Gliders2016: Integrating multi-agent approaches to tactical diversity

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Abstract. We summarize approaches to tactical diversity, mobility and field control developed over the recent years in team Gliders, ranging from tactic-dependent evaluation and selection of players' actions, to dynamic tactics based on Voronoi Diagrams, to tactical analysis and opponent modeling with information dynamics, to a bio-inspired mechanism for dynamic repositioning. All these approaches are sufficiently generic to be applicable to other RoboCup Soccer Leagues and various team sports scenarios. The reviewed approaches have been integrated in Gliders2016 and successfully tested against benchmarks.

1 Introduction

Developers involved in RoboCup simulation leagues are able to focus their effort on multi-agent algorithms underlying collective distributed intelligence, and advance virtual Artificial Intelligence (AI) techniques at a much faster rate than fully-embodied robotic AI [1]. It is well-accepted that tactical proficiency and diversity shown in the RoboCup Soccer 2D Simulation League stand out among all RoboCup leagues: the agents demonstrate autonomous decision-making under constraints, while adapting their tactics to different opponents [2,3,4,5,6,7,8]. In this paper we summarise approaches to tactical diversity, mobility and field control developed over the recent years in team Gliders. These methods include tactic-dependent evaluation and selection of players' actions [9], tactical analysis and opponent modelling with information dynamics [10,11], dynamic tactics based on Voronoi Diagrams [12], and a bio-inspired mechanism for dynamic repositioning [13].

Gliders [9,10,12,13] is a simulated soccer team developed for the RoboCup soccer 2D simulator [14]. Gliders2012 and Gliders2013 reached the semi-finals of RoboCup in 2012 and 2013, while Gliders2014 became vice-champions of RoboCup tournament in 2014. Gliders2015 finished third in RoboCup-2015. The team code is written in C++ using *agent2d*: the well-known base code developed by Akiyama et al. [15], and fragments of released source code of Marlik [16]. Other software packages are used as well:

- *librcsc*: a base library for the RoboCup Soccer Simulator (RCSS);
- *soccerwindow2*: a viewer and a visual debugger program for RCSS;
- *fedit2*: a team formation editor for *agent2d*.

2 Action-dependent evaluation

The approach introduced in Gliders2012 [9] retained the advantages of a single evaluation metric (implemented in agent2d [15]), but diversified the evaluation by considering multiple points as desirable states. The mechanism can be contrasted with some well known constructive models used by belief revision and belief update [17]. More specifically, for any current state of the simulation $w \in W$ and a feasible agent action $a \in A$, there is a number of tactics represented by a set of desirable tactical states S. For example, a tactical state can be given by a target ball position on the field. The function mapping a state and an action to its tactic is given by

$$\mathit{tactics} : A \times W \to S \ . \tag{1}$$

Then each feasible action is rated with respect to the corresponding desirable tactical state:

$$r(a, w) = D(S = \mathit{result}(a, w), S^* = \mathit{tactics}(a, w)) \ , \tag{2}$$

where D is a simple distance metric, identical for all actions. The selected action minimizes the distance between resultant and desirable tactical states:

$$a^*(w) = \arg\min_a r(a, w) \ . \tag{3}$$

Importantly, the desirable tactical states that the player is trying to reach are not independent of actions, but rather *are* action-dependent, and this dependence is tactical. The definition (2) allows for different desirable states $S_1 = \mathit{tactics}(a_1, w) \neq S_2 = \mathit{tactics}(a_2, w)$, where $a_1 \neq a_2$. Tactics are not imposed in a top-down fashion: instead, they suggest desirable states and guide self-organization of resultant behavior [18]. Ultimately, the function *tactics* implements the *mobility* aspect of evaluation, by diversifying options of the player controlling the ball in continuing the game. The other teammates can also use this function in selecting a desirable state for their positioning. The diversification in positioning achieves both *mobility* (by enabling better passes to these teammates) and *field control* — by taking key points and blocking key directions [9].

3 Dynamic Tactics with Voronoi Diagrams

Better mobility and more comprehensive field control are critical to successful performance in RoboCup Soccer. This idea can be traced to a generic framework describing abstract spatio-temporal relationships, suggested by Dylla et al. [19] with the use of Voronoi diagrams. A Voronoi diagram is the partitioning of a plane with n points into n convex polygons such that each polygon contains exactly one point and every point in the given polygon is closer to its central point than any other [19]. This was further developed by Akiyama et al. who used a dual representation of Voronoi diagrams — the Delaunay triangulation [20,21]. Voronoi diagrams are also known to emerge as a result of parallel computation, providing an optimal spatial configuration for a robust resource distribution and quick transportation [22].

Voronoi diagrams have been naturally embedded into the tactical schemes of Gliders2014 [12], providing desirable states for action-dependent evaluation. In other words, the function $S = \mathit{tactics}(a, w)$, utilizes (i) a *Voronoi diagram*, where the n points are given by $n = 11$ positions of the opponent players at the simulation state w; (ii) a set of possible *attacking nodes* $V(a, w)$, through which the team may develop an attack further, including the Voronoi vertices (nodes), i.e. the points equidistant to three (or more) points, as well as nodes located at intersections between Voronoi segments and specific lines, e.g., offside line; (iii) *constraints* on the set $V(a, w)$, i.e., $V'(a, w) \subset V(a, w)$ (e.g., considering only nodes within a certain radius to the possible resultant state); (iv) a mechanism selecting one of the vertices in $V'(a, w)$ as the most promising attacking node, by identifying $v^*(w) = \arg\max_{v \in V'(a,w)} d(v)$, for some measure $d(v)$ [12]. The field position of the selected node $v^*(w)$ is the final outcome: $S^*(a, w) = \mathit{position}(v^*, w) = \mathit{tactics}(a, w)$.

