THE NATURE OF PRISMS: EXPLORING DATA QUALITY AND VAGUENESS IN DYNAMIC SPATIO-TEMPORAL CONSTRUCTS.

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ABSTRACT:

Hagerstrand's minimalist representation of individual lives and opportunities as lifelines and prisms predates the technologies available to current GIScience but resonates with many emerging spatio-temporal data model describing human activity in space and time. It also offer strong synergies with the various approaches that use data sets representing the tracks of individuals in order to explore patterns in their movements and associated activities. Almost inevitably such tracking data sets utilise (x,y,t) and activity data (representing lifelines) which are sampled over time and space and are eventually embedded for analysis within a digital geospatial environment. There are clear issues of error in both the data defining the environment used for analysis and that defining the movement as sampled (x,y,t) points, and consequently specific properties of the interaction emerge which would be of interest to us. While the lifeline is one of a number of attempts to represent human (or any object's) presence in space-time the concept of the prism focuses more on interpolating where an object could be, or might be, when it is between two known points. This idea of prism is a derivative spatio-temporal construct which has a further dimension of vagueness and uncertainty attached to it. Such properties require both identification and representation. This paper explores two issues. The first is the nature of uncertainty and error in an actual or interpolated lifeline data models related to typical kinds of analysis of movement and activity within a digital representation of its embedding geography. The second examines the nature of any prism of opportunity that is inferred from partial lifeline data and then deployed in accessibility studies. Specifically it discusses how issues of spatio-temporal uncertainty in the derivation of prisms can be calculated, represented and analysed using the rod-field model proposed by McDowall. It contends that the personal prism is a legitimate and valuable construct within GI Science, but that allowing prisms to acquire appropriate qualities of continuity and vagueness is an important aspect of delivering information which is appropriately described as to nature and quality.

1. INTRODUCTION

Accurately describing the environment in ways that are amenable to interpretation and analysis, while remaining true to the components of the environment being described, is a fundamental responsibility of geographic information science. Inadequate performance in this area is highly prejudicial to attempts to extract information and added value from the descriptive data, and undermines the enterprise of building more sophisticated analyses and theories related to geospatial phenomena.

A critical aspect of constructing a map of geographic objects is establishing the relationships between a set of locations and a set of entities. GISystems traditionally assume that the relation between location and object identity is binary - an object either exists at a particular place or it is absent. According to this assumption, geographic information can be decomposed into atoms of the form <*x*, *z*>, where *x* is a location in space (and time) and *z* is a set of properties associated with that location (Goodchild *et al.*, 1999). This framing does not embody all forms of geographic information. Goodchild (2003), for example, contends that a crisply-linked location-value tuple is insufficient for representing uncertain geographic information and proposes that some concepts are only partially linked through logical relations that allow intermediary truth-values.

This situation has evolved a significant literature on data quality, a term with multiple connotations. Quality is generally understood to involve a quantitative component (precision, completeness, timeliness, certain aspects of accuracy), a ‘relative to purpose’ component (fitness for use, other aspects of accuracy), and a representational fidelity component (the consonance of the means of expressing an object or concept with the actual nature of the object). Decades of research have explored means of expressing these different dimensions of quality and expressing the nature of specific data to the user for guidance. While much work has focussed on informing the user how much data err from a perfect description of a crisp object, parallel work has sought means to embrace the inherent non-crispness of many spatial phenomena. This wide body of work was initiated when geospatial data capture and analysis fundamentally addressed analysis of static phenomenon, or at most comparative statics. The set of objects to be described essentially comprised those of the topographic realm, human mediated descriptions but in some ways essentially primary constructs for geographic and environmental description.

This paper addresses issues which arise as geographic information science and the pragmatics of geospatial analysis extend their capabilities. Three issues in particular are relevant here. First is the growing development of *shared* derivative data artefacts and geospatial objects derived from various combinations of primary objects and their known attributes. The *shared* is significant because it signifies the distinction between derivatives from private analyses created in a focused research or operational group, with its implications of implicit deep knowledge of the data, and the outing of that data for general use. Two examples of such data, taken from New Zealand, would be the national coverage of a social equity measure, the New Zealand Deprivation Index (NZDep) and the distribution of layers identifying the accessibility to health care services for policy use.

