Rugby: (a) union of space and time

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Presented at SIRC 2001 – The 13th Annual Colloquium of the Spatial Information Research Centre
University of Otago, Dunedin, New Zealand
December 2nd-5th 2001

ABSTRACT

The use of computer software as an aid to rugby, and sports coaching in general, is well established. 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 measuring the similarity of video-derived spatio-temporal information, and enabling timely access to relevant video clips. Specifically, methods by which a user of spatio-temporal sports software can pose a query will be discussed. Two issues are examined: user interface form and how it enables efficient query construction; and powerful spatio-temporal representation techniques for rugby constructs (such as the pitch, players and amalgamations of players: team, scrum, line out, back line).

***Keywords and phrases*:** spatial, temporal, video, representation, query, rugby

Wales are preparing for a test match against Australia. The coach warns his team about Gregan, a prolific halfback who scored over half of Australia's tries in the previous year. The coach knows that Gregan has a habit of running the ball from set plays such as scrums at least 22 metres from the opposition try line, and breaking to score a try. The tries he scores tend to be on the left-hand side – the coach knows this and has a video archive stretching back 6 years that contain games in which Gregan has played. Although the Welsh coach could probably quite swiftly find all the instances of Gregan's pièce de résistance within the past year or two to show his team, he has no automated way of doing this. Assuming a digital video archive, he would like to be able to formulate a query that involved a spatial element for easy retrieval of video segments with Gregan scoring a try on the left-hand side of the pitch, making a run from at least the 22-metre line. The coach has already viewed software that processes queries to retrieve timed segments of video, but here is a query that needs the spatial as well as this temporal element.

Fast-forward to the game itself, and the commentator has just witnessed and described a try by Gregan in the 8th minute down the left-hand side. The commentator has seen Gregan do this so many times before and 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…

1.0 INTRODUCTION

This paper describes a project that addresses the above situations. The project is entitled "Spatiotemporal similarity measures from video input" and aims to enable real time access to archive video footage, which is retrieved via a spatiotemporal query. A further aim is to display to users the retrieved video segment and its generalized 2D description. This paper concentrates on the display element - spatiotemporal representation. The display will be in the context of designing an interface for rapidly describing spatiotemporal patterns. Other tasks include 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. Initial progress towards the latter goal is also detailed. Whigham (2000) describes the project proposal, and also provides a review of video manipulation, representation, 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 back lines) and the referee. It is mainly this complexity that makes rugby a particularly suitable test for this research. Returning to the point at the start of this paragraph, the research is applicable to not just rugby, but any sport with two opposing teams, and beyond.

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 design, query building and representation. Finally a discussion will signpost what has been achieved and what is yet to be done.

2.0 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, which is no surprise given its ubiquity. A video recording contains a large amount of data waiting to be tapped but relatively little semantics behind it. This data is delivered in an easily understood form, as video is a visually powerful media, with no levels of abstraction to interpret. When viewed, the video recording is capable of providing a great deal of information for not only sports fans, but also coaches and players.

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.

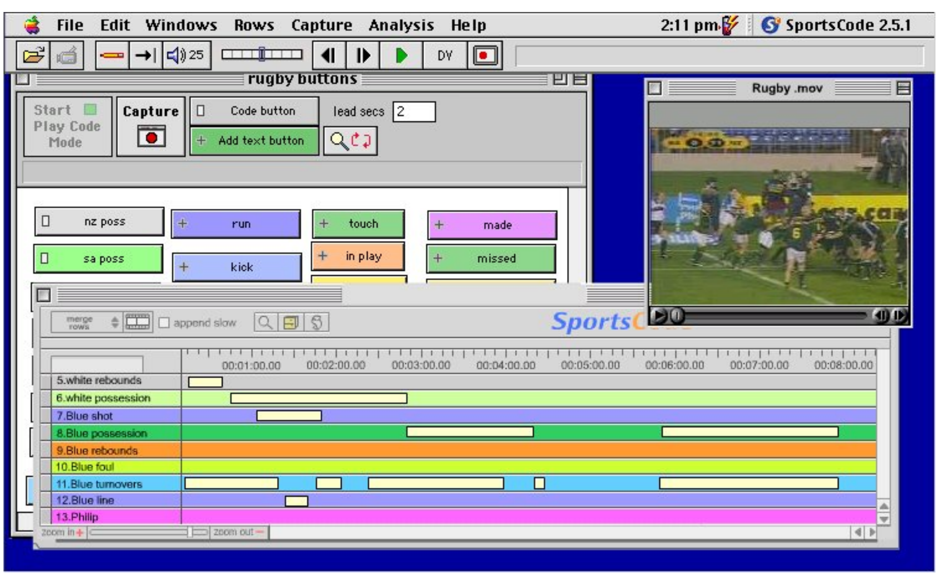

Figure 1: A screen shot of SportsCode. The user adds buttons to capture specific segments of a sports video, which are stored for future query and retrieval (SportsTec, 2001).

