)\). Therefore \(h \in L\).

We now prove the sufficient condition, that is \(L = \overline{\text{Pref}(L)}\) then \(\gamma(\hat{\sigma}_L) = L\). By Proposition 4.2, we have only to establish the inclusion \(\gamma(\hat{\sigma}_L) \subset L\). Let \(h \in \gamma(\hat{\sigma}_L)\).
We have $h_0 \in \hat{\sigma}_L(\epsilon)$ and $h_{t+1} \in \hat{\sigma}_L((h_0 \ldots h_t)^{-1}L, \forall t \geq 0$. That is, $h_0 \in \text{Pref}_1(L)$ and $h_{t+1} \in \text{Pref}_1((h_0 \ldots h_t)^{-1}L), \forall t \geq 0$. It is clear that $h_0 \in \text{Pref}(L)$ and $\forall t \geq 0, h_0 \ldots h_t \in \text{Pref}(L)$. It implies that $h$ admits an infinite number of left factors belonging to $\text{Pref}(L)$. Then $h \in L$ since $L = \text{Pref}(L)$.

The proof that the condition of the previous proposition is sufficient implies the following result.

**Corollary 4.5** *If $L$ is strategical, then $L = \gamma(\hat{\sigma}_L)$.*

The results obtained so far can be summarized in this way:

**Proposition 4.6** *The following properties are equivalent:

- $L$ is a strategical language.
- $\gamma(\hat{\sigma}_L) = L$.
- $\text{Pref}(L) = L$.

*It is now possible to give an explicit description of the minimal strategy. In fact, for a strategical language $L$, both strategies $\hat{\sigma}_L$ and $\sigma_L$ coincide.*

**Proposition 4.7** *For a strategical language $L \subset A^\omega$, we have $\hat{\sigma}_L = \sigma_L$."

*Proof*: It suffices to show that $\hat{\sigma}_L \subset \sigma_L$. Let $w \in A^\omega$. We have $\hat{\sigma}_L(w) = \text{Pref}_1(w^{-1}L)$. Let $x \in \hat{\sigma}_L(w)$. Then $wx \in \text{Pref}(L)$. So : $\exists h \in L, \exists t \geq 0$ such that $w = h_0 \ldots h_t$ and $x = h_{t+1}$. Since $h \in \gamma(\sigma_L)$, we have necessarily $h_{t+1} \in \sigma_L(h_0 \ldots h_t)$. Thus $x \in \sigma_L(w)$.

**5 Topological impact**

We consider on the set $A^\omega$ the distance $d$ defined as follows:

$$d(x, y) = (1 + \max\{|w| \mid w \in \text{Pref}(x) \cap \text{Pref}(y)\})^{-1}$$

with the convention $1/\infty = 0$.

**Proposition 5.1** *Equipped with this distance, $A^\omega$ is a complete metric space.*

The next proposition is shown in [2,5].

**Proposition 5.2** *A language $L \subset A^\omega$ is closed if and only if $L = \text{Pref}(L)$.*

**Corollary 5.3** *$L$ is strategical if and only if $L$ is closed.*
It is usual to note $\overline{L}$ the smallest closed language containing $L$. Corollary 4.5 can be generalized to any language of $A^\omega$ in the following manner:

**Proposition 5.4** For all language $L \subset A^\omega$, we have $\overline{L} = \gamma(\sigma_L)$.

**Proof:** Since we always have $L \subset \gamma(\sigma_L)$, it is sufficient to prove that $\gamma(\sigma_L) \subset \overline{L}$.

Consider a word $h \in \gamma(\sigma_L)$. Recall that:

$\gamma(\sigma_L) = \{ x \in A^\omega | x_0 \in \sigma_L(e) \text{ and } x_{t+1} \in \sigma_L(x_0 \cdots x_t), \forall t \geq 0 \}$

We have then: $h_0 \in \text{Pref}_1(L)$ iff $\exists y_0 \in A^\omega, h_0y_0 \in L$ and $x_{t+1} \in \text{Pref}_1((x_0 \cdots x_t)^{-1}L)羟 t \geq 0$. We call $\text{Pref}_1(L)$ the set of all good matches for player $i$ in $L$. Define now the sequence $(h^{(t)}_t)_{t \geq 0}$ of words of $L$ given by $h^{(t)} = h_0 \cdots h_ty_t$. It appears clearly that it admits the word $h$ as a limit. So $h \in \overline{L}$.

