A Time Geography Approach to the Visualisation of Sport

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Abstract

This paper proposes using the rich visual "language" of Hägerstrand's time geography to represent time-space relationships in sport, in particular within the spatial and temporal constraints of a game of rugby. Despite being applied outside of its traditional social context it is argued that time geography's ability to model movements and relationships at the individual level makes it (and its modelling constructs such as prisms and lifelines) a powerful visualisation tool able to provide valuable insights into goal-oriented team sport. The visual tools of time geography are shown in the context of a video information system, SCRUM (Spatio-Chronological Rugby Union Model).

1. Introduction

There are many spatial phenomena that operate in a limited space, whether by nature or constrained by artificially-imposed boundaries. One example is the behaviour of players in the context of team games. It is apparent that in this case the temporal dimension is an essential construct towards understanding and visualising spatial patterns, as such patterns are subject to constant change. Moreover, it is significant that in this example we are looking at the scale of activity at the individual level.

It is for just such a scale that time geography was devised by Torsten Hägerstrand over 30 years ago, with the intention of revealing and analysing the complex time-space movements and interactions of individuals in a social context (Hägerstrand, 1970). In this paper it is proposed that time geography has the potential to provide valuable insights for competitive team sport, specifically rugby. The application of geography to sport is comparatively recent (Gatrell and Gould, 1979; Wagner, 1981); more recent still is the application of GIS-based spatial and temporal modelling to sport (Whigham, 2000; Moore *et al*, 2001; Pingali *et al* 2002). A video information system called SCRUM (Spatio-Chronological Rugby Union Model) was built as an attempt to provide spatiotemporal analysis and visualisation to sport (Moore *et al*, 2001).

The SCRUM system effects spatiotemporal data capture (what could be called secondary data capture) from video recordings of rugby union matches (primary data capture). The dimensions of the rugby pitch form a spatial constraint to player pattern (the temporal dimension also has a very limiting constraint), and the video medium is a raw data source with a near-continuous timeline for this spatial behaviour, making the application eminently suitable for the study of spatiotemporal data. Most importantly, the potential abundance of data at an individual level and the self-contained and tightly constrained spatiotemporal environment make this a suitable case study for the application of time geography principles. Real-world social contexts do not have these practical advantages (an acknowledged drawback to the use of time geography - Forer, 1998).

The next section will outline a background of the application of geography to sport, an account of time geography principles, the use of video as a data source for sports visualisation and analysis, and video information systems. Then follows an attempt to translate time geography principles into a sporting context. Section 4 will introduce the SCRUM system and illustrate time geography elements in that software environment. Finally, there will be a discussion, mainly outlining future directions.

2. Background

2.1. Geography in sport

This research is an example of what Gatrell and Gould (1979) term a micro-geography. Their application of multidimensional scaling and notions of pressure systems in the field of play (football and basketball were the two sports exemplified) represents the first treatment of sport in a geographic context. Bale (2000) has defined sports geography through description of some of the spatial attributes (sports are played at sites and locations) and phenomena (e.g. analysis of places where sport occurs – stadia and the wider context of the supporters that migrate there from the surrounding area) associated with sport. This research is less a study of sports *places* (and the associated wider geographic connotations), more the representation and analysis of *space* in the context of a game. Team games such as rugby and football are highly constrained spatially, with a precise spatial structure within and rigid, precise boundaries (Bale, 2000). Given the subject of this paper it should be noted that there is a constraining temporal structure (e.g. two halves), though high precision is harder to maintain (e.g. injury time). Wagner (1981 – cited in Bale, 2000) wrote the first paper to examine the role of geography in sport from a general stance, making note of phenomena in achievement sports such as “struggles over space” and “trying to make space” and “conquest of territory”.

