Spatio-temporal and object visualization in rugby union

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Abstract

The use of computer software as an aid to rugby, and sports coaching in general, is becoming increasingly utilized. Videoed sport is the most widely used form of raw data for sports analysis, though it is currently not being used to its full potential. Patterns of player movement and position, both for individuals and groupings of players, are important for understanding the complexities of professional team sports, and yet are not being adequately addressed.

This paper outlines a project that aims to support coaching and/or commentary by visualizing and measuring the similarity of video-derived spatio-temporal information, and enabling timely access to relevant video clips. Specifically, methods by which a user of spatially-enabled sports software can visualize spatio-temporal and rugby object information will be discussed. Two issues are examined: (1) powerful spatio-temporal representation techniques for rugby constructs (such as the pitch, players and amalgamations of players: team, scrum, lineout, backline) and (2) user interface design and how it enables rugby object representation alongside the spatio-temporal visualization facility.

Keywords: spatial, temporal, video, representation, object, rugby

Introduction

The majority of team sports are inherently spatial in nature. Consider the following example of spatial behaviour from rugby union, where a prolific try scorer has been observed to score the majority of tries on the left-hand side of the pitch from set plays such as scrums occurring at least 22 metres from the opposition try line. The opposition coach has access to a digital video archive, and would like to be able to formulate a spatial query for easy retrieval of video segments showing the prolific try scorer performing his or her pièce de résistance. Similarly, a commentator, having just seen such a try executed live, would like to be able to call up the details of all such instances for presentation and use during half-time and the post game analysis of the match.

Software exists that can process queries to retrieve timed segments of video, but the spatial aspect has been neglected, which is surprising given that videos are rich in spatial information. This paper describes a project that explores the spatial as well as the temporal potential of video input. It aims to enable real-time access to archived video footage, which is retrieved via a spatiotemporal query. A further aim is to display to users the retrieved video segment and its generalized pseudo-3D description.

This paper concentrates on the visualization aspect - spatiotemporal and object representation. The display will be in the context of designing an interface for rapidly describing spatiotemporal patterns and for conceptualizing a sports domain in terms of a hierarchy of objects. Other tasks include implementing the query and retrieval elements, developing spatiotemporal similarity techniques (which will be tested on video input) and constructing a software system to allow spatiotemporal patterns to be coded, displayed and indexed. This would be a type of Video Information System, which, as defined by Chang and Lee (1997), "manages the video input, video processing, video query, video storage and video indexing to provide a collection of video data for easy access by a large number of users". Initial progress towards creating such a system is also detailed, exemplifying how spatiotemporal and object visualization interact. Whigham (2000) describes the project proposal in more detail, and also provides a review of video manipulation, spatial similarity techniques and indexing.

Although it is acknowledged that the research described in this paper could be applied to many disciplines in which the modelling of space and time is important, the domain of rugby union has been chosen for the initial prototype. In rugby, the playing field provides the requisite spatial reference, and the time of an event is always shown on the video. Unique to rugby are complex patterns involving players, groupings of players (such as scrums and the backlines) and the referee. It is mainly this complexity that makes rugby a particularly suitable test for this research.

This paper will first provide a background; outlining the track record of existing sports software in the main and identifying where they fall short in providing a much needed spatio-temporal facility. Such a facility will subsequently be described, from the point of view of spatiotemporal and object representation and interface design. Finally a discussion will signpost what has been achieved and what is yet to be done.

Background

The use of computer software in sport is well established; this section outlines a few examples, including one case study. Video is the most common raw data source used with software for sports analysis, for example Dennis and Carron (1999); Chang and Lee (1997), which is no surprise given its ubiquity. There is also an element of technological advances enabling widespread use of digital video, in improved data storage, image processing, data compression and telecommunications (Chang and Lee, 1997). A video recording contains a large amount of data but relatively little inherent semantics. This data is delivered in an easily understood form, as video is a visually powerful medium, being largely unabstracted. When viewed, a video recording is capable of providing a great deal of information for not only sports fans, but also coaches and players.

Recently, the viewing of sport has been given extra interest, with broadcasts of footage and associated graphics over the WWW ('webcasts') and a move from what has been a passive experience to an active experience, where the user is in control (Salzberg et al., 2001). Simulations and sports games form another group of software, enabling scenario exploration as well as the entertainment element. Though falling far short of reality, simulations can satisfy "What if. . . ?" speculation at the fan level, for instance if there was disagreement with a coach's tactics (Casti, 1997).

Examples of sports software include SportsCode, KeyToAnalysis and GamePlanner. SportsCode will be presented as a case study to exemplify where current sports software falls short on a spatiotemporal basis and what may be done to remedy this.

A screen shot of SportsCode is shown in Figure 1 (SportsTec, 2002). The software is designed to capture video segments for easy future query and retrieval. This would be useful in a rugby match situation where a coach may want to capture instances of basic events such as scrums, tries and kicks. The first stage is to create 'code buttons' representing the team in possession. The featured game of New Zealand v. South Africa has the buttons 'NZ poss' and 'SA poss' defined. Subsequently buttons related to specific events were also defined - these are 'text buttons'. Once the button configuration has been finalised, a digitised video of a rugby game can be played back, during which the user marks the start and finish of a given event with a press of the relevant button. The video segment (and time interval) associated with an event is stored for later query and subsequent retrieval.

