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Alignment in vision-based syntactic language games for teams of robots using stochastic regular grammars and reinforcement learning: The fully autonomous case and the human supervised case

Darío Maravall [a,c,1], Jack Mario Mingo [b,*], Javier De Lope [a,c,1]

[a] Computational Cognitive Robotics Group, Department of Artificial Intelligence, Universidad Politécnica de Madrid, Spain
[b] Department of Computer Science, Universidad Autónoma de Madrid, Spain
[c] Centro de Automática y Robótica, UPM-CSIC, Madrid, Spain

HIGHLIGHTS

- We use probabilistic grammars to find a syntactical consensus in a team of robots.
- We test the model in two configurations: only-robots and human–robots.
- Syntactical alignment is attained in a small number of dialogic rounds.
- For the fully autonomous case the final syntactical alignment is arbitrary.
- For the human supervised case the final alignment is the one used by the human.

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ABSTRACT

This paper approaches the syntactic alignment of a robot team by means of dialogic language games and by applying online probabilistic reinforcement learning algorithms. The syntactic alignment is studied under two different configurations of the robot team: (a) when the team is formed exclusively by robots and (b) when a human is included in the team, in which case the human is endowed with a natural language to communicate with the other members of the team. For the two above mentioned cases, we are interested in the analysis of the convergence of the team to an optimal common language. The main contribution of the paper is the application of stochastic regular grammars, with learning capability, to generate the robots team's language. Apart from the analysis of the convergence to a common language in the case of a fully autonomous robot team without human intervention we are also particularly interested in analyzing how the syntactic alignment of the robot team can be influenced or mediated by humans. The paper is organized as follows: first, we describe the syntactic language games, in particular the type of grammar and syntactic rules of the robots team's language and the dynamic process of the language games which are based on dialogic communicative acts and a reinforcement learning policy that allows the robot team to converge to a common language. Afterwards, the experimental results are presented and discussed. The experimental work has been organized around the linguistic description of visual scenes of the blocks world type. The general conclusion of our experiments can be briefly stated in this way: "for the fully autonomous case (only robots) the final emergent grammar is arbitrary, while in the second case of including a human in the team the final emergent grammar is the one used by the human".

1. Introduction

Language, at both lexical and syntactic levels, is one of the fundamental cognitive skills necessary for the development of advanced and intelligent multi-robot systems as it allows communication and cooperation among the individuals of a robotic

* Corresponding author. Tel.: +34 91 497 2291.
E-mail addresses: dmaravall@fi.upm.es (D. Maravall), mario.mingo@uam.es (J.M. Mingo), javier.delope@upm.es (J. De Lope).
[1] Tel.: +34 913367442.

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group. In previous work, using the so called language games concept [1] which is partly inspired in the ideas of Wittgenstein and de Saussure about the public and conventional dimensions of linguistic meaning, we have applied on-line reinforcement learning algorithms to the self-emergence of a common lexicon in robot teams [2]. In that work we modeled the lexicon or vocabulary of each robot as a look-up-table mapping the *referential meanings* (i.e. the objects or situations and states of the environment) into *symbols*. In this paper we extend our previous work on multi-robot lexical alignment through language games into multi-robot syntactic alignment also through dialogic language games and we study how the syntactic alignment can be developed in two different situations. First, in a group which is made up exclusively of similar artificial robots and second in a group including a robot that acts like a human being in the sense that this special robot is endowed with a grammar and a language similar to a human speaker. We will refer to this robot as *human*. Having two different configurations we can study if the artificial syntactic alignment can be influenced or mediated by the human intervention.