A second issue is the growing demand for geospatial data constructs and information systems which cope with the expression of time and dynamic data, whether in terms of representation of the changing nature of a largely static object (including intermittence), or the constant movement of a dynamic one.

The third is the emergence of a critical GI Science which places far greater emphasis on representations of phenomena in ways which are true to their essential nature. In particular the nature of imprecise and vague objects, in both space *and* time is stressed, as is the contestable nature of many objects. Examples of the former perspective include informal suburbs and communities, natural forests and transient lakes. Unsurprisingly, these can also serve as examples of the latter concern as well.

Between them these trends suggest new challenges in developing more complex geospatial-temporal constructs that can also function in an environment where contestable or vague descriptions need to be embraced. Ultimately these descriptions must also prove robust and of high quality when used in various independent contexts as well as in their specific project niche. Inevitably they also raise new issues for expressing quality, in both a quantitative and qualitative sense.

This paper is about such issues related to a particular spatio-temporal data set and a specific construct, the space-time prism of Hagerstrand's time geography. The following sections introduce the tenets of time geography and describe an innovative architecture for describing prisms and their use in large scale activity modelling (Huisman, 2006). They move discuss the nature of the prism and then to suggest that this nature can be expressed using an extension of McDowall's rod field data structure for the description of vague objects. These foundations form the basis for a commentary on the nature of quality in such data artefacts, and an exploration of different manifestations of the prism and the implicit nature of each.

1.1 The Evolution of Accessibility and Access Data Layers

The genesis of the ideas explored here lie in accessibility research, specifically ways to define and map both the inherent accessibility of a place and conversely the specific places to which an individual has accessibility. In recent years technological developments in GIS and spatial data infrastructure related to transportation have led to the routine operationalisation of many previously proposed access measures, and to the publication and use by others of data themes purporting to show access scores, which are then utilised in specific policy analyses. A short review of the field would include the evolution of projects on access to employment opportunities (Hughes 1991), evaluation of transportation networks (Garrison 1960, Portier et al. 1994), or particular transportation modes such as Public Transportation (O'Sullivan et al. 2000), access to primary Healthcare (Brabyn and Skelly 2003), access to public facilities for particular social groups (Janelle et al. 1998, Church and Marston 2003), or as an input into the planning process (Ryan and McNally 1995). A number of these have developed access measures and then circulated them as deployable data layers.

Many traditional accessibility measures were purely spatial, and generic in nature and derived from formulations based on either 'gravity' or distance decay formulations of interaction and access. Others owe some allegiance to the Chirstaller concept of range or the notion of reach: access exists only within a specified distance of a facility. These exclusively spatial and generic views have been slowly eroded as the issue of access has been set within the context of real constraints in peoples' lives. The three main implications of this perspective are to acknowledge firstly that accessibility is often not a physically-determined matter of distance: cost and travel time are better measures of impedance. This inevitably leads on to acknowledging that accessibility is therefore related to access to specific transport technologies, so is a very individual phenomenon related to the individual's access to private transport, or bike or the location of their reference place (typically home) relative to public options. The final insight stems from feminist critiques of the opportunities available to caregivers: namely real access to any facility or place of activity requires the ability to be there for sufficient time for the desired activity to occur, and a major constraint on this may be the individual's lifestyle and the free time within it. For instance, in families with both caregivers in full time jobs *realistic* ability to get to primary health care is very much constrained by the constraints in place by the working day.

These ideas have major implications for developing ways to measure accessibility of people and of places. While the great majority of measures of accessibility currently made accessible as data layers in third party GIS use traditional measures on the assumption they apply to the entire population equally, there is a growing acceptance that generic models of accessibility are crude compared to those that seek to model and represent individual circumstances. One solution adopted in the search for better measures of access (and interaction) has been to look at Hagerstrand's time geography (Hagerstrand, 1970) as providing a useful way of establishing individual conditions and thence individual access. Outcomes from individual circumstances can then be combined in different ways to identify access patterns in a population. (Huisman, 2006).

1.2 GIS-enabled space-time models

As noted, patterns of space and time access are being derived for more sophisticated analyses, driven by theoretical dynamics as well as the greater complexity of the geographic realities that analysts confront. Cities become daily more complex due to rapid advances in transport and communication technology, the impacts of globalisation, widening inequalities, fragmented lifestyles and targeted policy decisions. Human activities are increasingly complex in this milieu resulting in an increasing need to describe and understand what people do in time and space (Mey and ter Heide, 1997).

