A Structural Language for Multilevel Dynamics in the Design of Robot Soccer Systems

Conference or Workshop Item

A Structural Language for Multilevel Dynamics in the Design of Robot Soccer Systems

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Abstract

Relational structure is ubiquitous in complex systems but very hard to implement in machines. Traditionally relational structures were hand-crafted using logic-based methods including various relational approaches to pattern recognition. Today the hope is that machines will find relational structures automatically by techniques of deep learning. Both approaches require new methods for representing relational structure for dynamic complex multilevel systems. We use the platform of robot soccer to investigate these ideas. This paper follows a previous paper which presented new dynamic structures for evolving tactics and strategies in team robotics. Here the notation is extended to include structures of structures of structures. For example a red defender robot r_1 may closely mark a blue attacker robot b_2 to create a structure < r1, b_2; $R_{closely\_mark}$>. This may be part of another structure < < r_1, b_2; $R_{closely\_mark}$>, b_3; $R_{defenders\_dilemma}$ > as another robot b_3 joins in to change the relational structure. This approach is illustrated by a RoboCup simulation game. Our next step is to build a competitive player to show that the ideas are operational and may give tactical and strategic advantages.

Keywords: hypernetworks, hypergraphs, connectivity, robot soccer, design, multilevel dynamics.

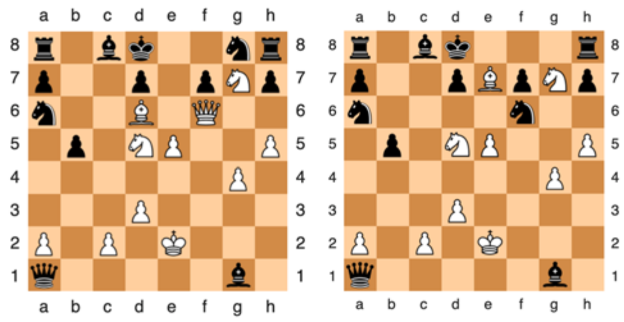
1. Introduction

A previous paper presented new dynamic structures for evolving tactics and strategies in team robotics[1]. The motivation for this research is to develop a coherent methodology for the planning, design, management and control of complex socio-technical systems such as cities, hospitals, airlines and banks, and to formulate socio-economic policy at local, national and international levels.

Team robotics provides an excellent laboratory subject for complex systems research since agent interaction can be studied 'from the outside' which avoids the complication of reflexivity when humans study human systems 'from the inside'.

The challenge of robot soccer can be simply stated as "By the middle of the 21st century, a team of fully autonomous humanoid robot soccer players shall win a soccer game, complying with the official rules of FIFA, against the winner of the most recent World Cup.[2] ". The RoboCup Simulation League used for illustration in this paper provides an excellent international platform for complex systems research.

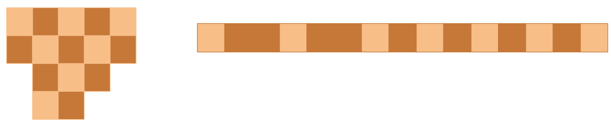
Our approach to robot soccer follows Atkin's method of analysing chess[3]. For example, Figure 1 shows the final moves in the 'Immortal Game' between Anderssen and Kierseritzky held on 21st June 1851. In this remarkable game white sacrifices most of it major pieces including the Queen on square f_6 (Fig. 1(a)). However when the black knight takes the queen the white bishop moves to square e_7 for checkmate.



(a) after Qf6+ (b) after Nxf6 and Be7#

Fig. 1. The final moves in the 1851 Immortal Game (source: https://en.wikipedia.org/wiki/Immortal_Game)

Although there are sixty-four squares on the board, only <d_5, e_5, d_6, e_6, f_6, c_7, d_7, e_7, f_7, g_7, c_8, d_8, e_8, f_8, g_8> play a part in the checkmate. We enclose them in the angular brackets < and > to show that they form a *structure*. This can be made more precise by making explicit the relation R_1 that assembles them (Fig. 2(a)). Figure 2(b) shows the squares assembled by a hypothetical relation, R_2, to form a different structure – a *row* of squares.