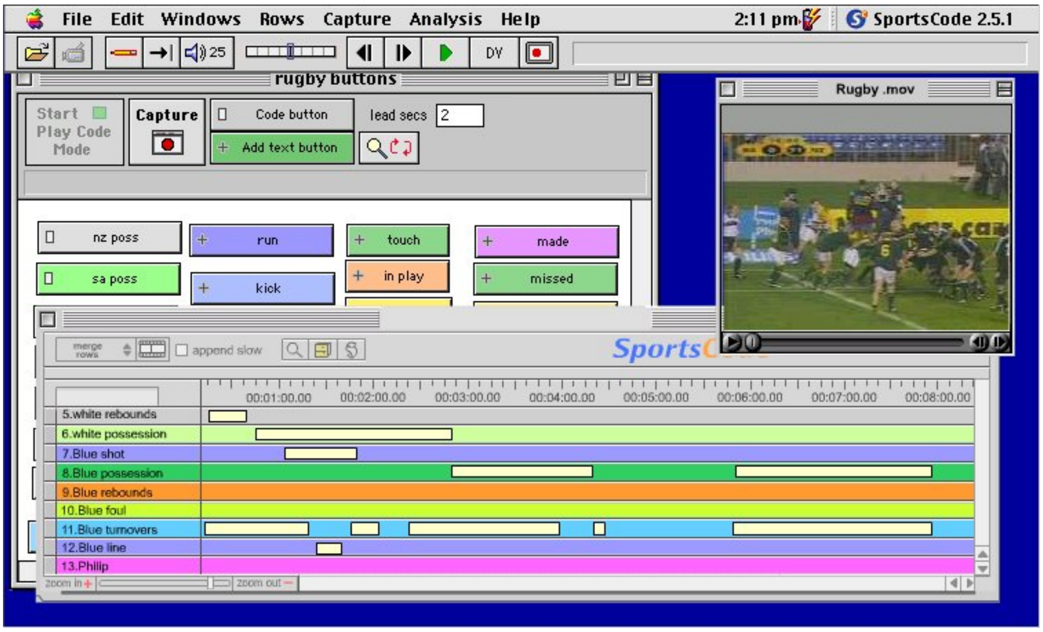

Figure 1: A screen shot of SportsCode. The user adds buttons to capture specific segments of a sports video, which are stored for future query and retrieval - (SportsTec, 2002)

SportsCode possesses a user friendly and effective interface for non-specialist usage. It has some useful features such as the use of lag time to capture events that occur too swiftly for the user to react at the video playing speed. (Lag times are pre-defined time intervals for starting video extraction before the time indicated by the first button click and ending extraction after the second button click). The invocation of the code buttons can be plotted against the instances of text buttons (e.g. tries, scrums) to produce a 2D code matrix, a display of statistics about the game. Furthermore, events can be combined (i.e. by checking for time overlap) to form a powerful query mechanism. This would enable a rugby union coach to ask for all instances of a specific scenario like a drop kick attempt that hit the post and then rebounded. In SportsCode the spatial dimension can only be implicitly represented by the configuration of buttons in the interface (e.g. in depicting a scrum and / or backline formation).

KeyToAnalysis allows the user to record event descriptions (and associated spatial locations) during a rugby game. However, this is as far as spatial capabilities stretch - there is no facility for linkage between spatial objects (Whigham, 2000). GamePlanner (GamePlanner, 2002) is designed for coaches to demonstrate game strategies to their players. It is an extension of the practice of using a whiteboard or blackboard to draw configurations and movements of players, with added support for animation and specific knowledge (e.g. in the rugby version of GamePlanner there is a facility to specify the number of players in and angle of a scrum). Other examples of software usage in sport include the investigation of aggression in sport (Kirker et al., 2000) and the teaching of sports skills (McKethan and Turner, 1999).

Unlocking Spatiotemporal Information

Shortfalls of Existing Software

In this example we contend that existing sports software goes so far, but not far enough, especially in the spatial dimension. SportsCode is good at 'propositions' (explicitly assigning attribute values to an object) but these get too numerous and cannot be programmed in advance. Considering the above drop kick example; in a query, events are grouped together through checking for overlapping time intervals, but there is no storage of sequence, so there is no way to query a drop-kick / miss / rebound / try scenario, unless coded extremely carefully with exactly such a query in mind. To introduce a spatial element, the rugby field could be divided into a 6x2 matrix (the pitch is divided along the field by the try lines, 22 metre lines and halfway line, and across the field by a line passing through the centre spot and between the posts), with each of the 12 areas mapped into a button in SportsCode. The user could then query any play in one of the centre 4 areas (i.e. between both 22 metre lines) that eventually leads to a try being scored. Without any links, there is no way of querying this, unless 'moves that lead to tries' was originally coded at a higher level of abstraction. But in this case the user has to do considerable work in coding complex relationships.

Value of a Spatiotemporal Approach

It is proposed here that a spatiotemporal approach to rugby can unlock the potential of a versatile, data rich medium such as the video. The potential for use of spatial and temporal information from video was recognised by Chang and Lee (1997). Adopting such a method would enable a move from propositions to relationships, in which events are linked in space and time. Implicit in this are patterns of player movement and position, their mode of representation and the ability to handle spatiotemporal queries. In rugby coaching, the area of systems rugby is closest to what is being proposed here, with events such as scrums and kicks depicted as boxes linked by arrows. The spatiotemporal framework enables a synoptic view of rugby, where an event is not tackled in isolation but is represented with all preceding and subsequent moves, as well as constituent objects. The next section explores visualizing rugby union in space and time.

Representation

An effective spatial and temporal representation of events on a rugby pitch is essential - removing space and time would render any event meaningless in the overall scope of the game. In spatio-temporal representation, the ideal situation is to have the mode of visualization as close to the visual richness of video as possible, but with semantics. The main reason is coach-player communication - complex ideas and strategies have to be put across from one party to the other. Depicting a rugby game in the same way as a military wall map (with arrows depicting army movements) will have a limited visual effect, even though this has been a principal means of communication for rugby coaches. This mainly results from a lack of adequate temporal visualization, where a specific arrow may have a date associated with it, but there is nothing dynamic immediately discernable to the viewer. This is a static view (a snapshot in time) that suits the medium used (i.e. paper, blackboards, whiteboards) but is ultimately restricted by it. The use of arrows are an attempt to break these constraints, and work well with simple moves. However, it would be confusing and chaotic to have all the rugby moves in a game on the same static graphic, indicating that a dynamic representation must be used to make optimum use of the resources available.