Hagerstrand's Time Geographic framework (Hagerstrand 1970) is a way of conceptualising movement in terms of paths through space and time which at root are driven by desire to undertake activities and the need to overcome constraints in achieving these goals (Forer et al, 2007). Hagerstrand's work is enjoying a renaissance because of the parsimony and power of his graphic notation to describe the human life. This is a notation which typically exists in a three dimensional geometry, two horizontal ones being Eastings and Northings, the vertical one being time. Two concepts serve to describe human options during the day: a continuous timeline describing the location of the user at any time is one. The other describes the region of space-time that is available to the user if there is a discretionary gap in their day, To investigate access for an individual given a set of immutable commitments (childcare, work, community detention) the timeline fills the committed period, but in between lies a specific opportunity space.

This is illustrated in Figure 1 below by a student's day. Lines represent time spent at a home base (blue), and attending lectures and work (red). The large prisms are zones of possible access to activities for this individual, an access measure that is being widely adopted in studies of accessibility. Traditionally it represents the area that the individual could theoretically travel to from the end of one key activity at one place, and get back to in time for the second activity at another. In the theoretical discussions of early time geography this volume was seen as a crisp object much akin to a light cone. Inside could be accessed by the individual, outside not. The prism embodies information on the maximum zone of interaction, and the maximum time available at any point therein.

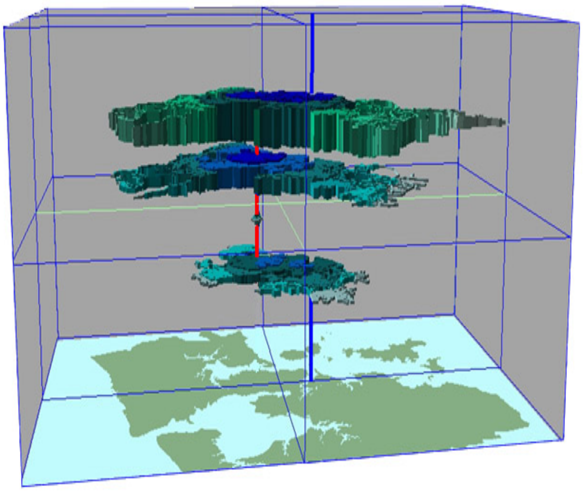

Figure 1: A Student's day. Source: Huisman and Forer (1998).

The geometry inherent in the Time-Geographic framework embodies notions of scheduling, constraints and opportunities or choices in a Newtonian 'aquarium' of space defined by time (also referred to as the Space-Time Cube or STC). Many recent computational implementations have focussed on the concept of lifelines (Kwan 1998, Theriault et al. 2002), but most of the substantial applications of Time-Geographic concepts predate these and have focussed on the prism, including Burns (1979) and Lenntørp (1978). Others have focused more on action spaces, in the form of isochrones (O'Sullivan et al., 2000), 'network paths' (Miller, 1991), or as ellipses (Dijst, 1995; Dijst and Vidakovic, 1997).

Prisms have a limited place in the wider literature because of two factors: limited access to the personal data that can be used to construct them, and the computational issues of computing and representing them. As Figure 1 shows the geometry of a real prism is not simple and generally not easily represented and queried in a vector data structure. The discussion in this paper is based on prisms generated by a particular process and a specific data structure, both of which are relevant to the issue of data quality. These are explained further in the next section, but their key salient features are :

1. Prisms are modelled on the basis of a crisp termination of one required activity (say a lecture) and the uptake of another. Their extent is calculated using network algorithms that allow for travel times to be computed using several modes of transport, and different states of road transport depending on time of day. Details of the algorithm are in Huisman (2006).
2. As an output of the algorithm the geometry of the prism is expressed through an array of cubes or *taxels*, each of which can indicate that the user can be present (1) or not (0).