A screen shot of SportsCode is shown in Figure 1 (SportsTec, 2001). The software is designed to capture video segments for easy future query and retrieval. For example, in a rugby match 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, 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.

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. For example, a basketball coach could ask for all instances of a 3-point shot that was missed then rebounded. In SportsCode the spatial dimension can only be implicitly represented in the configuration of buttons in the interface (e.g. in depicting a 4-4-2 formation in soccer).

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, 2001) 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).

3.0 UNLOCKING SPATIOTEMPORAL INFORMATION

3.1 Shortfalls of Existing Software

In this simple 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 basketball 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 3pt-miss-rebound-2pt-basket scenario, unless coded extremely carefully to produce just that. Focusing now on rugby, imagine the rugby field divided into a 4x2 matrix and each of the 8 areas corresponds with a button in SportsCode. The user queries any play in one of the centre four areas that eventually leads to a try. 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.

3.2 Value of a Spatiotemporal Approach

It is proposed here that a spatiotemporal approach to rugby can unlock the potential of a versatile medium such as the video. Adopting such a method would enable a move from propositions to relationships, where 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.

3.3 The Object Hierarchy

An initial stage in establishing links between events is defining a hierarchy of event classes (i.e. an ontology of rugby). Figure 2 contains a selection of classes and their inheritance links. For example, Kick has three subclasses: Chip, Grubber and Penalty. All inherit the characteristics of Kick, but Penalty is a special case in that it is also a set play. Therefore it inherits the characteristics of Set Play through multiple inheritance (see Worboys, 1995 for an introduction to object orientation).

It is natural to think of rugby constructs in terms of object orientation – each rugby player is an entity on the pitch with their own attributes. Also, individual players can aggregate to form higher-level objects such as scrums, which may have more value for querying. For example, the scrum class may have an attribute such as inScrum, which lists all players in a scrum at a given time.

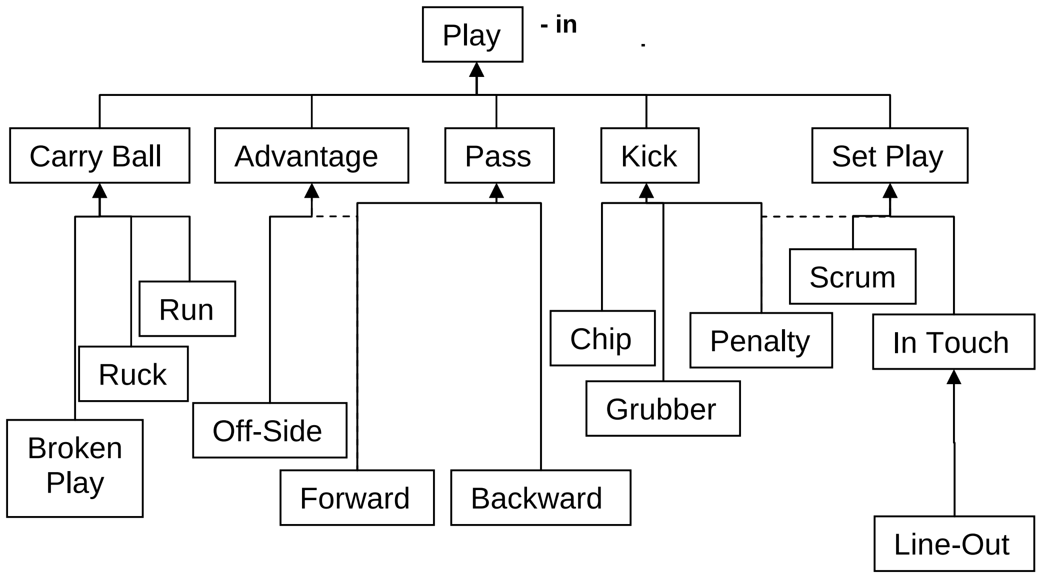

Figure 2: A selection of events as objects in rugby, arranged by class. A class inherits the characteristics of the class above it in the hierarchy. Dashed links denote multiple inheritance.