The overall temporal framework of a game is based on game time, which has certain characteristics. All games are split into one or more parts, and time is normally restarted at the beginning of each part. For instance, a normal game of rugby union is divided into two halves, lasting 40 minutes each. These parameters will change from sport to sport and even within rugby union (in the case of competitions), where equal points at the end of full time may add 10 minutes each way of extra time. Representation of this temporal framework is important, as queries may have to be made in a relative context. Relative queries may concern events that occur five minutes from the end of a game, or ten minutes from the start of a game. Such queries may be based on prior tactical knowledge about a team (a team may have a style of intense attack early in the game and so queries may be pitched relative to the start time) or common sense knowledge about athletes competing in a sport (tiredness may lead to mistakes late in the game - this would entail a query pitched relative to the end time of a game) (Whigham, 2000).

For temporal representation, a definition of an atomic event as a method of discretizing time is useful. Within a rugby game an atomic event is an episode of play between whistles, corresponding to a manageable and self-contained segment of digitized video.

A similar discretization of space could be used, producing a grid containing a set number of horizontal and vertical positions for any object (this grid is called a raster). Alternatively, location can be continuous where objects are pinpointed through coordinates relative to some point of origin (a vector representation). Within spatial representation there is a distinction to be made between global and local representation. To exemplify, the user could click on a general (or 'global') representation (such as a polygon enclosing a team) to derive 'local' representations that have more effective visualization when fewer elements are involved (e.g. Feynman diagrams - Fermilab, 2001; FO, 2002). These examples and more will be presented under the global and local types of representation.

Global Representations

Abstraction

Representation of the two teams as polygons. The two teams in a game of rugby can be represented as two contiguous and non-overlapping polygons in many play situations (especially set plays), which between them contain all the players on the pitch (Figure 2a).

There are important cases where this does not apply, most notably when the team in possession is on the break, and the two polygons (really two fronts, as the section of polygon facing away from the opposition is not important in most cases) may be intermeshed (Figure 2b). When this happens, the breaches in a front could be shown as a 'cut' in the opposition polygon, which can widen out to model the player support to the frontrunner (Figure 2c). A larger cut may indicate a greater breaking opportunity - this could be a useful query mechanism. The ultimate is a cut that divides the defending polygon in two; this is another useful query to potentially identify breakaway tries. The cut also applies (but may be a lot deeper) when there is an attacking kick, where the cut follows the line of the ball (and the ball is regarded as another 'member' of the attacking team). An analogous situation could be in the erosion of permeable rock, where the two fronts are surfaces in profile, subject to differing amounts of pressure or erosive power (dependent on the attributes of players in an attacking team).

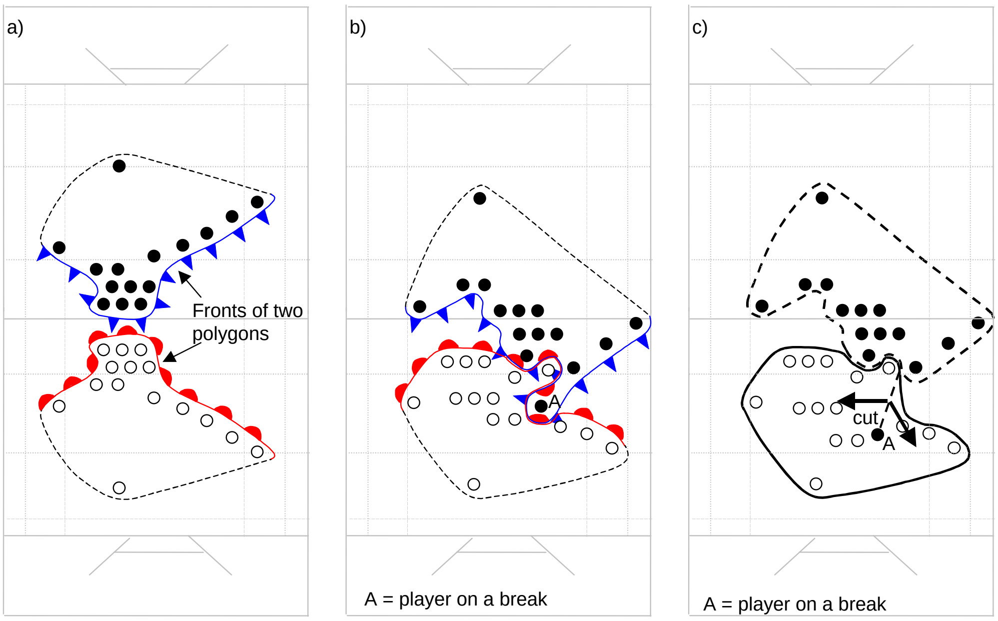

Figure 2: Examples of abstraction. (a) Teams shown as two polygons with opposing fronts (representative field positions taken from WRN, 2002); (b) Intermeshed polygons arising from an opposition break; (c) Figure 2b in terms of a polygon cut as opposed to intermeshed polygons. Arrows indicate a subsequent split of polygon

Analysis

Ideas about free space in rugby. The measurement of area between the fronts could be used to get an idea of the amount of space (and therefore time) available to a player with the ball. The player would have his or her own attributes, which would influence the area available to him or her. These 'spheres of influence' may be affected by speed, power, ability to change direction, and may be oriented. The differential strengths and weaknesses of the front (or surface) as outlined above may be correlated with the spheres of influence of the players along that front (Figure 3a). Also, the front of the opposing team (and the boundaries of the pitch) would spatially constrain any sphere of influence. The logical thing to do to lessen this constraint is to pass the ball to a player with a larger sphere of influence (which implicitly takes ability and constraints into account). In a backline this should result in the ball being passed along the line towards the wing, where there should be the most amount of space available.