6 Nash equilibrium

Intuitively, a strategy vector is a Nash equilibrium if no player has any interest in leaving his strategy, while his opponents remain faithful to theirs. Let us first introduce some basic notions, in order to give a formal definition of a Nash equilibrium. Let $\alpha = (\alpha_1, \ldots, \alpha_n) \in A$. We call $i$-variation of $\alpha$ every $\beta \in A$ such that $\alpha_i \neq \beta_i$ and $\alpha_j = \beta_j, \forall j \neq i$.

Let $X$ be a language of $A^\omega$. We call $i$-variation of a match $h = h_0h_1 \ldots h_t \ldots$ in $X$ every match $\overline{h} \in X$ for which there exists $t \geq 0$, an $i$-variation $\alpha$ of $h_t$ and a word $w \in A^\omega$ such that $\overline{h} = h_0 \cdots h_{t-1}aw \in X$.

A good match for player $i$ in $X$ is a match $h \in X$ verifying $\pi_i(h) = \pi_i(\overline{h})$ for every $i$-variation $\overline{h}$ of $h$. Denote by $\text{GM}_i(X)$ the set of all good matches for player $i$ in $X$.

**Example 6.1** Consider the language $L = (c, c)^\omega + (d, d)^\omega$. It is obvious that the words $(c, c)^\omega$ and $(d, d)^\omega$ do not admit any $i$-variation in $L$. So we have $\text{GM}_i(L) = L, \forall i = 1, 2$.

**Example 6.2** Let $L = (d, d)^\omega + (d, d)^*((c, c) + (c, d))^\omega$. This language involves the Prisoner’s dilemma game strategy in which the first player defects as far as his adversary defects and cooperates infinitely as soon as his opponent cooperates. We claim that $h = (d, c)(c, d)^\omega \in \text{GM}_2(L)$ if $\delta > 1/5$, otherwise $(d, d)^\omega \in \text{GM}_2(L)$. Indeed, let $\overline{h}$ be a 2-variation of $h$. Then $\overline{h} \in (d, d)^\omega + (d, d)^*((c, c) + (c, d))^\omega$. But, at the sight of the payment matrix given in the Introduction, we notice it pay more for the second player always to choose $d$ instead of $c$ after his first cooperation. Thus, we will only examine the 2-variations belonging to $(d, d)^\omega + (d, d)^*((c, c)(c, d))^\omega$. We obtain successively for $n \in \mathbb{N}$:
\[ \pi_2^\delta((d,d)^n(d,c)(c,d)^\omega) = (1 - \delta)(\sum_{k=0}^{n} \delta^k + \sum_{k=n+2}^{\infty} 5\delta^k) \]
\[ = (1 - \delta)[\sum_{k=0}^{n} \delta^k + 5(\sum_{k=0}^{\infty} \delta^k - \sum_{k=0}^{n+1} \delta^k)] \]
\[ = 1 - \delta^{n+1} + 5\delta^{n+2} \]
\[ = 1 + \delta^{n+1}(5\delta - 1). \]

The case of \( \overline{h} = (d,d)^\omega \) can be dropped when \( \delta > 1/5 \), because we have \( 1 + \delta^{n+1}(5\delta - 1) > 1 = \pi_2^\delta((d,d)^\omega) \). Furthermore, one can easily verify that the maximum of the function \( n \mapsto 1 + \delta^{n+1}(5\delta - 1) \) is reached for \( n = 0 \). Hence, the word \( (d,c)(c,d)^\omega \) belongs to \( GM_2(L) \).

The notion of Nash equilibrium also requires the introduction of some basic strategy vectors. Let \( \sigma = (\sigma_1, \ldots, \sigma_n) \) be a strategy vector and let \( X = \gamma(\sigma) \) be the associated language. We denote by \( \omega_i \colon A^* \to A_i \) the unpredictable strategy for player \( i \), given by \( \omega_i(w) = A_i, \forall w \in A^* \).