3.4 The Interface

This hierarchy has been used to form part of a user-friendly interface (programmed in Delphi), designed to extract and query spatiotemporal patterns from video. This interface is intended emulate the simplicity and ease-of-use of SportsCode (Figure 3). Part of the hierarchy is 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 the two-dimensional spatial representation of a rugby field (occupying the left-hand side of the interface). The remaining top-right pane displays a selected video (driven by the separate ‘Video Controls’ window), in this case showing a scrum from the Wales v. Australia game in the 1999 Rugby World Cup. The scrum (diamond shaped) and configuration of backs can be seen spatially on the 2D pitch and in the hierarchy, where the relevant node has been highlighted.

4.0 QUERY BUILDING

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 3. Spatiotemporal querying has historically been in the form of non-intuitive interrogation of databases with mismatched languages such as SQL (Egenhofer, 1992). Latterly, icon-based querying (e.g. Lee and Chin, 1995) and sketch-based querying has emerged. In the latter, the user sketches a map and the software retrieves the most similar cases from the database. Examples include Spatial-Query-by-Sketch (Egenhofer, 1997), latterly Sketcho (NCGIA, 2001).

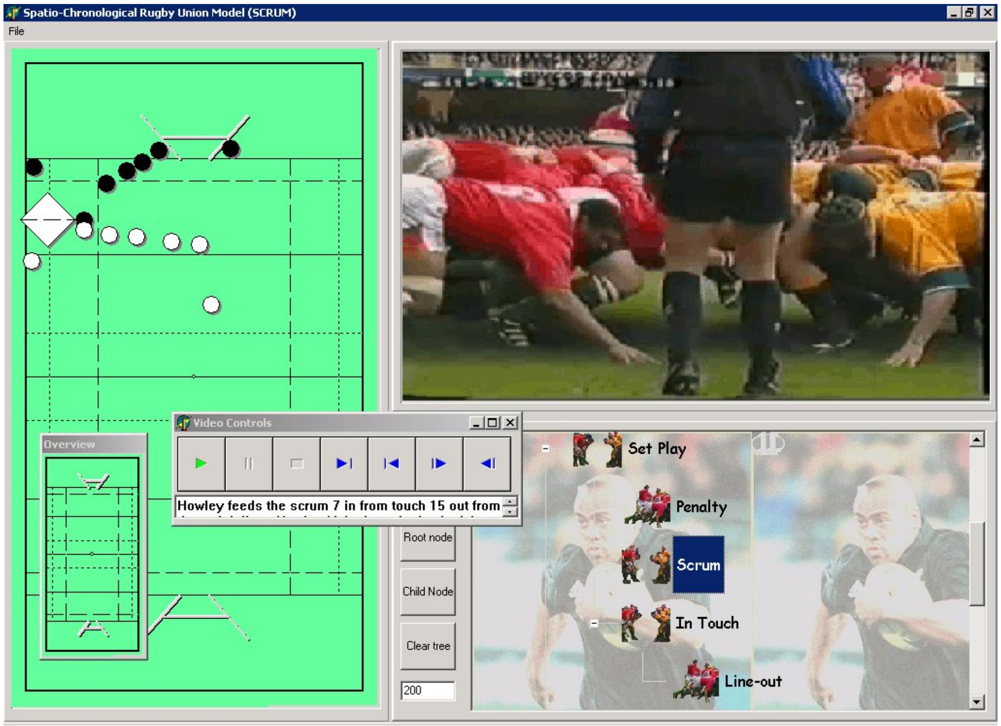

Figure 3: A screen shot from SCRUM, with the 2D spatial representation (with superimposed scrum and player objects) on the left; video is top-right; object hierarchy is

At this stage of the project we have decided to use a palette of predefined shapes (there are some examples in Figure 3) for querying, as opposed to using sketching, which is seen as a further step towards composing effective queries. Figure 4 uses a selection of objects (representing scrums, players and back lines) to demonstrate how spatiotemporal queries may be built. Figure 4a shows the start and finish positions of a back line, connected by an arrow. Figure 4b uses solid arrows to depict the movement of two opposing players (and subsequent crossing of paths). Finally, the Figure 4c query comprises a two-frame snapshot capturing an instance of broken play and a subsequent break to score a try.