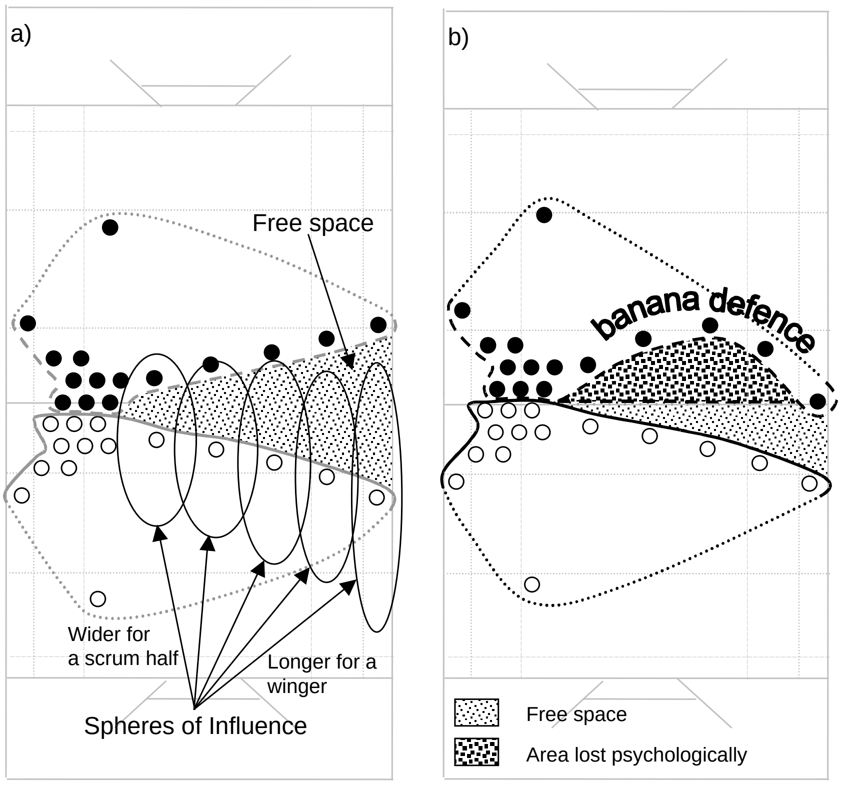

Figure 3: Examples of analysis: free space and individual player's space. a) Backline example: The free space between opposing backlines is shown, superimposed by the home backline's individual spheres of influence, which differ in orientation and size, depending on the attributes of the player; b) Psychological loss of space due to the banana defence

Rugby can be viewed in terms of trying to minimize the time and space within which the opposition has to act, giving them less time to think and move, and also forcing non-optimal play. There are ways of creating the illusion of less space to the opposition, for example in a 'banana defence' (Figure 3b). This is where the line of backs has become curved so that the winger is almost level with play. This creates the impression that the backs are more forward than they actually are. Although physically constraining space to a degree, most of the constraining effect is psychological, as the opposition perceives that they have less space than they actually have. Perhaps an area bounded by the curved backline and a straight line from pack to winger could be used to quantify the amount of space psychologically lost as a result of the banana defence.

An alternative to using spheres of influence for each player lie in Voronoi polygons to represent the space available to a given player (see Figure 4). The area within a player's polygon is closer to that player than any other player. Taking the concept further, weighted Voronoi diagrams can be used to indicate strength and directional mobility. The case of the left winger (Jonah Lomu) in Figure 4 reflects speed and strength in going forward, but also a relative weakness in going back (see Worboys (1995) for an introduction to Voronoi polygons). Finally, other ways of manipulating space include distortion along the xy plane as a function of displacement by spheres of influence. The result is similar in concept to a cartogram, a map where the size of an area is not proportional to geographic area, as is convention, but some other attribute (Dent, 1990). In this case the attribute in question is the determinant of sphere of influence size.

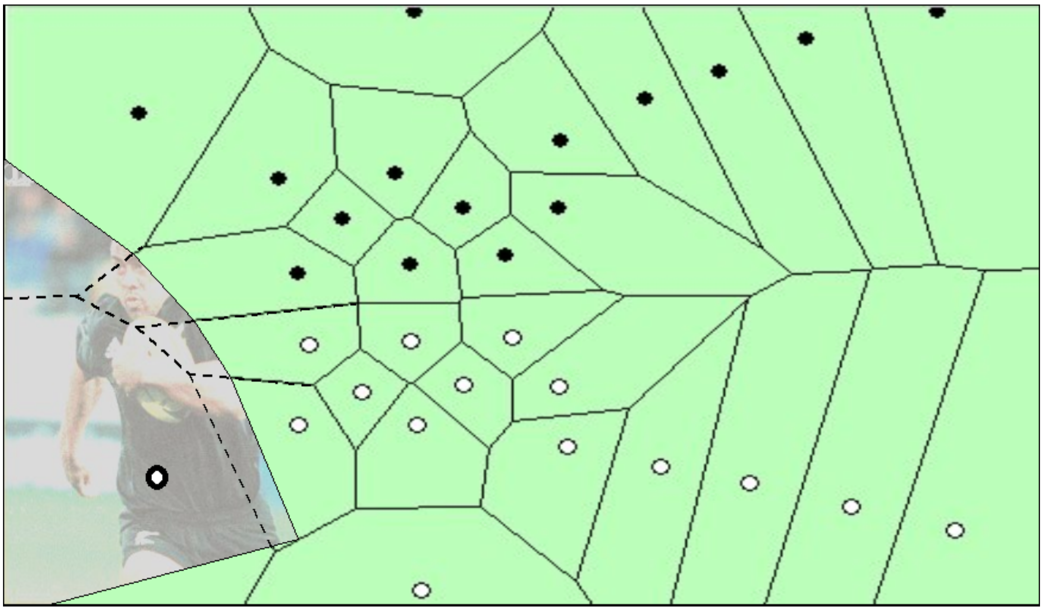

Figure 4: Using Voronoi polygons instead of spheres of influence to represent regions (home team on bottom). The case of the left winger ('Jonah Lomu') has been spatially weighted to reflect directional mobility.