(a) R_1 (b) R_2

(c) R_3 R_4 R_5

Fig. 2. (a) Squares d_5, e_5, d_6, e_6, f_6, c_7, d_7, e_7, f_7, g_7, c_8, d_8, e_8, f_8, g_8 assembled by relation R_1, (b) these squares assembled by R2 into a linear structure, (c) The squares and pieces assembled into structures by the relations R_3, R_4 and R_5.

The two structures in Figure 2(a) and 2(b) can be represented symbolically as:

< d_5, e_5, d_6, e_6, f_6, c_7, d_7, e_7, f_7, g_7, c_8, d_8, e_8, f_8, g_8; R_1> and

< d_5, e_5, d_6, e_6, f_6, c_7, d_7, e_7, f_7, g_7, c_8, d_8, e_8, f_8, g_8; R_2>

As a technicality an expression of the form <a, b, c, d> is called a *simplex* and the elements a, b, c, and d are said to be its *vertices*. The expression <a, b, c, d; R> is called a *hypersimplex* since it gives not just a list of vertices but also specifies the way these elements are to be assembled into a structure – *the relational structure* made explicit by the symbol R. A collection of hypersimplices is called a *hypernetwork* [4].

In much network theory the relational structure is implicit. A major methodological requirement of hypernetwork theory is that relations must be explicit [4]. This is done by listing the vertices followed by the semicolon symbol and one or more symbols to represent the relation. E.g. Figure 2(c) includes the structure <<kNight, g_8; $R_{occupies}$>, <Queen, f_6; $R_{occupies}$>; $R_{attacks}$> meaning that the black knight can take the white queen. Black has no choice but to accept this sacrifice (Fig. 2(b)) enabling the white bishop to move to f_6 to form the structure

< <K, d_8; $R_{occupies}$>, <B, f_7; $R_{occupies}$>, <N, g_7; $R_{occupies}$>, <N, d_5; $R_{occupies}$>; $R_{checkmate}$>.

This example illustrates the multilevel nature of the representation. <kNight, g_8; $R_{occupies}$> means the structure formed by combining kNight and g_8 by the occupation relation. This structure exists independently of anything else. As a whole, <kNight, g_8; $R_{occupies}$> exists at a higher level of assembly to its parts. If the parts are said to exist at *Level N*, then the assembly <kNight, g_8; $R_{occupies}$> exists at *Level N+1*. Similarly the expression

<<kNight, g_8; $R_{occupies}$>, <Queen, f_6; $R_{occupies}$>; $R_{attacks}$>

exists at level N+2 since it assembles two *Level N+1* structures.

Even systems with small number of elements can have astronomic numbers of relational combinations. The challenge is formulate a way to represent the system in a parsimonious way. One way to do this is to *name* structures, *e.g.* let <kNight, g_8; $R_{occupies}$> = BNg8. Then BNg8 is a *Level N*+1 structure formed from the *Level N* black knight and the square g_8. <BNg8, WQf6; $R_{attacks}$> is a Level N+2 structure formed from the two *Level N+1* structures BNg8 and WQf6. This way of forming structures provides a rich structural language for the multidimensional dynamics of complex systems.