2.2. Time geography

Time geography is a study of humans in space-time with an associated set of visual tools for looking at geographic reality at the individual level. It was developed by Hägerstrand (1970) as a remedy for the perceived tendency to generalize social process, in particular a disregard for the physical structure of the social environment. The “physicalist” approach that time geography acknowledges recognises that at the individual level it takes a certain amount of time to get from A to B (Thrift, 1977), and that while census data, for example, record that individuals live at fixed abodes (implying that they stay at this living space all the time), the reality is that on a day-to-day basis there are many social interactions to capture at a variety of times and at a number of locations (Gatrell and Senior, 1999). Thrift (1977) gives an example of a road accident in space-time, where time geography not only represents the space-time location of the accident itself, but its macro-scale social context. If two cars collide at an intersection, then their start points and destinations reflecting the purpose of their journey would also be of interest in a time geography context. This reveals more of the story of how the accident came to pass, increasing the opportunity to highlight alternative scenarios. The accident location itself would be represented as a potential collision in space-time.

2.2.1. Time geography notation

Time geography offers a set of visual tools with rich semantics. The environment in which space-time interaction is set is a cube, with the two horizontal axes representing the two spatial dimensions of x and y, and the vertical axis representing the time dimension. Hägerstrand (1974 – cited in Thrift 1977) has termed this an 'aquarium', within which are time geography elements such as lifelines, stations, bundles, domains and prisms (Figure 1). These elements are defined in Hägerstrand (1970).

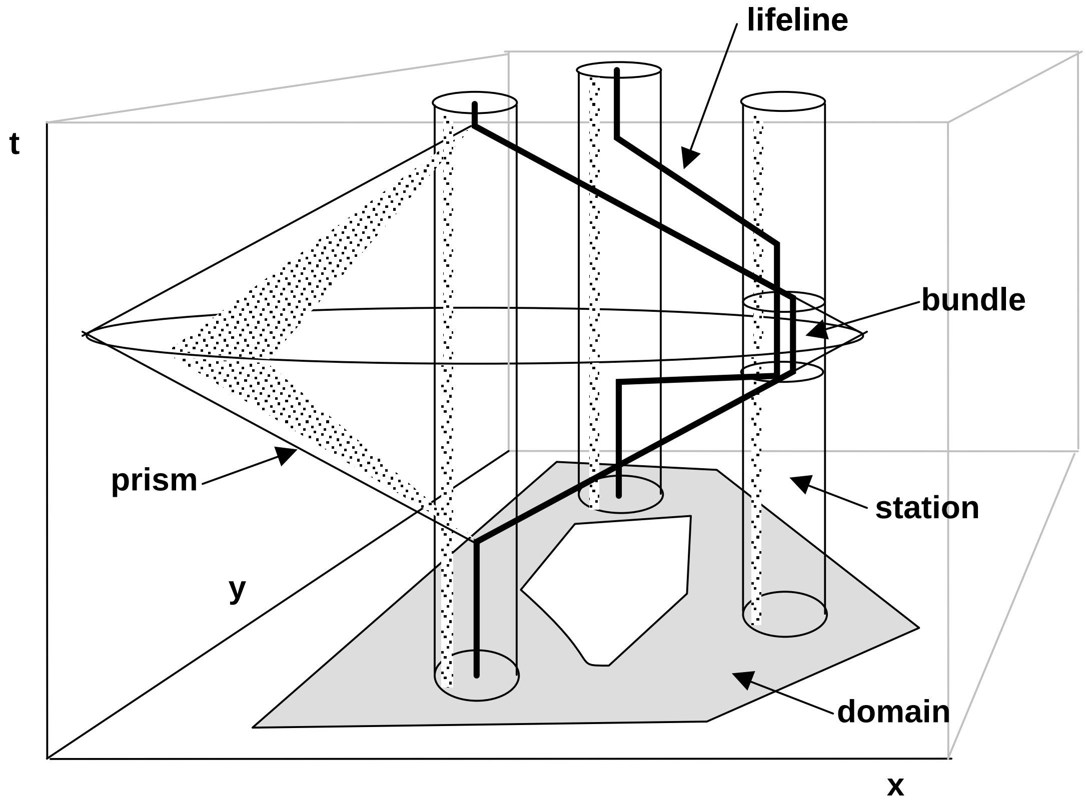

Figure 1. Some time geography elements

Lifelines represent the path taken by an individual in time-space. An individual will trace a path between stations (e.g. school, work, home – can vary according to size), where they congregate with other individuals to create bundles. Movement in space-time can be constrained by the boundaries of some domain, a physical manifestation of authority constraints. Finally, a prism represents the total area of space reachable by an individual in the time available (can be projected backwards in time as well as forwards). The shallower the slopes of the prism, the faster the individual is capable of travelling. The prism is symmetric if the station of origin is the same as that of the destination (as in figure 1), asymmetric if otherwise. Together, these time geography elements form a powerful analytical tool – it is hoped that they can provide good insights in a team sport context.

