# Interpretation of Spatio-temporal Relations in Real-Time and Dynamic Environments

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**Abstract.** With the more sophisticated abilities of teams within the simulation league high level online functions become more and more attractive. Last year we proposed an approach to recognize the opponents strategy and developed the online coach accordingly. However, this approach gives only information about the entire team and is not able to detect significant situations (e.g. double pass, standard situations). In this paper we describe a new method which describes spatio-temporal relations between objects. This approach is able to track the objects and therefore the relations between them online so that we are able to interpret situations over time during the game. This enables us to detect the above mentioned situations. We can implement this in the online coach in order to enrich our team with high level functions. This new method is domain independent.

## 1 Motivation

The online coach is still the most effective instrument to analyze the opponent, because it can obtain all information about the simulated environment. Therefore, it is important to continue the development of the online coach which we used for the Virtual Werder team in the RoboCup 2000 tournament. In [Visser et al., 2001] we describe how the coach determines the opponent tactical formation with a neural network and how it is able to change a team formation during a match. We showed that it makes sense to recognize strategies and change the own team accordingly.

However, our approach relies on information about the opponent's team in total and is therefore not able to recognize and/or predict 'local' situations. We believe that the detection of the opponents behavior in smaller areas, e.g. a double pass or a standard situation would help to find the appropriate countermeasures. The online coach is the optimal player for the collection of this kind of information and it is obvious that the coach should be able to process the data and find the appropriate tactic for the own team. Also, the analysis should be available online as the developed methods should be able to function in a real-time environment.

In this paper we describe a new method that is able to track moving objects in real time. The idea is to detect spatio-temporal relations between objects (players and ball) in a first step and then learn from this observations whether there is a repeating pattern, e.g. an attack over the wings with a pass onto the penalty point.

A. Birk, S. Coradeschi, and S. Tadokoro (Eds.): RoboCup 2001, LNAI 2377, pp. 441–446, 2002.

Our approach is related to the work from Raines and his colleagues [Raines et al., 2000] who describe a new approach to automate assistants to aid humans in understanding team behaviors for the simulation league. This approach is designed for the analysis of games, off-line after playing, to gain new experiences for the next games. Frank and colleagues [Frank et al., 2000] presented a real time approach which is based on statistical methods. A team will be evaluated statistically but there is no recognition of team strategies.

## 2 Approach

Object motion takes place in space and time. Therefore, it is useful to describe the behavior of moving objects in terms of spatio-temporal relations. This leads to a domain independent description. Once the spatio-temporal relations between the objects are described one can interpret the behavior of moving objects in the scenario.

### 2.1 Description of Spatio-temporal Relations

A spatial relation between two objects holds during a time interval and an object motion of continuous direction and speed also has a certain duration. Therefore, the idea is to describe both, the duration of objects motion as well as spatial relations holding between objects via time intervals.

The input data for the approach consists of a series of object coordinates which are updated at moments which occur within a certain time frequency. In a first step the time intervals of continuous object motion (OMI) and of duration of spatial relations between pairs of objects (SRI) have to be generated step by step at runtime.

At each moment and for each object a motion vector describes the objects displacement from the last moment to the actual by length and angle. OMIs are established for each object. As long as the length and angle of the motion vector is similar to the average length and direction of the motion vector already belonging to the actual OMI the interval is extended, otherwise a new OMI is started. The metric values for the average length and angle of the vectors are very precise but not intuitive for a human being. Therefore, length and angle within each OMI are classified to a fixed number of motion directions and speeds. The number of classes to be distinguished depends on the application. For the directions a wind rose is used to specify the classes. Concerning the speeds at least two classes are necessary to distinguish objects in motion from still ones. But in most cases it is useful to distinguish more speeds. The qualitative description of an objects movement consists of a continuous sequence of OMIs covering the whole duration of existence of the object. Obviously, each OMI refers to exactly one object $O$ and has exactly one start moment $i_s$, end moment $i_e$, motion direction $\alpha$ and motion speed $v$: $i_{om} = [O\langle\alpha, v\rangle]_{i_s}^{i_e}$.

Several methods on representing spatial relations between objects have been suggested [Clementini et al., 1997, Guesgen, 1989, Schlieder, 1996] and [Zimmermann and Freksa, 1996]. In this approach a spatial relation between two objects is specified through a direction in which the second object is located and the distance between the objects. On a quantitative level a metric distance and an angle in which direction the related second object is placed is calculated. The procedure of generating time intervals of the duration of spatial relations between two objects (SRI) is the same as for the motion intervals. Due to the fact that there is a maximum distance up to that a spatial relation between two objects is taken into account at all, gaps may occur in the sequence of SRIs referring to a pair of objects. To obtain a qualitative description a fixed number of directions and distances such as *meets*, *near*, *medium* and *far* are distinguished. The wind rose in used again for the direction. Each SRI refers to exactly one pair of objects $(O_1, O_2)$ and has exactly one start moment $i_s$, end moment $i_e$, location direction $l$ and displacement $d$: $i_{sr} = [O_1\langle l, d\rangle O_2]_{i_s}^{i_e}$.