2. Fundamental elements and relationships

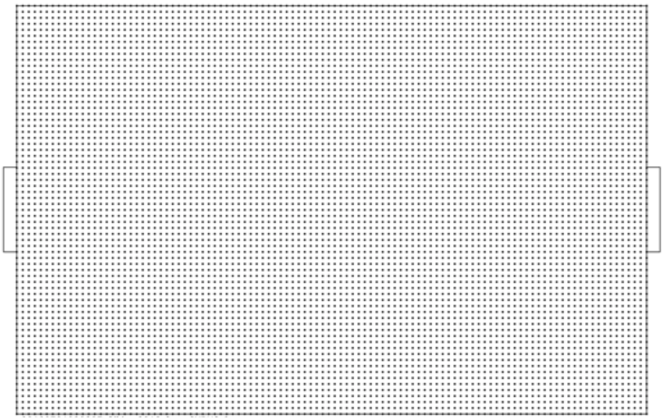


Fig. 3. The centres of the 105 x 68 soccer pitch cells

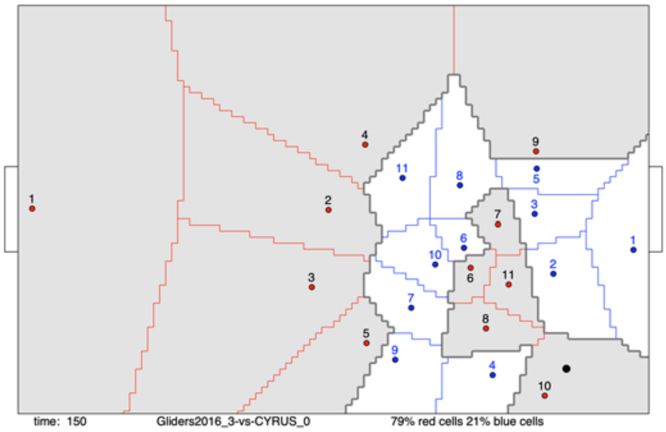
The soccer pitch is represented by a set of discrete square cells. The centres of the cells are shown in Fig. 3. The cells are *fundamental elements* of our soccer system. Others include the ball and the sets of eleven blue and eleven red soccer players.

The *fundamental relationships* include the spatial relationships between the players and the ball, and the closeness of the players and the ball to the centres of the cells. In contrast to the static ranks and files of chess, the salient areas of the pitch emerge and change rapidly in robot soccer as the players and the ball move.

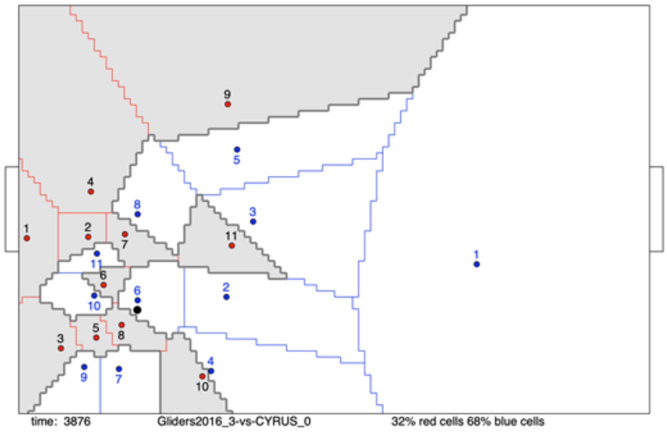
The cells closest to the players form polygons (Figs 4(a) and (b). The red team plays from left to right. The cells closest to each red player form a grey polygon with a red boundary. The polygons for the blue players are white bounded by blue lines. The ball is shown in black.

The occupation of the pitch depends on the positions of the players, *e.g.* in Figure 4(a) the red team occupies 79% of the pitch while in Figure 4(b) the blue team occupies 68% of the pitch. In general it is better for a team to occupy as much of the pitch as possible, and winning teams usually occupy the majority of the pitch for the majority of the game[5].

Figure 5 shows that in this game the red team occupied the majority of the pitch with a much greater frequency that the blue team. Red won by three goals to nil.



(a) the red team occupies 79% of the pitch



(b) the blue team occupies 68% of the pitch.

Fig. 4. Areas of the pitch as emergent features

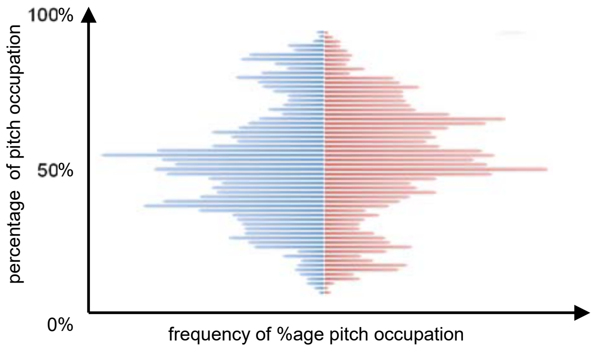


Fig. 5. During the game the red winning team occupies the majority of the pitch cells significantly more frequently than the losing blue team.

3. Analysing a robot soccer game.

Of course, it is not just pitch occupancy that matters – it is the way the players position themselves to form favourable structures. It also depends on the position and motion of the ball.

This section concerns a robot soccer game between the Gliders2016 and CYRUS teams. The data set for this consists of the x-y positions of all the players and the ball for 6000 one-tenth second ticks of the clock – games last for ten minutes. Figures 6 to 14 show a remarkable sequence of structural development that is a precursor to the red team scoring a goal. It is characterised by the creation of 'islands' of ownership and passes between the islands creating an irresistible structure from which the red team scores a goal.