Representation of the rugby field as a probability map. The maps in Figure 5 show different ways of expressing the probability of a player getting to a certain part of the pitch. A way to represent barriers and difficulty of movement is as an attribute in uniform xy space. The product would be a surface that could be superimposed on the rugby pitch (where barriers are expressed as hills and mountains) - Figure 5a. The 3D visualization of this surface could be effected by development with graphics languages such as OpenGL (within the existing Delphi development environment).

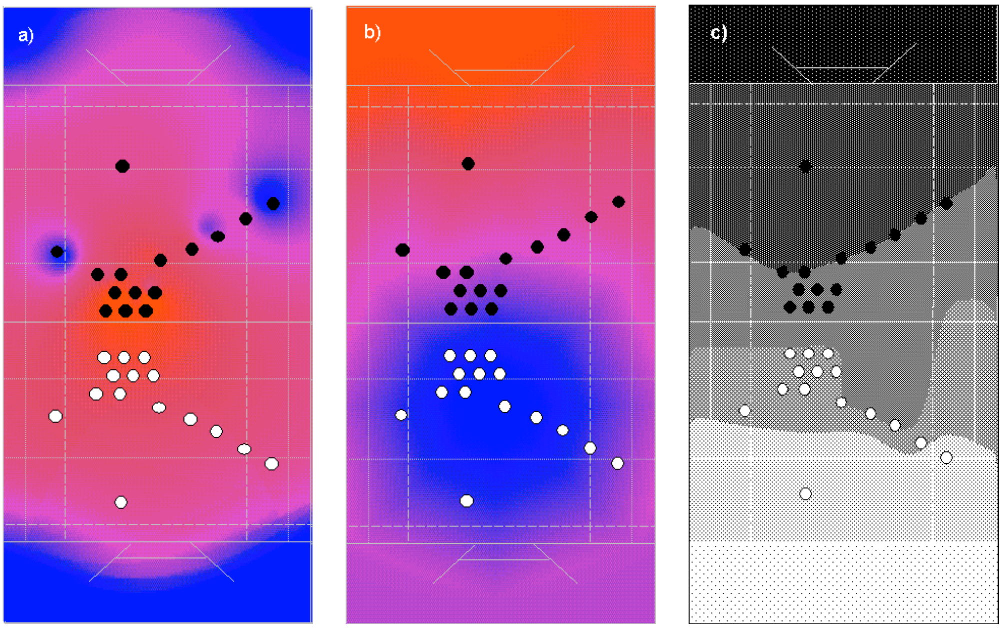

Figure 5: Examples of analysis: Probability maps. a) 2D surface showing the players' strength and speed attributes as heights above the pitch (opposing team). Barrier strength ranges from red (high) to blue (low); b) Cost surface derived from the 'elevation' surface, indicating those parts of the pitch that are easiest and (in blue) hardest (in red) to get to, from the scrumhalf's point-of-view; c) Desirability map for the white team. Desirability ranges from dark (high) to light (low).

The Voronoi representation in Figure 4 can be used to implement Delaunay triangulation. The resulting TIN (Triangulated Irregular Network) can be combined with the raster attribute values to create a space-filling map showing the same information as Figure 5a (i.e. an alternative method to the interpolation routines used to derive the rasters). From this surface a cost surface could be calculated (Figure 5b), expressing how hard it would be to get to the other side of the barrier. Closely related to this map would be a desirability map (Figure 5c), showing the most attractive areas on the rugby field to an attacking player, ranging from opposition try line being most attractive to own try line being least attractive.

Local Representations

Local representations capture situations that are too complex to represent at the global scale. The examples in this section are based on the diagrams that Richard Feynman developed to depict interactions in particle physics (Fermilab, 2001; FO, 2002).