The issues this paper seeks to raise centre around an example based on the above methodology, in which the final data artefact that will be produced will be a data layer that expresses zones of generic access of students to potential work opportunities (or of employers to potential workers). This is generated from the aggregation of multiple individuals' available opportunity space(time), i.e. their prisms. In particular the paper seeks to explore the quality issues with representing a typical binary prism, the sources of error and uncertainty in a prism, the existence of redundancy in the expression of the prism and the needs of prisms as vague objects.

2. THE NATURE OF EMPIRICALLY DERIVED PRISMS

2.1 Methodologies for building prisms

Any issues of data quality in a fabricated prism between two known (x,y,t) events will hang on the way that a prism is assembled. Prisms in the early literature are usually represented with highly simplified conic geometries and a simple binary nature: without ambiguity any part of space-time can be said to lie either within them or outside. The simplicity usually reflects a very simple treatment of space, namely in the theoretical world movement is accepted as being on an undifferentiated isotropic surface.

The rather complicated geometry exhibited in Figure 1 illustrates how the realities of transport technology produces a much more sophisticated view of the way that space and time interact in moulding opportunity options for the individual. In practice, any such empirically derived prism will have had to involve a model of a transport network and its properties. These will be used to identify the quickest routes to any places that lie within the maximum travel time available to the individual, as well as derive the travel times back in to the place where the new required activity has to start. Algorithms to find the quickest routes between locations on networks are not new, and unambiguous ways exist to allow such techniques to be applied to deriving prisms (Huisman, 2006). In a simple world, say a small town, such tools provide adequate ways to generate accurate and unambiguous definitions of prisms. For a city with multiple mode choices the situation is more complex. As an example our exemplar prism is derived from a model of transport space that incorporates various mode options, including car travel, public transport (the bus), walking and cycling.

The general process for 'assembling' a prism is as follows. Let *t* be a time interval and *d* the duration of a free time window defined by t_3-t_1. Moreover, let *i* be an origin location and *j* the location of the start of the next 'event' or activity. For all modes, the maximum space-time extent (action space) which an individual can reach can be derived for all time intervals between t_1 and t_3 at any time interval. This will generate *t / d* action spaces from the origin *i.* The current model uses standard allocation functions based on Dijkstra's shortest-path algorithm and dynamic segmentation to derive these areas. The ability to be present at any location in any of these action spaces does not imply the ability to eventually reach the location of the next activity. This constraint can be implemented by reversing this procedure for the destination *j*, and performing a geometric intersect ($Ai_t \cap Aj_t$) Where A*i* and A*j* are relevant action spaces for time interval *t* (Figure 2 below). This identifies common areas in both spaces where the individual can be physically present, while satisfying both temporal and spatial constraints.

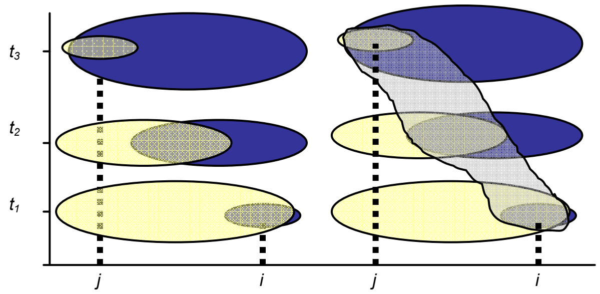

Figure 2 : Assembly of a simple space-time prism with three time intervals

2.2 Representation of prisms

While the definition of the extent of a prism can be derived using largely vector representations of networks, and applications of existing functionality in GIS (Huisman, 2006) the satisfactory representation of the prism counsels a different approach, even with the simple binary representation of a prism. The network analysis and associated techniques yield both a network of nodes, arcs and parts of arcs where the individual could be present, as well as the information to project this into a 3-D prism. However, geometric representation as a vector polyhedron carries high penalties, which become even higher when the combination or comparison of large numbers of prisms is required. Representation in a raster/voxel format is adopted useful initially for reasons of technical simplicity, although additional benefits accrue as identified in section 3.