2. Multi-robot syntactic alignment

Although we acknowledge the fundamental relevance of lexical competence concerning language use and meaning [3] we do also believe that compositional, structural or simply syntactic competence is vital for an agent to efficiently describe reality in a symbolic, linguistic way, so that in this paper we approach the syntactic alignment of a robot team by means of dialogic language games applying also on-line reinforcement learning algorithms. The remaining part of this paper is organized as follows. First, we describe the syntactic language games among robots, in particular the type of grammar and syntactic rules of the robots' language and the dynamic process of the language games which are based on dialogic communicative acts and a reinforcement learning policy that allows the robot team to converge to a common language. Next, we adapt these concepts in a new configuration where a human is included in the team. Afterwards, the experimental results related to each configuration are presented, discussed and compared. The experiments have been organized around the linguistic description of simple visual scenes of the block world type. A note on conclusions and future work closes the paper.

3. Syntactic alignment among robots

In a first step, alignment language games must be applied so that a team with robots gets a common lexicon for the objects present in the environment as well as a common lexicon for the spatial relationships (*right, left, front, behind*). The acquisition of the objects lexicon is performed through a fully autonomous interactive process in which the robots are able to converge to common names for the different objects perceived as sensory discriminant variables, typical of Pattern Recognition methods. This coordination process is fully autonomous and based on a reinforcement learning algorithm that controls the robot team's alignment of the mapping of names and objects besides an unsupervised clustering algorithm applied for the objects categorization. As for the acquisition of the common spatial lexicon we have applied a supervised process based on injecting to each robot the corresponding spatial concepts: *right, left, front* and *behind*. In this paper we do not describe the concrete processes behind these lexical alignments as we rather concentrate on the syntactic alignment.

After acquiring both the objects lexicon and the spatial relationships lexicon, the robot team engages in a dialogic language game aimed at converging to a common grammar as explained in the sequel.

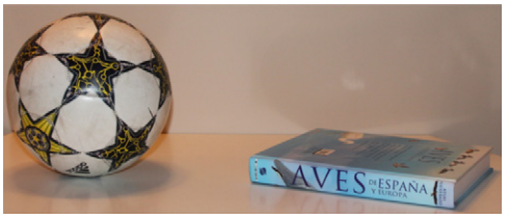

Fig. 1. Digital scene: book on the right of the ball.

Fig. 2. Digital scene: pencil on the left of the glasses.

3.1. The environment's visual description

The robots are situated in an environment that they perceive through visual sensors or video cameras. As in this paper we are mainly interested in the syntactic alignment of the robot team, we depart from linguistic sentences obtained as linguistic descriptions of the scenes captured by the robots' video cameras and after their corresponding segmentation and analysis by means of standard computer vision techniques. Under this linguistic-centered set-up we have worked with digital scenes as the ones displayed in Figs. 1 and 2.

3.2. Stochastic Learning-Grammars for visual scene description

For this kind of scenes the robots' language is formed by sentences like "*object such* is on the *spatial relation* of *object such*" or specifically "the *book* is on the *right* of the *ball*", which can be formalized as a string *aRb* where **a** and **b** are objects names and **R** is a spatial relationship. Alternative strings would be *Rab* and *abR*. These three alternatives only differ in the ordering of words. As we are interested in using a language formalism that allows the robots to learn their language by means of an interactive process, we propose to use stochastic grammars with learning capability for visual scenes description as explained in the sequel. In this regard, the probabilities associated to the production rules provide the plasticity of the robots' language by changing these probabilities by means of a reinforcement learning algorithm.

As commented above, in order to allow the robots to develop a suitable language for the description of the type of visual scenes displayed in Figs. 1 and 2 that are composed of two objects and in order to allow also the syntactic alignment of a group of robots, we propose to use stochastic grammars in which the probabilities of the production rules can be learnt by the robots through reinforcement as they engage in language games. The terminal vocabulary of the robots' language is formed by the objects appearing in the visual scenes and by the corresponding spatial relationships (*right, left, front, behind* ...). The probabilistic production rules of the proposed grammar are the following:

<sentence> ::= <object> <relation> <object> p_1
| <relation> <object> <object> p_2
| <object> <object> <relation> p_3
<object> ::= anObject
<relation> ::= aSpatialRelation