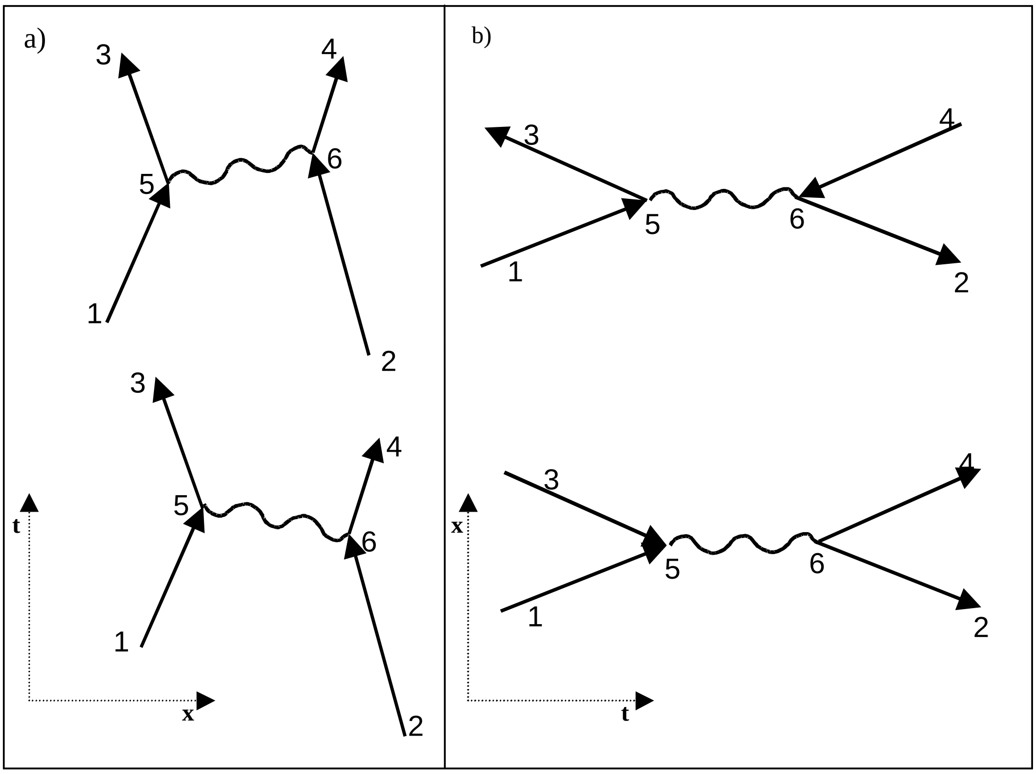

Figure 6: Local Representation: Feynman diagrams (Fermilab, 2001; FO, 2002). a) In particle physics the top diagram shows photon emission and collision. In rugby terms (bottom) a similar configuration has been used to represent a pass; b) Collision of an electron and positron to produce a photon before splitting to produce a tau minus and tau plus particle (top). The rugby interpretation (bottom) can be players converging to form a scrum, ruck, maul or tackle situation before disentangling.

Figure 6 shows two such interactions and how they could be used to describe situations in rugby. In Figure 6a, the top diagram shows an electron starting at 1, emitting a photon (wavy line) at 5, then changing direction to 3. The photon hits another electron (from 2) at 6, then changes direction to 4. The bottom diagram shows what this might represent in rugby terms. If the two electrons are players and the photon emission represents the offloading of the ball through passing (hence the changed angle of the 'photon' - though in Feynman terms the angle now indicates that it is the electron starting at 2 that emits the photon) or kicking. In Figure 6b, the top diagram shows an electron (1) and positron (3) meeting at 5, where they are obliterated, emitting a photon. At 6, a photon splits into a tau plus (4) and a tau minus (2) particle ('directions' of arrows in Feynman diagrams do not indicate direction but the type of particle). In rugby terms we may choose to ignore the direction of arrows to avoid confusion (bottom). What results is a rich representation; the initial two constructs could be the player and the ball, separate at first but joining together to achieve a special state indicated by the photon line, before parting. Alternatively, the initial constructs could be both players and the photon line represents a tackle. Finally the configuration could represent players from the same team converging to form a scrum or a ruck or maul.

Implicit in both types of interaction shown in Figure 6 is movement in two dimensions where one axis represents space (x) and the other represents time (t). In the electron - photon - electron diagram, x is left-to-right and t is upwards; in the electron/positron - photon - tau plus/tau minus diagram, x is upwards and t is left-to-right.

This representation alone may be sufficient for limited situations, but the game of rugby is a 3D phenomenon (or more if the rugby players are represented with attributes), which implies a representation that can use the second spatial dimension (y). Some attempts at a 3D Feynman representation for the rugby moves in Figure 6 have been shown (Figure 7).

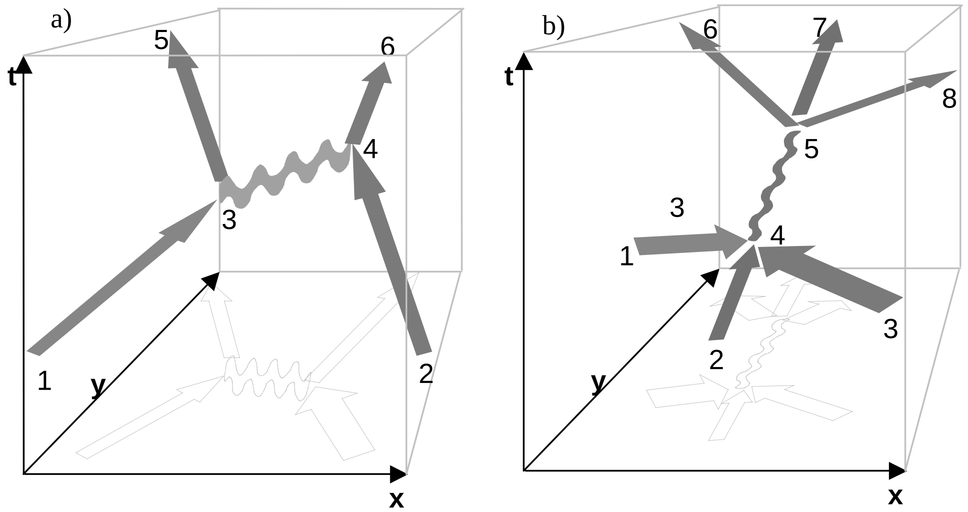

Figure 7: Local representation: 3D Feynman diagrams (arrows indicate player movement, wavy line indicates special state and xy projection is shown). a) A player (moving from 1 - 5) passes the ball at 3 and is received by a second player (moving from 2 - 6) at 4; b) Formation of a maul - players 1,2 and 3 converge at 4, move forward a little distance as a maul and disband at 5, moving to positions 6, 7 and 8 (the y axis is from end-to-end of the rugby field).

Object Representation

The Object Hierarchy

The previous means of representation depict at some level various rugby elements. These could be the polygonal configuration of an entire team, smaller groupings such as scrums, individual players and the movements of objects. Each of these elements leave a spatio-temporal footprint, but they have to be classified in some fashion so that there is an entity (which is embedded in a logical framework) onto which spatio-temporal data can be attached. This is effected through conceptual classification in terms of an object-oriented hierarchy (i.e. an ontology of rugby). In terms of object orientation, objects are instances of classes. In this case, classes can be said to be the result of breaking down the domain of rugby union into its constituent elements (see Worboys (1995) for an introduction to object orientation).