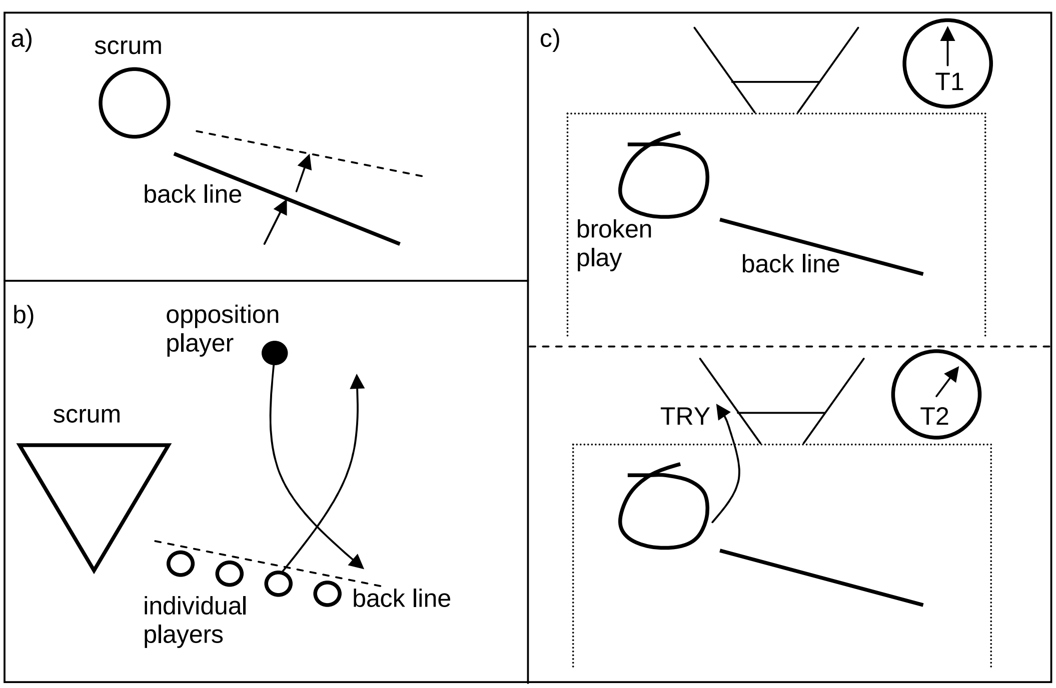

Figure 4: Various methods of graphical querying. a) start and end point of back line with arrow; b) using solid arrows to depict movement of players; c) drawing a scene at two times, T1 and T2.

5.0 REPRESENTATION

An effective spatial and temporal representation of events on a rugby pitch is essential; the mode of visualization must almost be as visually rich as the video itself – but with semantics. The main reason is coach-player communication – complex ideas and strategies have to be put across. Depicting a rugby game in the same way as a military wall map (with arrows depicting army movements) will not work. This principally results from a lack of adequate temporal visualization therein: a specific arrow may have a date associated with it, but there is nothing immediately discernable to the viewer. This is a static view that suited but was restricted by the medium used. It would be messy and confusing to have all the rugby moves in a game on the same static graphic, indicating that a dynamic representation must be used.

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

Within 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, FeynmanOnline, 2001). These examples and more will be presented using these two groupings.

5.1 Global Representations

5.1.1 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 5a).