The 'action spaces' defined by these nodes and arcs are used to populate a discrete 3D array of raster cells, referred to here as *taxels*, as they represent two dimensions of space and one of time (Forer, 1998). In keeping with all common raster formats (ESRI 1999), positional information is stored in rows (x) and columns (y). Time is modelled as an orthogonal z-dimension, through temporal referencing of raster layers. In this way it is possible to preserve the classic time geographic concept of the aquarium, and utilise existing raster GIS data structures, albeit in an unusual way. Topology is inherent in this data structure, as it is for any raster data structure (Worboys, 1994). The cell size (in terms of the spatial and temporal resolution along the x, y and z dimensions) is also explicitly defined, allowing the user to set the resolution appropriate to the given phenomena under study. The choice of cell size in terms of spatial and temporal granularity is clearly critical; the most appropriate taxel resolution will almost certainly depend on the specific context and spatial and temporal scales of the research. The key advantage of using a 3D array is that temporal querying can be performed upon the geometric properties of a data model rather than its attribute data, similar to matrix algebra. This actually makes certain types of query, and the provision of certain key derivative outcomes, such as statements of potential presence or maximum visit duration, far simpler.

2.3 Quality issues in a typical prism

Assuming that the underlying spatial data sets such as road networks are accurately recorded, the study area is a small town with free traffic movement and the start and stop points of the prism are accurate then we might feel some sense of confidence with our ability to create quite robust and worthwhile binary prisms. The one obvious issue would be the effect of the *digitisation* of space into taxels, which creates an uncertainty effect on the boundary of the prisms of a kind which is familiar in all raster applications, although not usually considered with a temporal dimension appended. One positive characteristic of such error is that it reduces as the resolution of the cells is increased. One way of looking at digitisation error for a simple binary volume is that they occur only in the taxels on the border of the prisms. Options for dealing with this are well known, including decision rules for full inclusion or full exclusion. An alternative option is to interpret the contested cells as in a fuzzy or uncertain state of possible presence. That option may be of limited practical value at this point, digitisation error is probably a minor concern for most prisms: in most issues of accessibility individuals do not explore the extremes of their available prism and so never engage with the errors. However the quantitative error in prisms deriving from the chosen data model is minor compared to uncertainties which emerge from their initial fabrication in many contexts. The nature of travel and human activities, leaving aside the vagaries of free will, suggest the original formulation of the prism as a crisp object is over-specified.

Two significant sources of error can be identified. The first is the ability to specify a definite start and end time for the prism episode. For lack of a better term we can define this as *marker elasticity*. Certainly, Traditional Time-Geography always assumed that marker events were fixed (in absolute terms) in space-time. In reality, people have learned to cope with and adjust to the environments and constraints of their increasingly dynamic lives. While some closely timetabled events have clear termination or start points many others are defined more imprecisely and may be conditional on the start or end of activities which have informal dynamics. The second issue can be more significant, however, and that is the impact on the prism of short-term fluctuations in the state of the transportation system. In large cities traffic behaviour often has a diurnal rhythm superimposed with a strong irregular dynamic that can extend journey times by 15-50%. We refer to this category as *travel-time uncertainty.* It is possible to model the likely state and its range of perturbation for both the start and end times of a prism, which will extend or contract the whole prism in a fairly regular way. Typically the impacts of a fluctuation in service level or traffic congestion will have rather more spatially complex effects and modelling them will be far more time intensive (Friesz et al., 1996). However, simulation methodologies offer a way to explore the envelope of a best case prism, some worst case scenarios, and some identification of a likely norm state. Given perturbation functions for departure and arrival times, and exploratory modelling of transport to derive prisms under different traffic conditions modelling can derive the percentage of the time that a taxel will be never accessible, sometimes accessible and always accessible. The prism ceases be binary and exhibits a classic egg and yolk structure: a clear inside, a clear outside and a complex border zone.

There are no examples in the literature of such a rendition of a prism, but Figure 3(a) provides a diagrammatic example. Such explorations can be interpreted as either an artefact which reveals aspects of the data quality of a particular manifestation of the original binary construct, or as an enhanced version of the original binary idea. The issues with the former are relatively narrow, while the latter stance raises serious questions about the nature of the prism itself. For the former we can accept the variance as the result of imperfect measurement or uncertainty over measurement. In the latter the issue of whether the prism can ever be truly measurable is raised and thence a concern over what kind of object the prism represents: crisp, uncertain or vague.