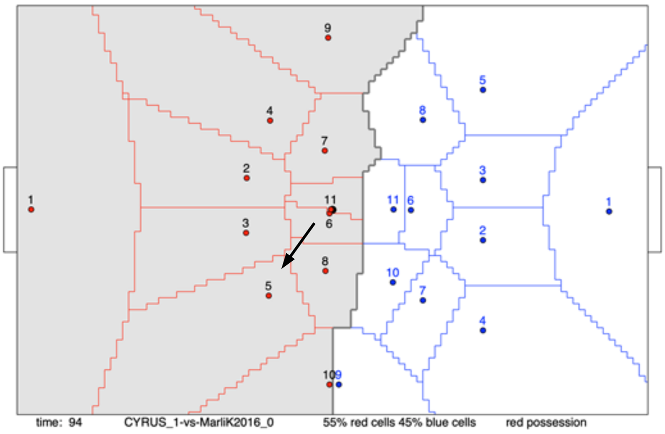


Fig. 6. time 94: < <r11, ball; ownership>, r_5; pass>

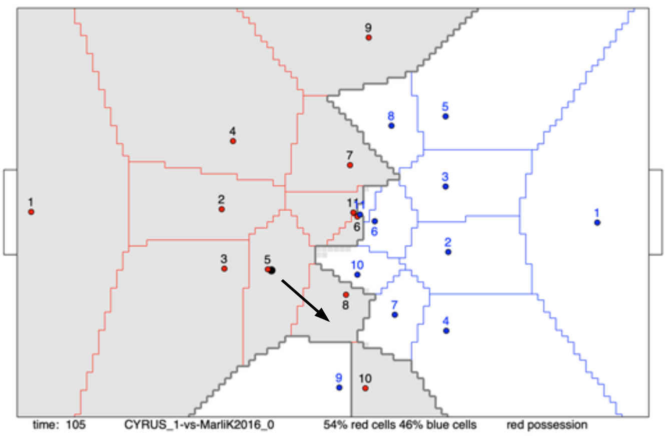


Fig 7. time 105: <<r_5, ball; $R_{ownership}$>, r_8; R_{pass}>

In Figure 6 red player number 6, denoted r_6, is at the centre for the kick-off. It possesses the ball to form the structure <r_6, ball; $R_{possession}$>. It passes to r_{11} to form the structure < <r_6, ball; $R_{possession}$>, r_{11}; R_{pass}>. This is followed by < <r_{11}, ball; $R_{possession}$>, r_5; R_{pass}>.

Two important changes occur between times 94 and 105 when r_5 receives the ball. The first is that r_6 and r_{11} move forward towards b_6 and b_{11} to form the hypersimplex <r_6, r_{11}, b_6, b_{11}; $R_{close\_together}$ > on the forward edge of red's space (Figs 6 and 7). The second is that r_{10} moves past b_9 creating an island around b_9 in red's half but also giving r_{10} a significant near-island in blue's half. At first sight this might seem to be even trade-off, but it is not since red has the initiative and the ball is moving into blue's half. Already the blue team has suffered a serious structural weakness (Figs 7 & 8).

Player r_8 receives the ball at time 114 to form the hypersimplex <r_8, ball; $R_{ownership}$>. r_{10} has moved forward to create a detached red island in blue's half, enabling the structure <<r_8, ball; $R_{ownership}$>, r10; R_{pass}>. This is a bad position with poor prospects for blue.

What happens off the ball between times 114 and 127 at the centre of the pitch is quite remarkable – b_{11} moves *towards* the red goal. This inexplicably bad move enables red to form the structure <r_6, r_7, r_{11}; R_{island}> which is very strong for red and very weak for blue. At the same time b_6 hardly moves as the red island moves past it towards the blue goal (Figs 8 and 9).