The focus with time geography notation is not so much on metrics (i.e. space and time precision – Langran, 1992) but a rich visual language with which to express social interaction. Nevertheless it is subject to objective space (Schatzki, 1991). Gatrell

(1983) gives an account of other ways of treating space and time in an integrated manner, including the ‘plastic space’ (i.e. distorting space to reflect travel time) put forward by Forer (1978).

2.2.2. Time geography applications

Fyfe (1992) used time geography for modelling local routine police activities, in particular representing linkages of the individual police officer to the wider community and the law in general. Other contexts of time geography use include the time and management of time in the work environment (of an IS development team for a large multinational company – Nandhakumar, 2002) and the modelling of the agency of grizzly bears in zoogeomorphology (Baer and Butler, 2000). Building in an awareness of the isotropic geographic environment, Miller (1991) and O’Sullivan *et al* (2000) use space-time prisms and isochrones to model transport accessibility. Forer (1998) also advocates distorting the conventionally uniform space-time prism to reflect barriers and channels in space. Finally, McBride *et al* (2002) put forward a novel treatment of lifelines, storing them using a linear referencing system, to be accessed through dynamic segmentation.

2.3. Using video for sport visualization and analysis

Video is the most common raw data source used with software for sports analysis, for example Dennis and Carron, 1999; Chang and Lee (1997). A Video Information System, 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”.

As an example of a video information system, Pingali *et al* (2002) have developed LucentVision, sports software able to capture video data from multiple sensors, and convert them in real time to a multimedia database, with instant indexing. Users of the software are able to receive output in the form of 3D virtual replays, visualization of player strategy or performance, and customized video clips of highlights. The system represented a step away from what the authors saw as a prevalent “resynthesizing” trend, where the emphasis is on reconstructing the game environment or parts thereof, virtually (through augmented reality or 3D virtual replays), without providing in-depth analysis facilities to help provide insights. A major way in which the authors achieve the latter is in introducing a spatiotemporal capability through enabling the visualization of motion trajectories and occupation of game space (a tennis example is given).

2.3.1. Segmentation and Abstraction

In order to process digital videos for feature extraction, or just for efficient management of a video stream of long duration, some kind of segmentation is essential. As Dawood and Ghanbari (1998) put it: “[a] long video clip [has a] complex signal [and] cannot be…characterized with its long-term mean and autocorrelation”. They describe a system for video browsing, archiving and retrieval, performing the temporal segmentation of video clip into stories (each describing a piece of video with a specific action). A story is further subdivided into similar video shots – a shot will have similar properties from frame to frame (in terms of motion and texture). For archiving purposes, a single frame of each – or the most memorable – shot is used as an icon for the story. This method opens out a way of letting scene content dictate the video model rather than processing it in one long sequence. More recently, Jadon *et al* (2002) used evolutionary computation to create fuzzy rules to segment sports videos into semantic categories.

Some kind of semantic organization of objects and events in a game is also desirable. Regarding the imposition of a structure to segments, hierarchies can be used. For the tennis application that Pingali *et al* (2002) used to demonstrate their LucentVision software, an “event” hierarchy was derived, wherein “matches” consist of “sets” which consist of “games” which consist of “points”. They also state that one of the key tasks in translating their system to other sports and applications is in building a suitable alternative event hierarchy.

2.3.2. The spatiotemporal elements of sport videos

A video in its original raw form contains no explicit spatiotemporal data, yet it is there to be mined (Moore *et al*, 2001). One of the earliest sports information systems that was able to process videos could also record spatiotemporal information (Franks and Nagelkerke, 1988). A system for field hockey was described, which allowed recorded footage of player behaviour and the recall of selected video instances. Input was through a keypad, with 72 spatial zones representing a scaled hockey pitch on a touch sensitive digitising tablet. There were also keys representing each of the players, set pieces and other elements of the hockey game.