We define for all \( 1 \leq i \leq n \), the following strategy vectors :
\[ \mu^{(i)} = (\omega_1, \ldots, \omega_{i-1}, \sigma_i, \omega_{i+1}, \ldots, \omega_n) \]
\[ \nu^{(i)} = (\sigma_1, \ldots, \sigma_{i-1}, \omega_i, \sigma_{i+1}, \ldots, \sigma_n). \]

We denote by \( X_i \) the language \( \gamma(\mu^{(i)}) \) and by \( Y_i \) the language \( \gamma(\nu^{(i)}) \).

**Proposition 6.3** We have :
- \( X = \bigcap_{1 \leq i \leq n} X_i \);
- \( Y_i = \bigcap_{j \neq i} X_j \forall 1 \leq i \leq n. \)

**Proof.** For the first part, we obtain the succession of equations :
\[ X = \{ h \in A^\omega \mid h_0 \in \sigma(\epsilon) \text{ and } h_{t+1} \in \sigma(h_0 \ldots h_t), \forall t \geq 0 \} \]
\[ = \{ h \in A^\omega \mid h_{0,i} \in \sigma_i(\epsilon) \text{ and } h_{t+1,i} \in \sigma_i(h_0 \ldots h_t), \forall 1 \leq i \leq n, \forall t \geq 0 \} \]
\[ = \bigcap_{1 \leq i \leq n} \{ h \in A^\omega \mid h_{0,i} \in \sigma_i(\epsilon) \text{ and } h_{t+1,i} \in \sigma_i(h_0 \ldots h_t), \forall t \geq 0 \} \]
\[ = \bigcap_{1 \leq i \leq n} \gamma(\mu^{(i)}) \]
\[ = \bigcap_{1 \leq i \leq n} X_i. \]

The second part of the proof is easier, since we immediately obtain by using the lines above :
\[ Y_i = \{ h \in A^\omega \mid h_{0,j} \in \sigma_j(\epsilon) \text{ and } h_{t+1,j} \in \sigma_j(h_0 \ldots h_t), \forall t \geq 0, \forall j \neq i \} \]
\[ = \bigcap_{j \neq i} \gamma(\mu^{(j)}) \]
\[ = \bigcap_{j \neq i} X_j. \]

**Definition 6.4** A strategy vector \( \sigma = (\sigma_1, \ldots, \sigma_n) \) is a Nash equilibrium if
\[ \bigcap_{i=1}^n GM_i(Y_i) \neq \emptyset. \]
In other words, a strategy vector is a Nash equilibrium if there exists a match that represents a good match for each player in the set of matches of the others. In particular, in the case of two players, the general definition becomes:

$$GM_1(X_2) \cap GM_2(X_1) \neq \emptyset.$$ 

**Example 6.5** We consider in the Prisoner’s Dilemma game, the vector $$\sigma=(\sigma_1, \sigma_2)$$ in which both players follow the grim-trigger strategy. In this case we have:

$$X_1 = (c, c)^\omega + (c, c)^*(c, d)((c, c), (d, d))^\omega,$$

$$X_2 = (c, c)^\omega + (c, c)^* (d, c)((c, d), (d, d))^\omega.$$ 

We claim that $$\sigma$$ is a Nash equilibrium if and only if the discounting factor $$\delta \geq 1/4$$.

Indeed $$(c, c)^\omega \in GM_1(X_2) \cap GM_2(X_1)$$. Suppose $$\overline{h} = (c, c)^{k-1}(c, d)(d, d)^\omega$$ be a match with defection of the first player at the rank $$k \geq 0$$. We obtain after computations

$$\pi_1^\delta(h) - \pi_1^\delta(\overline{h}) = \delta^k(4\delta - 1).$$ 

Then $$\pi_1^\delta(h) - \pi_1^\delta(\overline{h}) \leq 0$$ if and only if $$\delta \leq 1/4$$, which proves that $$h \in GM_1(X_2)$$ whenever $$\delta \geq 1/4$$. In the same way, we can show that $$h \in GM_2(X_1)$$.

**Conclusion and perspectives**

This paper was essentially devoted to a topological characterization of the family of strategical languages. It also embeds a new definition of a Nash equilibrium that uses infinite words.

Our purpose in the future will consist of analyzing more precisely the structure of good matches sets, then the strategy vectors that admit Nash equilibria. We also wish to study mixed strategies (with probabilities). It is obvious that this kind of strategies involves the nondeterministic ones.

**References**