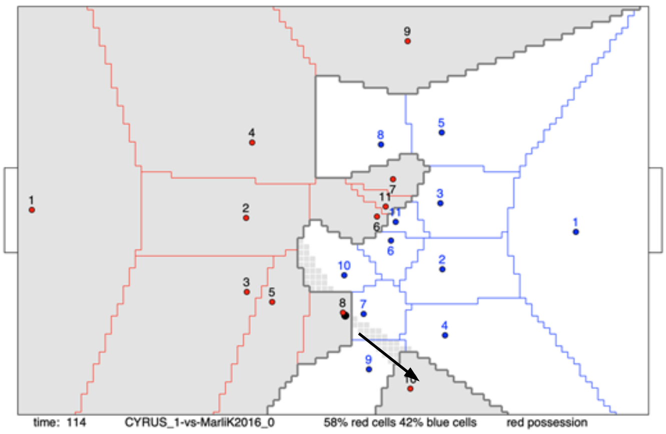


Fig. 8. time 114: <<r_8, ball; $R_{ownership}$>, r_{10}; R_{pass}>

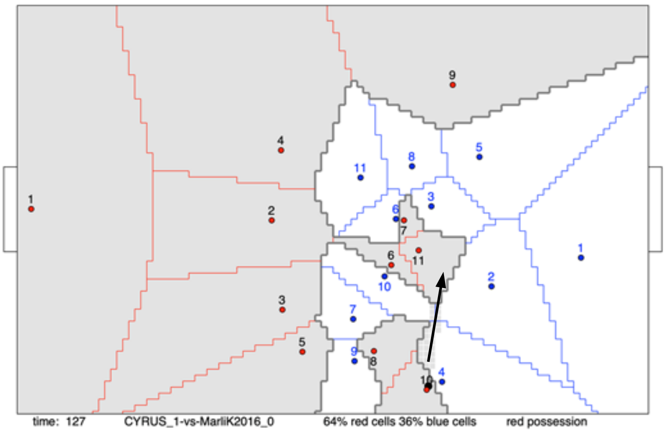


Fig. 9. time 127: <<r10, ball; $R_{ownership}$>, r11; R_{pass}>

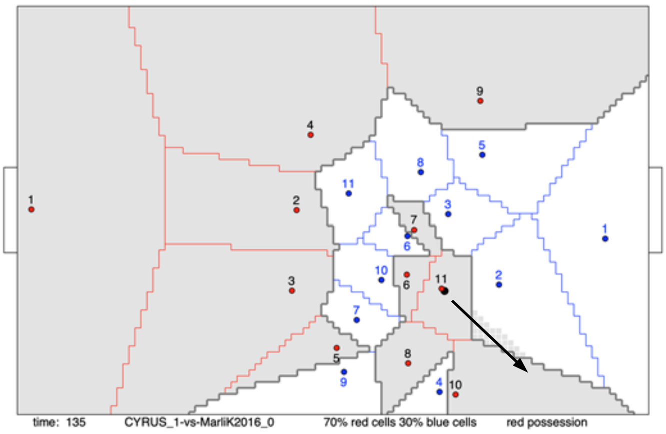


Figure 10. time135: <<r11, ball; $R_{ownership}$>, r10; R_{pass}>

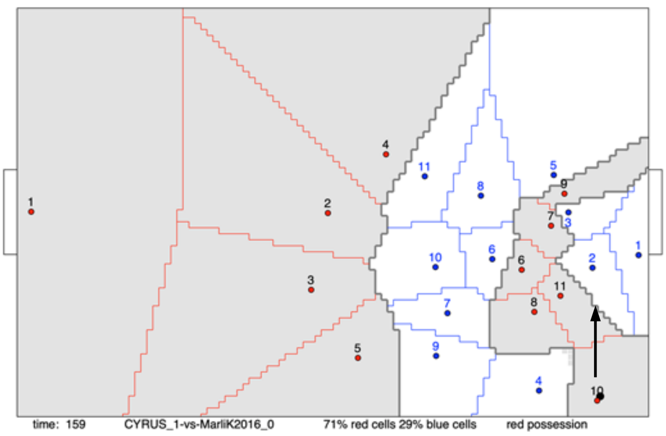


Fig.11. time 159: <<r11, ball; $R_{ownership}$>, r10; R_{pass}>

Although red is playing a very strong attacking game, between times 114 and 127, r5 moves down to deny b9 the space it enjoyed – a strong defensive move (Fig. 9).

Red presses home its attack between times 114 and 127. <r_6, r_7, r_{11}; R_{island}> occupies more of the pitch and r_8 moves fast towards r_{10} to create <r_8, r_{10}; R_{island}> on its right wing (Fig. 9).