An example and an illustration of this selection mechanism are detailed in [12].

4 Information dynamics

Starting ftom 2013, Gliders [10] utilized information dynamics [23,24,25,26,27] for tactical analysis and opponent modeling. This analysis involves computation of information transfer and storage, relating the information transfer to responsiveness of the players, and the information storage within the team to the team's rigidity and lack of tactical richness.

The *active information storage* quantifies the information storage component that is directly used in the computation of the next state of a process [23,27]: it is the average mutual information between the semi-infinite past of the process $x_n^{(k)} = \{x_{n-k+1}, \ldots, x_{n-1}, x_n\}$ (as $k \to \infty$) and its next state: $A_X = \langle a_X(n+1) \rangle_n$, where

$$a_X(n+1) = \lim_{k\to\infty} \log_2 \frac{p(x_n^{(k)}, x_{n+1})}{p(x_n^{(k)})p(x_{n+1})}. \tag{4}$$

Transfer entropy [28] is designed to detect asymmetry in the interaction of subsystems by distinguishing between "driving" and "responding" elements. The *local information transfer*, based on *transfer entropy*, captures information transmission [24] from source Y to destination X, at a particular time-step $n+1$. Specifically, the local information transfer between a source and a destination agent is defined as the information provided by the source y_n about the destination's next state x_{n+1} that was not contained in the past of the destination $x_n^{(k)}$:

$$t_{Y\to X}(n+1) = \lim_{k\to\infty} \log_2 \frac{p(x_{n+1} \mid x_n^{(k)}, y_n)}{p(x_{n+1} \mid x_n^{(k)})}. \tag{5}$$

Information transfer between two variables does not require an explicit communication channel, but rather indicates directional synchrony between the source and the destination.

Sometimes it is useful to condition the local information transfer on another contributing process W, considering the *local conditional transfer entropy* [25]:

$$t_{Y\to X|W}(n+1) = \lim_{k\to\infty} \log_2 \frac{p(x_{n+1} \mid x_n^{(k)}, y_n, w_n)}{p(x_{n+1} \mid x_n^{(k)}, w_n)}. \tag{6}$$

Computational experiments with Gliders2013 [10,11,29] verified two conjectures:

(i) *a higher information transfer* $t_{Y\to X|W}$ *from the source* Y *(e.g. dynamics of player* Y*) to the destination* X *(e.g., dynamics of another player* X*), in the context of some other dynamics* W *(e.g., the movement of the ball* W*), is indicative of a higher responsiveness of the process/player* X *to the process/player* Y*.*

(ii) *a higher rigidity* $A_{\mathbb{X}}$ *within the team is indicative of a higher dependence of players on each other, or a higher redundancy within the team's motion.*

This allowed us to identify the areas of most intense one-on-one contests, as well as the extent of dynamic interactions constraining mobility. Several detailed examples of tactical analysis are provided in [10,11,29] .

5 Bio-inspired dynamic repositioning

Building on the information dynamics measures, it is possible to investigate group behavior in complex systems, such as swarms [30]. Constraints on mobility, identified by information dynamics, were investigated and partially overcome with bio-inspired avoidance of opponents which employ marking or blocking [6,13]. Gliders2015 utilized a well-known element of flocking behavior: repulsion or separation, attempting to keep each player's position as close as possible to that suggested by a specific tactical scheme, while incorporating slight variations in order to maximize the chances of receiving the pass and/or shoot at the opponent's goal.

The flocking behavior used by Gliders allows the players to achieve a high degree of coherent mobility: on the one hand, the players are constantly refining their positions in response to opponent players within a certain interaction zone (being sensitive to the opponent players), but on the other hand, the repositioning is not erratic and the players move in somewhat predictable ways. This achieves a balance between sensitivity and predictability which is typical of guided self-organization and coherent behavior [18,26,31,32].

Typically, swarming agents follow three different types of forces: repulsion (separation), attraction (cohesion), and orientation (alignment). Each agent responds to other agents located within a local interaction zone with the radius r.

The swarming behaviour defined for repulsion (separation) is quite simple: to move directly away from neighbors located within a local interaction zone with the radius r. The repulsion of the agent X from opponent Q located within the radius r, at the distance $d_Q \leq r$, can be defined by the squared relative distance:

$$g_Q = \left(\frac{r - d_Q}{r} \right)^2 . \tag{7}$$

The overall repulsion vector $\mathbf{X}$ is calculated as the (weighted) sum of all unit vectors from the "interacting" neighbours to the agent X:

$$\mathbf{X} = \sum_{Q: d_Q \leq r} g_Q \frac{\mathbf{QX}}{d_Q}, \tag{8}$$

where $\mathbf{QX}$ is the vector from Q to X. A detailed example and C++ code implementing this simple behavior are provided in [13].

6 Conclusion

This integrated approach has been successfully applied to opponent modeling and selection of the best available tactics in an opponent-specific way. The overall framework may be useful for analysis of tactical diversity, mobility and field control in different multi-agent team sports, where dynamic interactions shape performance both locally and globally, as well as for analysis of general distributed dynamics, e.g., decentralized coordination [33,34], optimal distributed decision making [35], swarm engineering [30], reconfigurable sensor networks [36], and modular robotics [37,38].

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