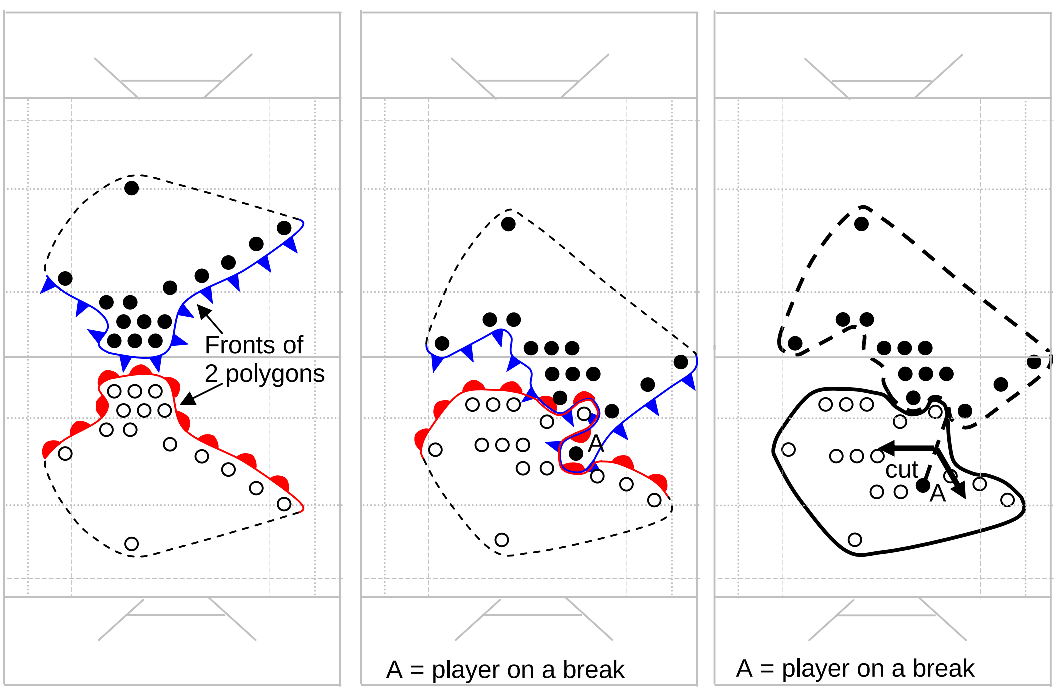

Figure 5: Examples of abstraction. a) Teams shown as two polygons with opposing fronts (representative field positions taken from World Rugby Network, 2001); b) Intermeshed polygons arising from an opposition break; c) Figure 5b in terms of a polygon cut as opposed to intermeshed polygons. Arrows indicate subsequent split of polygon.

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 5b). 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 5c). 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 (dependant on the attributes of players in an attacking team).

5.1.2 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 own attributes, which would influence the area available to him. 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 6a). 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 back line this should result in the ball being passed along the line towards the wing, where there should be the most amount of space available.