Measurement error and unpredictable variation in transport performance have already undermined the idea that the prism can be a crisp object, except in a purely theoretical sense. However, the prism can be further redefined if it is considered in terms of identifying really usable space-time for a given purpose or activity (or bundle of the same), such as visiting the doctor, going to a film or having coffee with a friend. Hagerstrand identifies various constraints that act to limit the occasions when and where activities can happen. Adequate time at a location to perform a function is one such constraint. Presence of appropriate facilities is another. We could redefine the prism as being a volume of space time which was physically accessible to an individual for discretionary use and able to support that use, or bundle of possible uses. In such a case only certain parts of the original prism's volume would be functionally accessible in terms of providing, or being likely to provide, a required activity. Indeed, using various forms of conditional assumptions, areas of the prism might be considered to offer a certain probability of being a successful locus for desirable activity, not a binary yes or no. Such a prism would be internally quite complex, with much of the prism being a zero on account of unambiguously failing to be both accessible and useful to the individual. Other well suited parts would unambiguously be in the prism. The remaining taxels could under some conditions be 'in' and in others 'out', and could be seen as having a probability of being one or the other.

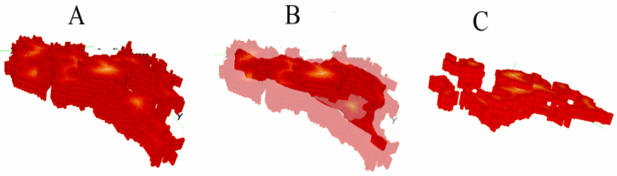

Figure 3 : (a) A 'crisp' space-time prism, (b) incorporation of vagueness and uncertainty parameters to derive 'most probably usable' space-time volume, and (c) 'yolk' displaying remaining space-time volume for activity bundles.

Figure 3(b) and (c) illustrate how such a prism would look. Such a complex entity poses representational problems in terms of data structures as well as philosophical ones regarding the nature of the object itself. The next section addresses the question of the nature of such a prism and what properties an appropriate data model would require to represent it adequately.

3. ERROR, UNCERTAINTY AND VAGUENESS

3.1 Definitions and clarification

Uncertainty manifests when we have incomplete information. Given that all measurement instruments are subject to error, measurements of position on the Earth's surface are fraught with inaccuracies. However, not all uncertainty is the product of measurement error. Responding to proposals by Fisher (1999) and Zhang and Goodchild (2002), Leyk et al. (2005) propose a conceptual framework for uncertain geographic data where indeterminacy is classified into three categories: error, ambiguity and vagueness. Under this framework, error should be considered "the difference between a computed, observed or measured value or condition and the true, specified or theoretically correct condition" (Leyk et al., 2005, p. 294). This category of uncertainty includes inaccuracies related to instrument error, sampling frameworks and random fluctuations.

Indeterminacy may also be the product of ambiguity. Ambiguity, for example, can result from discord as to where a boundary is located. Alternatively, it may be the product of an agency being non-specific as to which version of a boundary is valid when there are a finite number of possible alternatives (Leyk et al., 2005, p. 294). The hallmark of ambiguity is that there are a finite set of possibilities and insufficient information to ascertain which should be employed.

A third form of geographic uncertainty is vagueness. Vagueness is seemingly ubiquitous in geographic concepts, frequently persisting despite attempts to construct precise definitions (Bennett, 2001). This form of uncertainty is concerned with borderline cases where, even given complete knowledge of the nature of a geographic entity and the context of its representation, the entity's spatial, temporal or categorical boundaries are indeterminate. Moreover, the indeterminacy is such that the various possibilities can not be reduced to a small number of determinate candidates.

There is room for considerable debate as to whether prisms are imprecise, indeterminate or vague in nature. In any event a structure is needed to describe them. Cova and Goodchild (2002) propose that a crisp object's spatial embedding can be described by an infinite binary field defining whether the object is present or absent at each location. Such an object's spatial embedding S can be defined:

$$S = \{(x, f(x)) \mid x \in R^n, f(x) \in \{0,1\}\} \qquad [1]$$

where x is a location vector, R^n is n-dimensional real number space and f is a function that defines whether the object is present or absent at a given location. This function can be interpreted as being a field where the truth-status of an object's existence is specified for every location in a space. This model of the spatial manifestation of objects can be extended to objects with a spatially or temporally gradated identity in a space-time aquarium by substituting n-