The relationship between the time intervals – OMI and SRI – are described using the seven temporal relations *before, meets, overlaps, starts, during, finishes* and *equals* and their inverse described in [Allen, 1981]. Any scenarios of moving objects can be described by use of OMIs and SRIs which are temporally related.

## 2.2 Interpretation of Spatio-temporal Relations

The first step to interpret scenarios with moving objects is to identify the concepts a human observer uses to describe the movement of objects. Then the concept is split into OMIs and SRIs and the temporal relations between these time intervals are described. This leads to a definition of the concept in terms of spatio-temporal relations and makes it possible to identify the concept within a scenario.

Elementary concepts describing simple motion events are domain independent and build a basis for the construction of more complex events. Complex events are often domain specific and are described as a combination of simple events.

The entire set of simple events can be divided into groups according to the number of involved SRIs and OMIs and their temporal relations. The following group of simple events includes two objects that are spatial related and may move within duration of the spatial relation, i.e. three overlapping time intervals are involved:

$$i_{sr} = \Big[O_1\langle l_1, d_1\rangle O_2\Big], i_{om_1} = \Big[O_1\langle \alpha_1, v_1\rangle\Big], i_{om_2} = \Big[O_2\langle \alpha_2, v_2\rangle\Big] \qquad (1)$$

To distinguish and recognize the different simple events belonging to one group the attributes motion direction, speed, direction of spatial location and distance have to fulfil certain constraints, e.g.:

- Two objects *meet* each other: $d_1 = meets$.
- $O_1$ is *approaching* $O_2$ ($app(O_1, O_2)$): $v_1 > 0 \wedge \alpha_1 = l_1 \wedge v_2 = 0$.
- $O_1$ is *departing* from $O_2$ ($dep(O_1, O_2)$): $v_1 > 0 \wedge opposite(\alpha_1, l_1) \wedge v_2 = 0$.

In the same manner it is possible to define constraints for objects moving in parallel or following each other.

In addition to this there are several further groups of simple events that are not mentioned in this paper.

## 3 Application and Results

In this section we explain the usage of simple events to interpret the behavior of the players in a soccer match to support the coach. Each simple event lasts at least from one simulation cycle to the next. The cycles are snapshots of the match that build the boundaries of the time intervals.

A meaningful simple event is *departing* ($dep(b,p)$), i.e. a player $p$ is passing the ball $b$. A further evaluation of the balls motion direction leads to a more detailed information whether the ball is played to the front (i.e. in direction to the opposite goal) or backward. This simple event is part of numerous complex situation such as player $p_1$ passes the ball ($b$) to player $p_2$. This situation consists of four simple events, with $p_1 \neq p_2$:

$$se_1 = meets(p_1, b) \wedge se_2 = dep(b, p_1) \wedge se_3 = app(b, p_2) \wedge se_4 = meets(b, p_2) \tag{2}$$

The temporal relations between the simple events are $meets(se_1, se_2)$, $equal(se_2, se_3)$ and $meets(se_3, se_4)$. This example shows how complex situations are constructed by using temporal related simple events. To make this interpretation more specific it is also possible to distinguish different types of players such as defenders, forwards or keeper semantically, i.e. draw conclusions from their behavior rather than taking the information provided by the soccer server.

To explain this in more detail we give an example taken from a match with 4 vs. 4 players. The example situation lasts over 60 cycles. The beginning of the situation is illustrated in fig. 1. For the next cycles we focus on the area high lighted in fig. 1. The ongoing situation is illustrated in fig. 2. The nine detailed images give a brief overview over the sequence of 60 cycles: The forward succeeds to pass the ball. Another forward of team 1 runs for the ball and tries to approach the opposite goal with the ball. This is noticed by the defenders of team 2 which move backwards and then try to stop it. One of them is approaching the forward and unfortunately there is no other forward of team 1 he could pass the ball to. The defender of team 2 takes the ball from the forward and passes it in the opposite direction. The description leads to the following interpretation

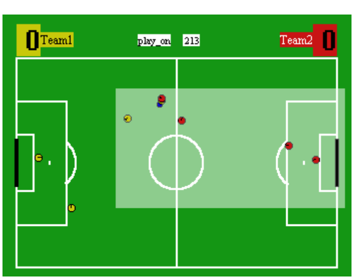
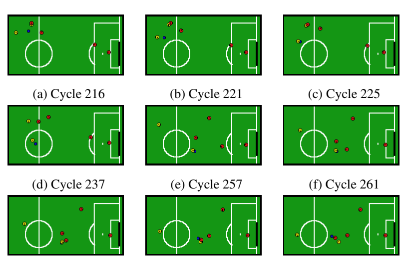