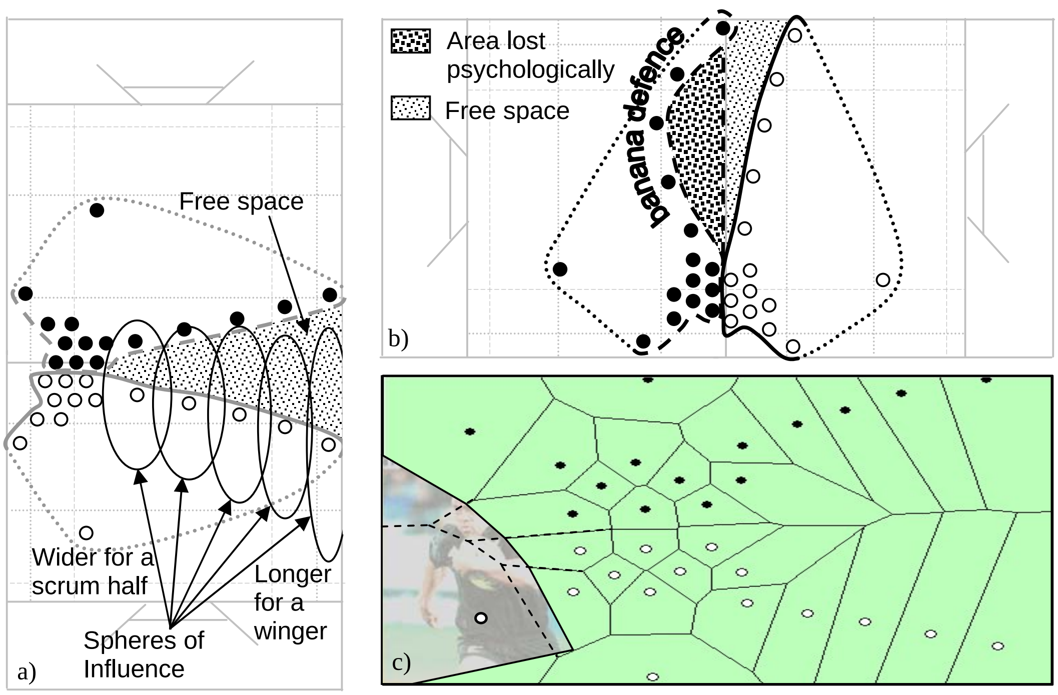

Figure 6: Examples of analysis: free space and individual player's space. a) Back line example: The free space between opposing back lines is shown, superimposed by the home back line's individual spheres of influence, which differ in orientation and size, depending on the attributes of the player; b) Psychological loss of space due to the banana defence; c) Using Voronoi polygons instead of spheres of influence (home team on bottom). The case of the left winger ('Jonah Lomu') has been spatially weighted to reflect directional mobility.

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 6b).

This is where the line of backs has become curved so that the winger is almost level with (or even forward of) 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 back line 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 6c). 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 6c reflects speed and strength in going forward, but also relative sluggishness in going back. Finally, other ways of manipulating space include distortion along the xy plane as a function of displacement by spheres of influence (similar to cartograms – Dent, 1990).

Representation of the rugby field as a probability map

The maps in Figure 7 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 7a. The 3D visualization of this surface could be effected by development with graphics languages such as OpenGL (within the existing Delphi development environment). The Voronoi representation in Figure 6c 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 7a (i.e. an alternative method to the interpolation routines used to derive the rasters). From this surface a cost surface could be calculated (Figure 7b), 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 7c), 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.

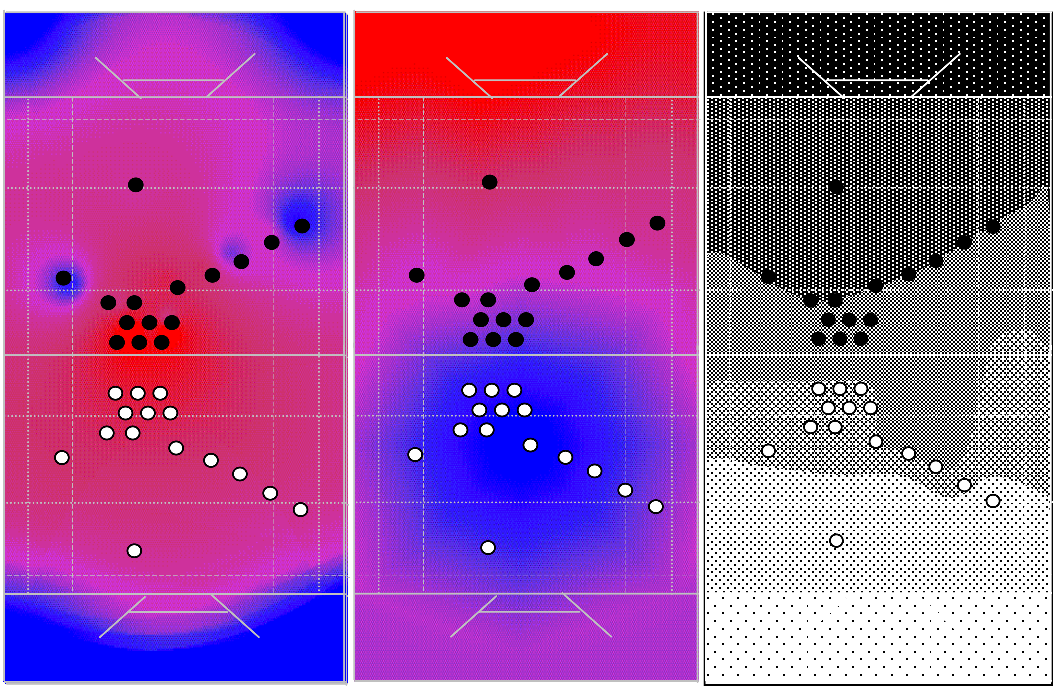

Figure 7: Examples of analysis: Probability maps. a) 2D surface showing the players' strength and speed attributes as heights above the pitch (opposing team). Barrier strength ranges from red (high) to blue (low); b) Cost surface derived from the 'elevation' surface, indicating those parts of the pitch 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).

5.2 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, FeynmanOnline, 2001). Figure 8 shows two such interactions and how they could be used to describe situations in rugby. In Figure 8a, 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 8b, 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 8 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.