At time 127 (Fig. 9) r_{10} receives the ball to form the structure <r_{10}, ball; $R_{ownership}$>, creating the possibility of a pass structure <<r_{10}, ball; $R_{ownership}$>, r_{11}; R_{pass}>.

Between times 114 and 127 b_4 moves towards r_{10} to try to form <r_{10}, b_4; tackle>. However (Fig. 9) b_4 encounters the *defender's dilemma*: b_4 has two choices (i) tackle r_{10} to try to gain the ball, giving r_{10} the possibility of passing to r_8 within the island <r_6, r_8; R_{island}> or passing the ball into the newly formed <r_6, r_7, r_{11}; R_{island}>, or (ii) moving away from r_{10} to try stop these passes. Here b_4 chooses to try to tackle r_{10}, but r_{10} passes the ball into the island <r_6, r_7, r_{11}; R_{island}>.

There are two defenders dilemma structures in Figure 9: <b_4, r_{10}, r_8; R_{dd}> and <b_4, r_{10}, r_{11}; R_{dd}>. The first is weak because <b_9, r_8; R_{close}> and a pass to r_8 could lose the ball. <b_4, r_{10}, r_{11}; R_{dd}> is safer and r_{10} passes to r_{11}.

Between times 127 and 135 b_4 makes the error of letting r_{10} move pass it towards the goal (Fig. 10). This gives r_{10} control of a large part of its left wing, and lets it connect with <r_6, r_7, r_8, r_{11}; R_{island}> to form <r_6, r_7, r_8, r_{11}, r_{10}; R_{island}>. Although b_4 subsequently moves back to try to improve the defensive position on red's right wing it has lost a tempo and cannot stop the advance of r_{10}.

Red's dominant structure at time 135 within blue's half is a great weakness and enables r_{11} to consider a pass to r_{10} deep in the blue half (Fig. 10).

The pass is made and r_{10} makes a fast run down the wing to receive it at time 159. By now red's position has become very strong (Fig 11).

The red island <r_6, r_7, r_8, r_{11}, r_{10}; R_{island}> is moving towards the blue goal and by time 159 has surrounded it to create a much weaker defensive island <b_1, b_2, b_3; R_{island}> with attackers outnumbering defenders by 6 to 2 (excluding the goalkeeper).

By time 170 red has an immensely superior position and following a sequence of thrilling short passes within the red attacking island, <r_{10}, r_{11}; R_{pass}> between times 159 and 170, <r_{11}, r_9; R_{pass}> between times 170 and 172, <r_9, r_7; R_{pass}> between times 172 and 174, with r_9 shooting at time 174 to create the structure <r_9, ball, blue_goal; R_{goal_scored}> (Figs 12, 13, 14) at time 180.

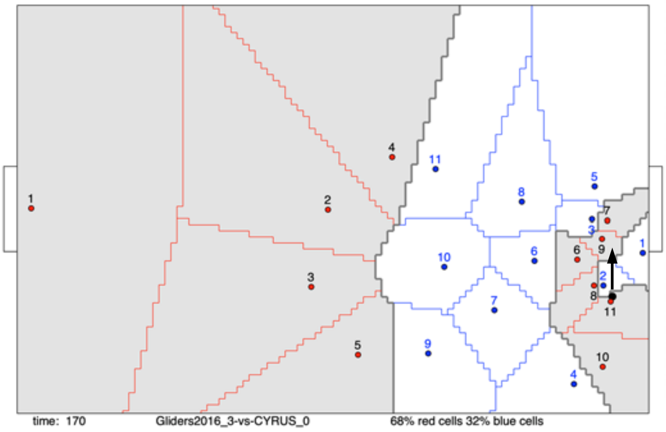


Fig. 12. time 170: $<<r_{10}, \text{ball}; R_{ownership}>, r_{11}; R_{pass}>$

Discussion

This is a sad story for blue, but could the outcome have been avoided?

Figure 15 shows a critical state in red's development at time 105. Figure 16 shows, counterfactually, that if blue players b_3, b_4, b_5, b_9 and b_{11} had moved differently between times 94 and 105 they could have denied red the structure from which it launched its attack.