Use of the software reaped benefits for both coach and player, according to subjective evaluation reports. The coach thought that the system lent structure to any subjective impressions of the game; the player reckoned that the coach’s demands had become more objective and realistic since using the system.

Pingali *et al*’s LucentVision (2002) explicitly uses spatiotemporal data, in the form of motion trajectories, stored in a relational database. However, this database does not support spatiotemporal queries, so a separate spatiotemporal analysis structure was built for that purpose.

3. Translating time geography concepts to sport

An important fact to note is that translating time geography to sport constrains its scope and robs it of most of its potential capability to analyse social situations in the wider context. This can be seen from another viewpoint, as the constrained environment common with achievement sports (in a spatial, temporal and human activity sense) fosters a lack of natural behaviour (Wagner, 1981 – cited in Bale, 2000). Individuals represented through time-space have been characterized as being subject to a “choreography of existence” (Pred, 1977); in team sport there is a tighter choreography being observed, governed by the aforementioned constraints. However, human activity within these boundaries is intense and, if captured, forms a rich source of data ideally suited to time geography notation. Also, the human activity constraint (imposed by the rules of rugby – in time geography terms a steering constraint) in particular can be broken, wherein players may break out of their “unnatural” behaviour and enter interaction which has an equivalent in the social world outside the pitch (e.g. a fight). Finally, the “physicalist” approach of time geography is especially applicable here, as there is a much greater emphasis on the physical capability of individuals; indeed it is minute differences in speed and stamina that can greatly affect the outcome of a game (this is reflected by the importance attached to player statistics). What may be harder to represent is the spatiotemporal effect of strategy and tactics.

Hägerstrand (1970) outlines three types of constraint to activities of individuals in time-space. These are human capability (limited by the need for sleep, for example), coupling constraints (the obligation to group together at certain places at certain times) and steering constraints (or the effect of authority). In rugby these could, in order, translate to skill and stamina limiting an individual's mobility, the need for forwards to congregate in a scrum or a line-out (though this need can be relaxed); and the constraining effect of the rules of the game, and its agent the referee.

Translating Fyfe's (1992) time geography interpretation of police activity to team sport, coupling constraints occur at even greater frequency (in the case of rugby, set pieces such as scrums and line-outs represent coupling constraints). Also the law serving as a steering constraint in a police context has an analogy in the rules of rugby in the case of this research.

Drawing from the fundamental assumptions in time geography as applied to social situations in general (Hägerstrand, 1975), there are parallels to be made in the limited social and somewhat ordered context of a rugby pitch. These are the limits on time and space (in Hägerstrand's terminology this is the lifetime of the individual and some boundary to modelled space, respectively; in a rugby match scenario, these are rigidly set and are constant from match to match: the 80 minute length of the game and the dimensions of the pitch) and also that every situation is rooted in past situations (the causality of set pieces such as scrums and line-outs is a good illustration of this). Other conditions of our physical reality, as specified by Hägerstrand, apply here as well: the indivisibility of the individual, who also solely fills the space that he / she is occupying at any time; every task has a duration (e.g. it takes a certain amount of time to travel from A to B); and the limited ability to multitask.

Most relevantly for this research, the time geography notation maps well to objects, plays and concepts in sport (the following examples are based on rugby). The aquarium representation maps well, since players do not deviate from the horizontal x, y plane; the pitch is assumed to be flat. This lack of movement in the vertical plane means that the z-dimension can be freed up to represent time. This will mean limiting the representation of the ball, since its height is assumed to be on the ground and constant, suppressing any high kick or even high pass information. A possible solution is to make the width of the ball's lifeline proportional to height (see later for the role of the lifeline).

Within the space-time cube, the pitch boundary will form a domain (being a manifestation of the rules of rugby), within or near which all match-related activity will take place. The domain can be limited yet further in a dynamic fashion, changing to reflect the offside zone (Pingali *et al* [2002] report on software that uses augmented reality to superimpose an offside line on digital video) or a zone for backward passing.