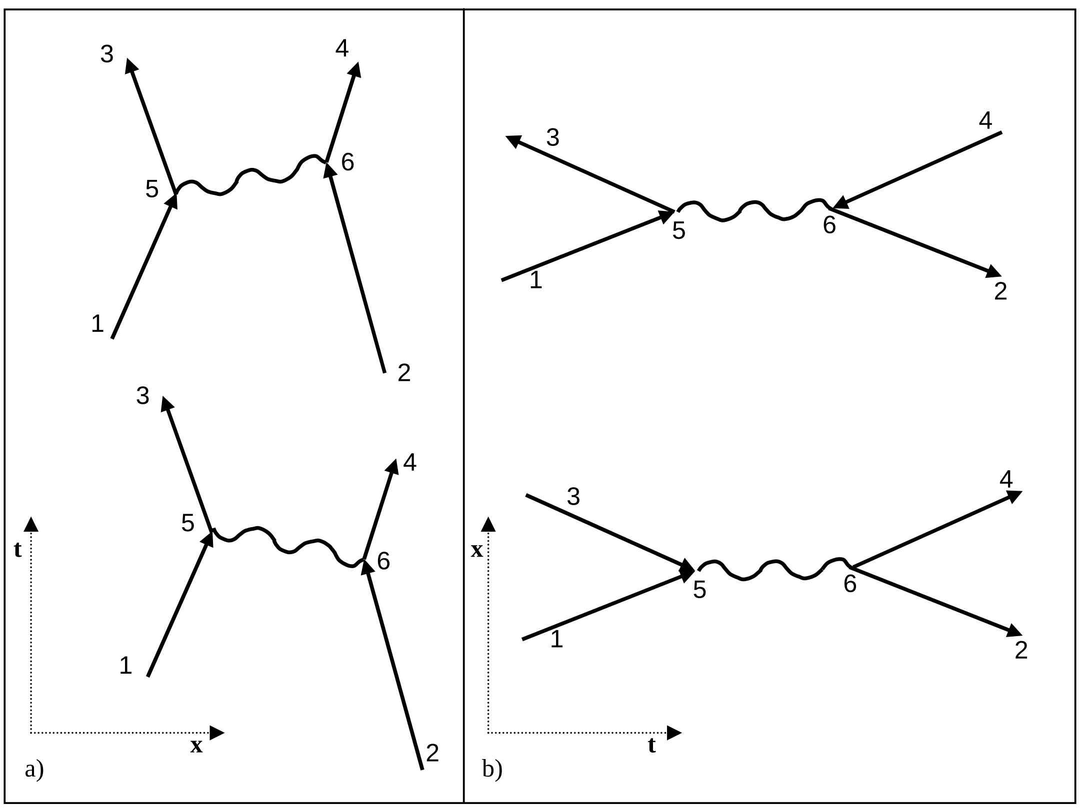

Figure 8: Local Representation: Feynman diagrams (Fermilab, FeynmanOnline, 2001). a) In particle physics the top diagram shows photon emission and collision. In rugby terms (bottom) a similar configuration has been used to represent a pass; b) Collision of an electron and positron to produce a photon 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.

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 8 have been shown (Figure 9).