**Fig. 1.** Two players fighting for the ball



(a) Cycle 216 (b) Cycle 221 (c) Cycle 225 (d) Cycle 237 (e) Cycle 257 (f) Cycle 261 (g) Cycle 265 (h) Cycle 270 (i) Cycle 273

**Fig. 2.** defense situation

in terms of time intervals of simple events which is close to the interpretation an human observer would probably give:

- Player of team 1 and team 2 are both in meets-relation to the ball. This is interpreted as fighting for the ball (fig. 1).
- In the following time interval the ball is *departing* from both players, i.e. it is passed (fig. 2 a).
- A second player of team 1 approaches the ball (fig. 2 b).
- Then the second player of team 1 reaches the ball (*meets*) (fig. 2 c).
- The player and the ball move in direction to the opposite goal, while the spatial relation between the player and the ball is *meets* or close (fig. 2 d-f and also fig. 3 for a detailed view).
- While the player moves with the ball some players of team 2 are moving backwards. They are building up a defensive position (fig. 2 d-f).
- Then two defenders of team 2 are approaching the player with the ball, until one of them is meeting him (fight for the ball again) (fig. 2 e-g).
- The player of team 2 is still in *meets* relation to the ball whereas the player of team 1 is *close* to the ball but no more meets it, i.e. has lost it (fig. 2 h).
- At last the ball is departing from the player of team 2, i.e. he is passing the ball in the opposite direction to avoid the player of team 1 to score (fig. 2 i).

This defence strategy is typical for team 2 and occurs for several times in the game. To support the coach such situations can be detected by the sequence of time intervals described above. If the situation occurs again, it can be recognized early, so that team 1 could try another way e.g. positioning a second player near to the forward to pass the ball to when the defenders approach. For a more detailed example on how the temporal

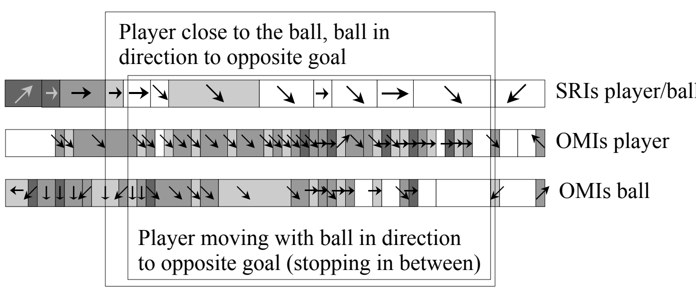



**Fig. 3.** SRIs and OMIs of the attacking player and the ball.

relations between the SRIs and OMIs are interpreted refer to fig. 3. The diagram focuses on the attacking player. It shows the SRIs between the player and the ball and the OMIs of the player and the ball. Light colors refer to small distances, dark color to large ones, white means still stands resp. meets (spatial). The arrows represent the motion direction resp. the direction in which the spatial related object (in this example the ball from the viewpoint of the player) is placed. Within the entire sequence of SRIs there is an interval in which the distance is either meets or close and the ball is placed in direction to the opposite goal (large rectangle). Within this time interval both objects – player and ball – are moving in direction to the opposite goal except for short interrupts where they stand still. This time interval is *during* the previous described interval (smaller rectangle).

## 4 Conclusion and Future Directions

We presented an approach of how objects are spatially and temporally related to others and track this over time. We showed that simple events such as $meets$, $departing$, $approaching$, $equals$ can be detected and combined to more sophisticated events. We also showed that interpretations of situations can be more specific. We argue that an implementation of this method within the online coach could enhance teams abilities.

Another interesting feature is the ability to analyze games not only online but also off-line. One of the biggest advantages of this approach is the independence from the domain. In the near future, we will also test other domains such as cell tracking in biological systems. Here, the objects are monitored with a camera and the method is able to track the objects over time and describe and store the spatial relations between them as well. However, there are also difficulties with the approach at the moment. For a human being it is relatively easy to follow a RoboCup soccer game on the monitor and see situations fluently and continuously. Because the objects are described on a discrete level it sometimes happens that the approach is not able to detect a continuous flow. For example, while attacking a goal with the ball the player is moving, kicking the ball in the goal direction and so on. However, there will be moments when either the ball or the player have no movement so that the approach terminates the continuous flow and starts a new situation. The next step with the current approach is to detect complex situations over time and learn patterns such as attack over the wing with a pass in the penalty area, double pass etc.

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