The individual has an obvious counterpart on the pitch as the player. This player will have a lifeline for the time that he or she is on the pitch. ‘Stations’ will have a dynamic nature on the pitch, not being fixed to a particular location. Set pieces such as scrums and line-outs will form the stations at which bundles of players will congregate. In Forer’s (1998) description these equate to ‘dynamic facilities’, “occurrences / facilities whose members vary spatially over time”, as opposed to ‘discrete facilities’, which are fixed. This may be a way to address one of the acknowledged shortcomings of time geography, taking account of what Giddens (1985) calls the “transformational structure of human action”.

The prism offers the greatest potential analytical capability for goal-oriented sport. The prisms formed will be very short term, as the interrupted nature of the game will mean that stations as players encounter them will never be far apart from each other (a notable exception is the breakaway try). There is a real opportunity to reflect the anisotropy of the rugby field, creating what Forer (1998) terms diffuse prisms to reflect capability constraints (players favouring going forwards rather than backwards) and barriers to movement (the opposing team).

Forer (1998) notes a number of shortcomings in time geography that have come to light since its inception. Out of these, two are of note here:

- “limited progress in making the theoretical translation from simple, convincing case studies of specific processes and small groups to general operational models”
- getting practical cost-effective working models for use in theory development / empirical investigation, due to problems of generating space-time prisms for individuals.

Although devoid of a true real world social setting, the team game scenario offers something beyond a ‘case study’ and the chance to create a model of a tightly-constrained, self-contained system. Furthermore, due to ready access to video and the tendency for in-depth statistical analysis at the professional level, there is no shortage of potential data from which to build the necessary space-time constructs. While this may provide little insight on social geography, the benefits for sport analysis are potentially numerous.

4. The system

These time geography principles are being built into SCRUM (Spatio-Chronological Rugby Union Model – Moore *et al*, 2001), a video information system that facilitates the recording of spatiotemporal data from digital video. The internal elements of SCRUM are shown diagrammatically in figure 2. A screen shot is shown in figure 3.