In particular the movements of b_9 and b_{10} disconnect red's structure isolating r_{10} from r_5 so that the pass $<<r_5, \text{ball}; R_{ownership}>, r_8; R_{pass}>$ is no longer a feasible option. Nor is the alternative $<<r_5, \text{ball}; R_{ownership}>, r_{10}; R_{pass}>$. See the green circles in Figure 16.

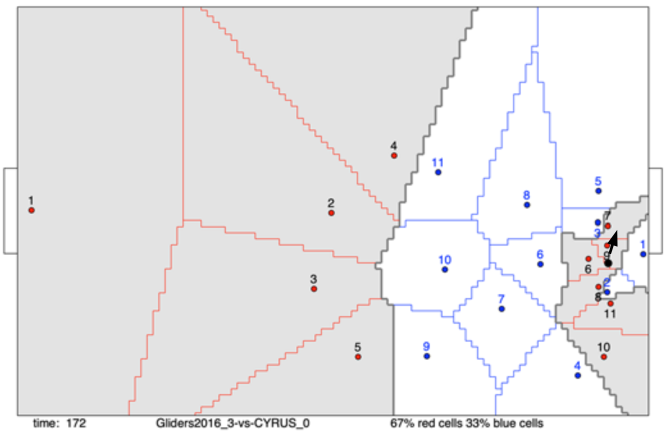


Fig. 13. time 172. : $<<r_{11}, \text{ball}; R_{ownership}>, r_9; R_{pass}>$

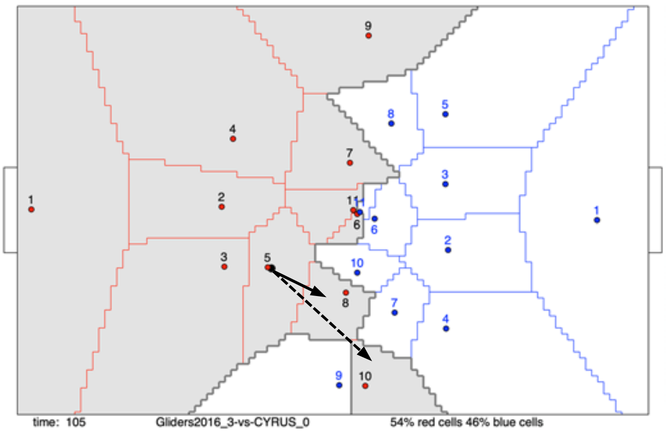


Fig. 15. The position at time 105 given in Figure 7.

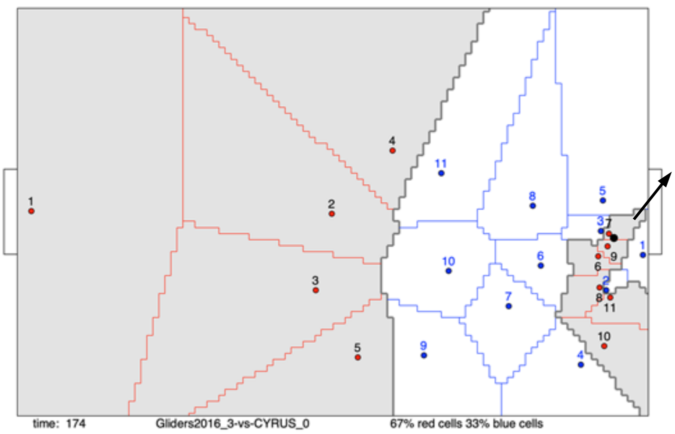


Fig. 14. time 174. : $<<r_9, \text{ball}; R_{ownership}>, r_7; R_{pass}>$

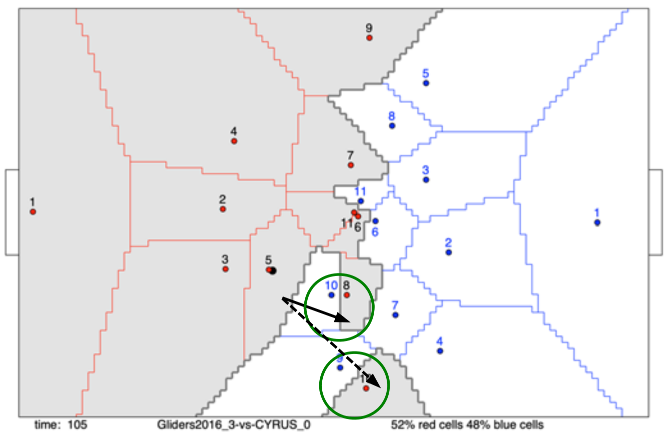


Fig.16. time 105: Counterfactual movements of b_9 and b_{10} could have disconnected the red structure and denied red the pass structure $<<r_5, \text{ball}; R_{possession}>, r_8; R_{pass}>$ and the pass structure $<<r_5, \text{ball}; R_{possession}>, r_{10}; R_{pass}>$