Three categories of class (mappable to a rugby element) have been defined: objects (objects that are found on a rugby field as opposed to objects in a conceptual hierarchy), actions and templates (Figure 8). Objects are elemental entities (cannot be broken down further) found in rugby, such as a player, referee and ball. Actions form a classification of object behaviour, such as pass and kick i.e. the player (object) kicks (action). Finally, templates are combinations of objects and actions, stored because such a grouping has meaning as a whole (i.e. a grouping of players to form a scrum). As well as storing recognised constructs in rugby, templates can be used as signposts to specific rugby strategies (e.g. banana defence).

The figures depict hierarchies of classes, where subclasses are said to inherit from the classes above them. For example, in Figure 8b, Kick has three subclasses: Chip, Punt and Grubber, all of which inherit the characteristics of Kick.

Similar classification activities have been observed in soccer, in the design of ToPlay software. A hierarchical model (or ‘digital rulebook’) of two parts was devised, outlining key components and application to a specific game (which is a subset of all possible moves - Salzberg et al., 2001).

The Interface

These hierarchies have been used to form part of a user-friendly interface (programmed in Delphi), designed to extract and query spatiotemporal patterns from video. This interface (called SCRUM - Spatio-Chronological Rugby Union Model) is intended emulate the simplicity and ease-of-use of SportsCode (Figure 9). Parts of the three hierarchies are displayed in the bottom-right pane. Root and child nodes can be added and named by the user, then linked to an object to place on

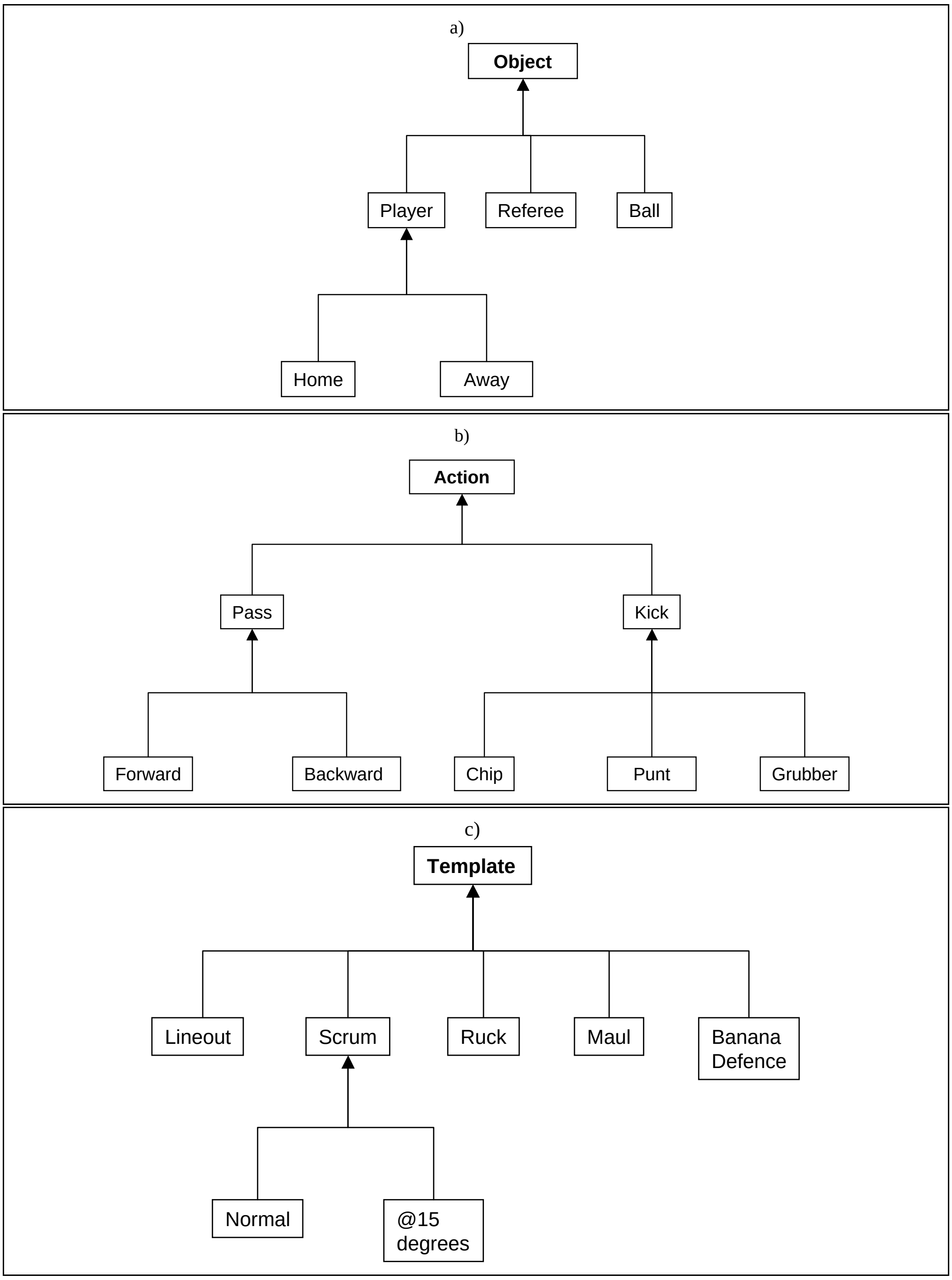

Figure 8: A selection of (a) objects (b) actions, and (c) templates found in rugby rendered in an object-oriented hierarchical arrangement, arranged by class. A class inherits the characteristics of the class above it in the hierarchy.

the pseudo 3-dimensional spatial representation of a rugby field (occupying the top-left of the interface). The rugby video clips themselves can be accessed via a database which appears bottom-left, listing clips (or atomic events) occurring in three games of the 1999 Rugby World Cup. The user can click on a record in the database and a Video Controls window will be displayed to manipulate the video (with controls such as play and slow motion). The remaining top-right pane displays the video itself, in this case showing a scrum from the Wales v. Australia game. The scrum and configuration of backs can be seen spatially on the pseudo-3D pitch and in the hierarchy, where the relevant node has been highlighted.