dimensional real number space for the model of space-time. Moreover, the various models of vagueness that are employed by the GIS community (fuzzy logic, rough sets, egg-yolk theory and supervaluationism) can each be accommodated through either (1) adjusting the permissible truth values for representations based on many-valued logics, or (2) evaluating the truth status for multiple valuations according to supervaluationist representations. Assuming the interval of the membership function *f* is equal to one, at every point in the aquarium the object is either present or absent. Under this modified relation, a crisp prism has a spatiotemporal embedding:

$$S = \{(x, f(x)) \mid x \in Aq, f(x) \in \{0,1\}\} \qquad [2]$$

where *Aq* signifies a location history aquarium. Cova and Goodchild note that if the membership function *f* is defined continuously on the interval 0 to 1 it describes the spatiotemporal embedding of fuzzy objects[1]. This relation between an object's identity and a set of locations can be understood:

$$S = \{(x, f(x)) \mid x \in Aq, f(x) \in \{0,\ldots,1\}\} \qquad [3]$$

This membership function permits statements pertaining to the existence of an object at a location, such as "Woodhill Forest exists at NZMG coordinate 2668320E 6463730N", to be evaluated as being partially true. Egg-yolk and rough set representations may be modelled if the interval between 0 and 1 is a real number determining the number of classes. For example, the membership function in the statement:

$$S = \{(x, f(x)) \mid x \in Aq, f(x) \in \{0,.5,1\}\} \qquad [4]$$

acknowledges that the identity relation between object and location has three truth values: {0, 0.5, 1}. These truth values signify the falsity (0), indeterminacy (0.5) or truth (1) of statements about the existence of objects at particular locations and instants.

Supervaluationist descriptions of vague geographic entities represent an object's manifestation in space-time using multiple crisp valuations. These valuations may be true under some framings of the object and false under others. According to supervaluationism, the spatiotemporal manifestation of a vague prism can be represented as:

$$S = \begin{Bmatrix} S_1 = \{(x_1, f(x_1)) \mid x_1 \in Aq, f(x_1) \in \{0,1\}\} \\ S_2 = \{(x_2, f(x_2)) \mid x_2 \in Aq, f(x_2) \in \{0,1\}\} \\ S_n = \{(x_n, f(x_n)) \mid x_n \in Aq, f(x_n) \in \{0,1\}\} \end{Bmatrix} \qquad [5]$$

where S_1, S_2 … S_n are valuations of an object's existence in space and time that are each true under particular interpretations as to how the object should be conceptualised.

The aforementioned formalisms describe three membership functions, in addition to Cova and Goodchild's original formalism, for describing the spatiotemporal embedding of a vague geographic object. The membership functions differ in terms of the range of truth values they permit and the number of relations that can exist between a location and an identifier. The rod field model described in McDowall (2007) allows the expression of these relationships, and since its structure can be expressed is a set of vertical (time) lines, or points, arranged in a regular grid there is clearly geometric compatibility with the taxel model of space-time used in prisms. Work is under way to explore how well the model can perform in parsimoniously describing complex prisms, and allowing both appropriate representation of the same and the derivation of measures of reliability of quality.

4. CONCLUSION

This paper has sought to explore the data quality issues surrounding a particular kind of derived geospatial construct, namely an increasingly used artefact of space-time analysis: Hagerstrand's prism. There are complex issues surrounding the description of quality in constructs derived from spatial analyses of various kinds. The prism is one of the more complex constructs at present in use, given its spatio-temporal nature and the complex processes which need to be modelled in order to derive the prism. This disqualifies it from being seen as a typical example of its class, but the issues it raises are nonetheless relevant in considering wider issues.

Various forms of potential error or indeterminacy have been identified, and a means proposed for building these factors into a description of a prism which is no longer binary. A data model has been identified that can manage various forms of imprecision or vagueness in the resultant prisms, and so extend ideas proposed by Cova and Goodchild (*op cit*) into a more widely applicable tool. We would argue that this offers a way to simultaneously achieve a more appropriate representation of the prism as object, and a better way to characterise its complex structure and quantify the nature of departure from the purity of the binary prism. Future work will look at evaluating the efficiency and parsimony of such a description, and ways in which the data model may also allow a way to describe prisms that are informed by possible activity options within prisms as well the possibility of simple access to a specific volume of space and time.

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