Figures 17 and 18 show the counterfactual outcome if blue players b_6, b_9 and b_{11} had moved differently between times 105 and 114. Then the structure would again be less favourable for the red team and deny it the pass <<r_8, ball; $R_{ownership}$>, r_{10}; R_{pass}>.

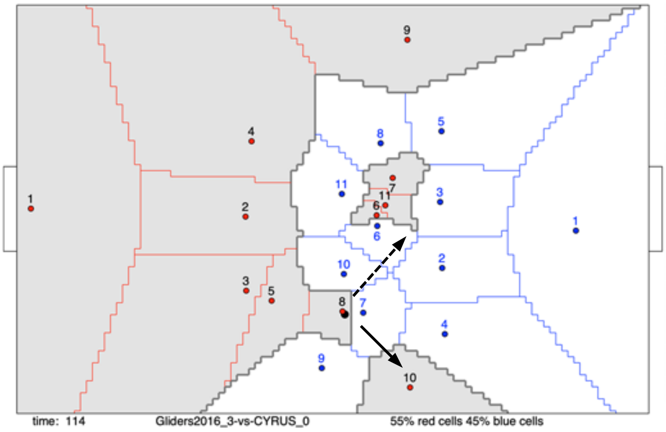


Fig. 17. The position at time 114 given in Figure 8.

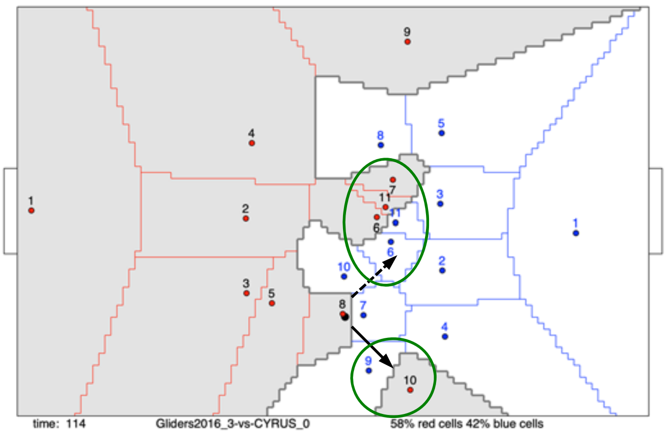


Figure 18. Counterfactually, blue can achieve a better position at time 114 if b_9, b_{10} and b_{11} move differently.

4. Conclusions

In [2] we give three research questions concerning our approach to robot soccer. The first was whether some hypersimplices are particularly disposed to scoring goals? Our recent research suggests that the ability to force a defender's dilemma indicates that teams are disposed to win [5].

In this paper we have focused on the hypersimplex notation and the requirement to make relations explicit. What is new about this is that have shown how to form higher level relational structure between lower level relational structures of the form

< <a, b, c; R_1>, < <x, y; R_2>, z; R_3>>, d, e, f; R_4 >

Also it has been shown that using this notation can be a bridge between free format speaking to analyse multilevel systems and the precise notation required for machines to manipulate the structures. This relates to the second question in [2] which concerned machine-learning the relational structure of hypersimplices. For machine learning it is necessary to have a way of representing structures that can be implemented in computers.

Our approach to robot soccer is explicitly relational and follows the approach taken by Atkin for computer chess. It has been illustrated that the highly dynamic connectivity of the relationships between the cells of the pitch, the players and the ball has an important role in robot soccer. This provides a tentative answer the third question in [2] about exploiting the multidimensional connectivity of hypersimplices to develop tactics and strategies in robot soccer.

5. Further work

Having spent a considerable effort developing the ideas presented in this and previous papers, the next step is to develop a competitive RoboCup robot soccer player. We expect to report progress on this at ICAROB 2021.

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