Figure 9: A screen shot from SCRUM, with the pseudo-3D spatial representation (with superimposed scrum and player objects) on the top left; video clip database is bottom left; video is top-right; object hierarchy is bottom-right.

Discussion and Conclusion

Sports software provides valuable facilities for visualizing and analyzing games such as rugby, mostly by using video as a raw data source. However, they ignore the rich store of spatiotemporal information implicit in a video. A prototype software system has been constructed that exploits this resource, wherein spatiotemporal patterns are coded, displayed and indexed. This paper pays particular attention to the display of objects (in a hierarchy) and the complex spatiotemporal patterns assumed by those objects during a game of rugby, distinguishing between global and local representations. It is intended that some of these visualization methods will be used to extend the existing capabilities of the software. A querying capability will be built into the interface, where the query is built up from active objects or icons such as those on the pitch plan in Figure 9. This approach is similar to the use of sketching for data query and subsequent retrieval (Egenhofer, 1997). A further task is to develop similarity measures based on the representations.

The use of video to study spatiotemporal patterns implies that objects within events have to be distinguishable and generalisable. Also there should be sufficient data captured for a number of patterns of interest to be tested. Finally and most importantly, recorded events have to be spatially and temporally referenced. The referencing schemes outlined in this paper assume that objects in a video can be pinpointed precisely using only information contained elsewhere in the video shot. For instance, photogrammetry and videography could use reference points (i.e. points that are precisely known, such as any line intersection on the pitch) to fix the position of mobile objects, video frame by video frame. An experiment with photogrammetry applied to a video still (Figure 10) has established that it is possible to adequately calculate the position of objects from long camera shots, although error increases with distance from the camera. However, the majority of rugby game video coverage employs close range action shots rather than a synoptic view, making continuous object location tracking challenging. Another factor reducing precision is object movement. A possible solution may lie in the use of software such as ToPlay (for soccer), which uses missile tracking technology to transfer ordinary footage to 3D graphics (Chaudhary, 2001), subsequently disseminated in a webcast (Salzberg et al., 2001).

In the short-term, video is the best available spatio-temporal data source, however the time will come when it is superseded by technological advances such as GPS receivers small enough to be attached to players and delivering high precision data. Anticipating such a time, in this paper we have assumed that precise and accurate coordinates will become the norm. There is already compelling evidence of progress in wearable technology, with the recent announcement of a soccer shirt that uses sewn-in devices to monitor the pace, acceleration, pulse rate, and temperature of the wearer (Fox, 2002).

For now, and from a spatial point of view, a more suitable path would be an emphasis away from precision and more towards recording and representing the topology of objects and the fuzzy spatial modeling of objects, which would have an effect on object representation. The emphasis on relative position that is associated with topology comes to the fore when describing patterns.

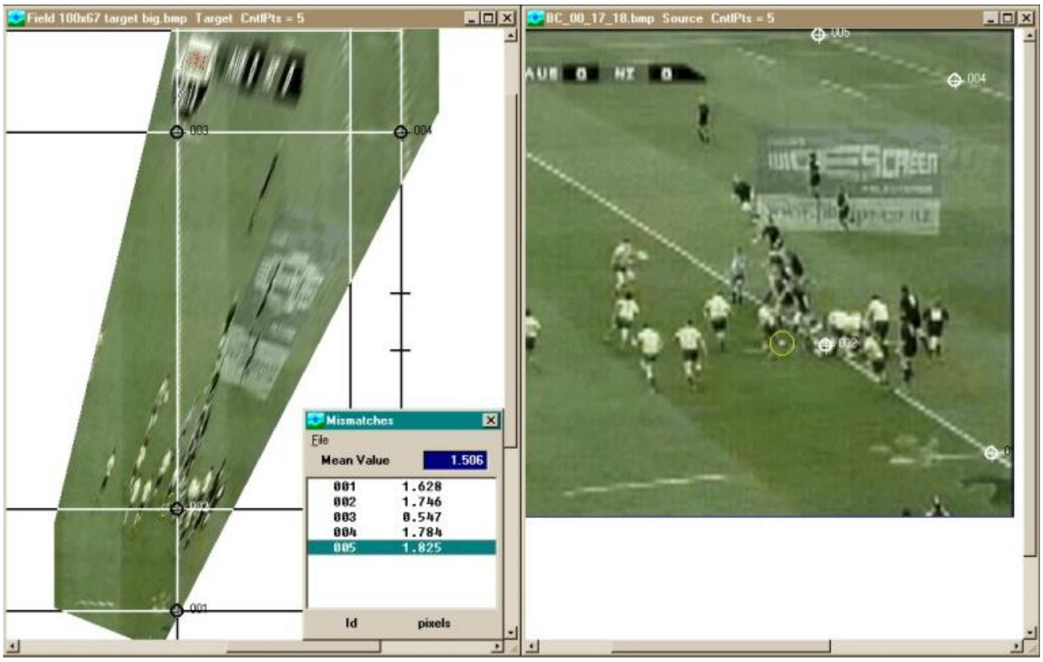

Figure 10: Using broadcast video to capture player coordinates. The right-hand pane is a single video frame marked with four control points corresponding to identifiable field locations. The left-hand pane contains the corresponding rectified image located on a (partial) pitch outline. (From 2001 Bledisloe Cup Match, Australia vs. New Zealand, Carisbrook, Dunedin.)

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