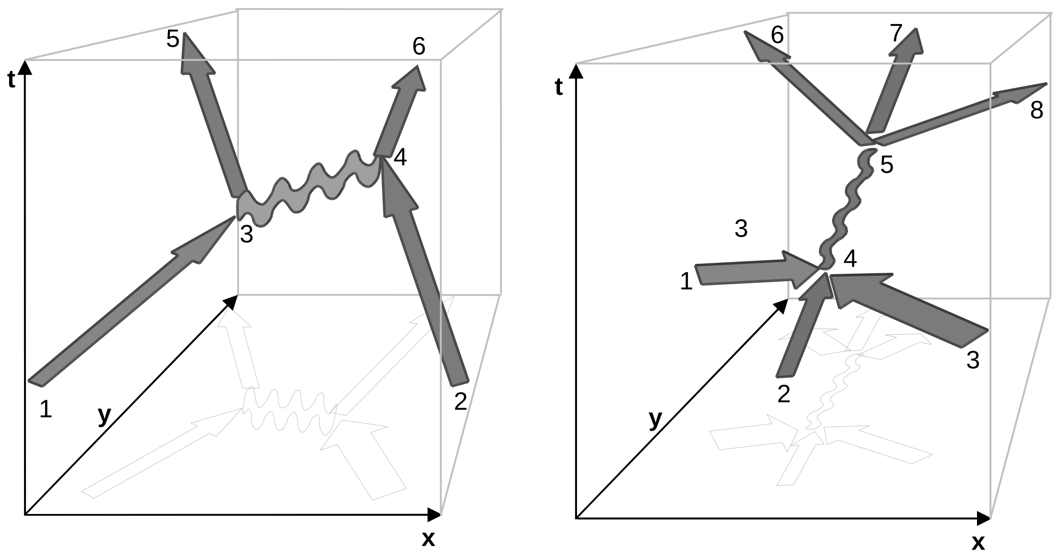

Figure 9: Local representation: 3D Feynman diagrams (arrows indicate player movement, wavy line indicates special state and xy projection is shown). a) A player (moving from 1 - 5) passes the ball at 3 and is received by a second player (moving from 2 – 6) at 4; b) Formation of a maul – players 1,2 and 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).

6.0 DISCUSSION AND CONCLUSION

Sports software provides valuable facilities for visualizing and analyzing games such as rugby, mostly 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 complex spatiotemporal patterns that occur 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 in the software. A further task is the development of 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. 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 (though 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.

In the short-term, video as a spatio-temporal data source is the best available, but the time will come when it is superseded by technological advances such as GPS receivers small enough to be attached to players. Anticipating such a time, in this paper we have assumed that precise and accurate coordinates will become the norm. For now, 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.

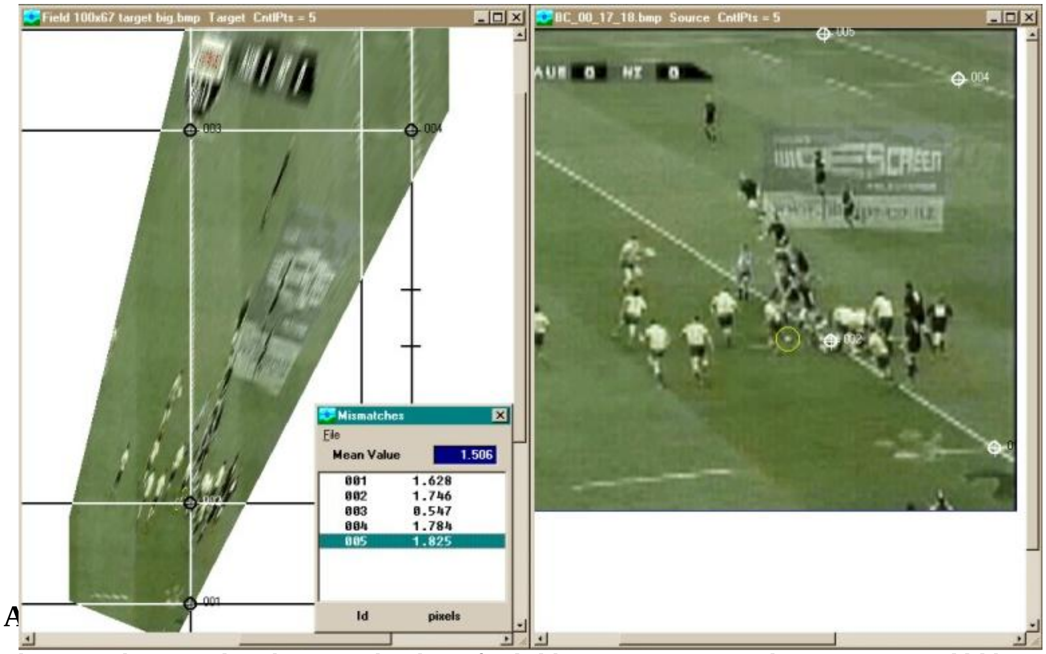

Figure 10: Using broadcast video to capture player coordinates. The right-hand pane is a single video frame marked with four control points corresponding to identifiable field locations. The left-hand pane contains the corresponding rectified image located on a (partial) pitch outline. (From 2001 Bledisloe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

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The research reported in this paper has been funded by an Otago Research Grant. We would like to thank Jarrod Carroll for digitising games from the 1999 Rugby World Cup and compiling the associated metadata. We are also grateful to Iain Ansell of the NZ Academy of Sport – South Island for demonstrating SportsCode and Kelvin Duncan of Community Communications (Christchurch) for information on KeyToAnalysis.

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