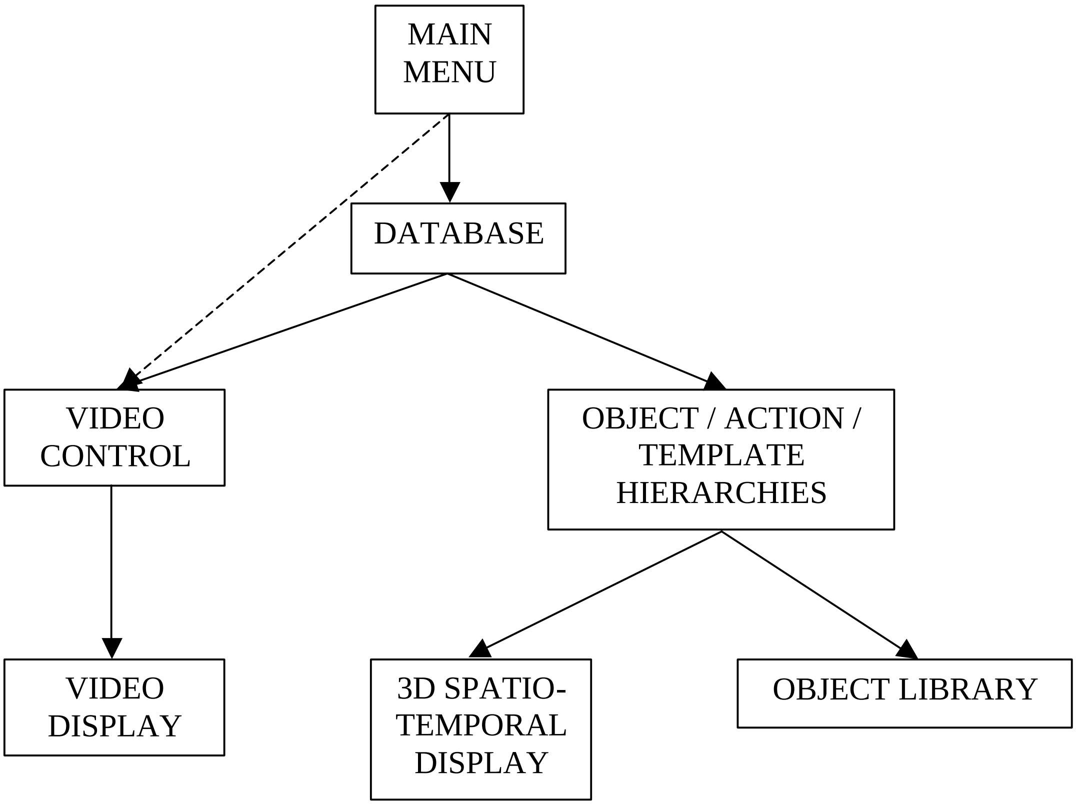

Figure 2. The components of SCRUM

Figure 3. A screenshot of SCRUM, showing database, hierarchies, video and 3D display (bottom left) components

The core of the system is the database, storing instantiations of the objects, actions and combinations of both (called ‘events’) during a game, with associated coordinates (relative to the centre of the field) and timestamps. The database also stores links to specific videos which themselves are linked to “atomic events”, and associated metadata (for SCRUM, the video of a rugby match is divided into atomic events, defined as a segment of the game that is temporally bounded by when the referee blows the whistle - this is the equivalent of Dawood and Ghanbari’s [1998] ‘stories’, which can consist of a number of camera shots). Finally, for semantic linkage, the database also stores object, action and template hierarchies in BLOB format. Any element of one of these hierarchies represents a discernable and discrete element in the game of rugby. These are loaded into the ‘hierarchies’ component when the database is opened, ready for editing.

Like Pingali *et al* (2002), the SCRUM software adopts hierarchies to arrange the elements of the sport. The basic architecture of the system encompasses a tree-based taxonomy of objects (e.g. players, referee, ball), actions (kick, pass) and templates (unique combinations of objects and actions comprising a set play or tactic).

The recording mechanism for the data capture is via a 3D representation of the rugby field, with objects superimposed (these objects are capable of a subset of actions) and moved as the game unfolds on digital video (the display and control of which forms another part of the system), their spatiotemporal coordinates being stored periodically in the database. It is in this component that the visual elements associated with time geography, such as prisms and lifelines can be displayed, making for effective visualisation and facilitating analysis. Figure 4 shows what this may look like in SCRUM.

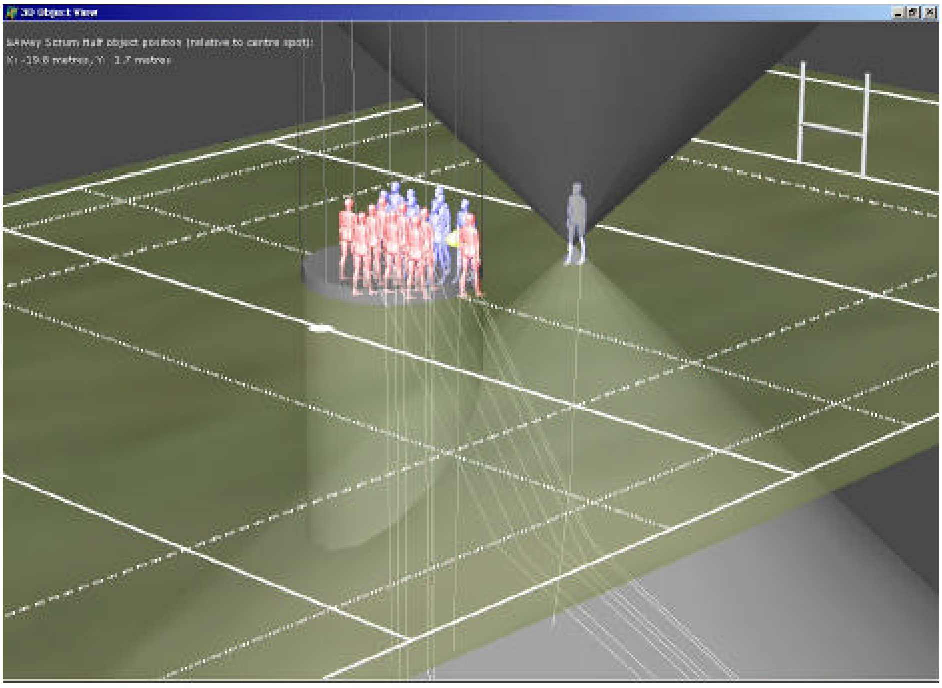

Figure 4. Time geography elements for a game of rugby. Opposing players have congregated in scrum formation, forming a bundle (solid cylinder). The potential for a station at the same location is also shown (cylindrical skeleton). Each player’s lifeline is shown ‘below’ the pitch (i.e. in the past). Finally, the past and future prisms are shown for the opposing scrum half, indicating potential scope of movement across the pitch.

5. Discussion

There is much to recommend the use of time geography in the context of a rugby match, providing a rich visual environment with which to explore spatiotemporal relationships, potentially providing novel insights. In addition, there is the potential to animate the space-time environment as changes. Although lacking a wider social context, contrary to what you would expect with time geography applications, professional goal-oriented team sport has several practical advantages over the real-world social environment, when regarding the potential for use of time geography elements. These are:

- a time-space that is manageable and tightly bounded in both the spatial and the temporal dimensions
- intensive data capture in the form of videos (small wearable devices could adopt the same role in the future), providing an ample resource from which to visualise and analyse relationships in space-time at the individual level. In a wider societal context, data from surveillance cameras found in city centres could provide a similar magnitude of resource (Hägerstrand [1970] looks forward to a time when technology provides instruments that "help…judge the impacts on social organization and thereby the impact on the ordinary day of the ordinary person"), though there are likely to be serious ethical issues involved with this.

5.1. Alternative and advanced structures and processes

Forer (1998) has put forward a 3D raster environment (an amended version of voxels, called taxels – x,y,t instead of x,y,z) within which time geography can be applied. Although there is a huge storage cost associated with voxels, the use of octrees have been suggested to compress the data. The key advantage over the boundary representations used in this paper is the ease with which analysis is carried out in a raster, making it an attractive alternative representation.

Looking towards automated spatiotemporal feature extraction from videos, Pingali *et al* (2002) describe the tracking of player and ball objects in the context of a tennis match. They rate this as the toughest task in translating their LucentVision software set-up to other applications such as rugby (though their tracking module is suitably multithreaded so that the paths of multiple objects can be recorded).

Langran (1992) gives an introduction to using spatial access mechanisms such as grid files and R-trees to facilitate access to space-time data. In the context of the R-tree, the use of a Minimum Bounding Cube in the x, y and time dimensions was put forward, and would be relevant in the context of accessing prisms, lifelines and bundles in the space-time 'aquarium'. Latterly, Kollios *et al* (2001) use a 3D access mechanism for animated maps. Zhou and Jones (2001) describe a 3D R-tree to integrate scale and space in the context of a multi-scale database.

5.2. Issues of error and scale

The imprecise metrics involved with extracting spatiotemporal data from a digitised video by sight are not an issue in this case, especially since the time geography notation was not designed to represent precise data. Much of the analytical capability provided by time geography comes from the ability to record and represent spatiotemporal topology or interactions between individuals (this is especially applicable to achievement sport).

Peuquet (1994) has noted time geography's inability to express multiple temporal (and spatial) scales (a "temporal hierarchy"). More recently, Hornsby and Egenhofer (2002) have investigated granularity in relation to lifelines. The issue of scale is not as pressing in the context of a team game: all the major activities in a game can be represented at the match scale. We could conceivably enlarge the spatial scope to that of the entire stadium and build a time geography of the supporters (thus bringing back a less constrained social element into the model). This may work well if still considered at the match temporal scale, despite the barrier between the player and supporter domains (e.g. try to map the supporter's actions and relate them to events on the pitch). It would be less effective if the spatial (and temporal) scale was greatly extended to include in- and out-migration of the supporters before and after the game. Schatzki (1991) recognises such "sporting events" as spatial phenomena, also noting that their spatial characteristics have been ignored in geography.

At the finer scale, time geography elements such as prisms, when used in a team game situation, may need a high temporal resolution to even exist. Running at fastest speed, a player could reach any boundary of the pitch within several seconds, meaning that visualisation and analysis at this scale has to be facilitated in the system. To be able to view the game at the micro level as well as the macro level implies that a spatiotemporal zooming capability should be provided; the SCRUM software already has routines for this.

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