Computational agents and urban life spaces: a preliminary realisation of the time-geography of student lifestyles

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Abstract

This paper is part of a research initiative that seeks to investigate the interactions between urban structure, life styles and individual spatial choice. In so doing, it seeks to advance our treatment of the concepts of accessibility and location in urban space. The paper itself adopts Hägerstrand's Time Geography as an organising framework and proceeds to deploy GIS and other tools of computational geography to create routine realisations of individuals' action volumes and potential life lines. It then attempts to create an aggregate picture from these. The paper aims to translate earlier work on a discrete cellular implementation of Hägerstrand's geometric conceptualisation of space and time into an improved treatment of access and interaction.

Hägerstrand's concepts of the *life-line* and *time-space prism*, and consequent derivations from these, have provided a means of interpreting an individual's opportunities and constraints in space, and have simultaneously questioned the wisdom of separating time from space in evaluating accessibility and location. The current paper reports on research in progress at the University of Auckland, which attempts to operationalise and generalise these core concepts of Time Geography in the context of student life styles. The initial goal is to provide easier access to the insights available from Hägerstrand's view of the individual, but the long term aim is to develop means of dealing with aggregate phenomena, an area that traditional Time Geography developed only theoretically.

Specific individual models are developed for the case of university students in Auckland, New Zealand. Simplified daily paths are developed for these students through rule-based selection using real-world opportunities and constraints. Key components of the daily paths specified include access to home, work and study in specific locations. The concept of the space-time prism is used to identify discretionary opportunities and action volumes for students. In order to create an analytical structure to manipulate these life-lines and prisms a discrete, three-dimensional model of urban space-time is utilised. Approximately 20 students' daily life-lines are generated to form the basis for assessment of the technique.

Building on these individual life-lines the paper goes on to develop a means of expressing the aggregate manifestation of student activity, including the potential for interaction between students, work and campus sites. A number of spatial parameters of the system are described, including measures of opportunity and access in different parts of the study area. The paper reports on the range of behaviours of the surrogate students that form the basis of the current model, and on aspects of actual student geographies in Auckland. Extensions and areas of practical application in the context of changing university structures are discussed.

Keywords: accessibility, geometric models, space-time, action spaces, time geography.

1. Introduction

The focus of this paper is the problem posed by working with aggregate spatial data when reality is composed of individual, spatio-temporal actors. A critical area in this respect is human process at the spatial and temporal micro-scales: daily life activities at work or on holiday. The two major components of the problem, aggregation/generalisation and time in spatial modelling, are both well known and subjects of considerable literature. In particular, much work has been done on working with aggregation issues based on spatial data, both atomistic (unit record) or existing small area aggregations and interest remains high in this area (for instance Openshaw 1996, Wrigley 19995, Rushton and Lolonis (forthcoming)). A longstanding debate exists on measuring accessibility, a generally aggregate concept derived from an atemporal perspective, and is ongoing (Forer & Huisman, 1998). In coping with this fundamental problem, one significant barrier to progress has been the limited data available regarding individual activity over time and space.

The research strategy adopted in this paper takes three directions. The preliminary one is an exploration of the utility of time geographic concepts as a practical framework (in a computational sense) for describing individual opportunities and constraints. The second is an attempt to identify a range of individual spatio-temporal behaviour options, given known constraints on an individual's time: i.e. to generate the space-time opportunities of realistic actors. The third is to investigate approaches which generalise the phenomena represented by these individual actors into higher-level statements of aggregate activity. This paper demonstrates initial progress in these three areas using the domain of student life styles and a prototype sample of some twenty students.

Section two of the paper outlines some of the developments in time geographic research with particular reference to accessibility and activity scheduling, and relates these to the context of GIS-based modelling initiatives. Section three presents a brief review of work on activity scheduling related to time-geographic concepts, and links this to GIS-based modelling initiatives. Subsequently, section four develops an individual-based geometric model of individual accessibility, and attempts to link the notions of absolute spatial opportunity with the likely occurrence of an activity. Section five elaborates further on this, and draws upon processing power to generate aggregate manifestations of individual-level spatial opportunity and activity potential. The paper concludes with a brief summary and suggestions for future research.

2. The rationale for Time-Geographic concepts as a basic framework

The field of Time-geography is enjoying a resurgence since its popularity in the 1970's and early '80's (Pred 1982, Miller 1991, Ettema and Timmermans 1997). There are two main reasons why this is so. Firstly, continual advances in spatial modelling packages provide a tool-set for the application of concepts to 'real world' problems. This has resulted in both enhanced concepts of access and spatial interaction, and new areas of application. Secondly, there is a growing recognition that the adequate functioning of urban areas depends to a large extent upon the scheduling of many events: public transport services, working hours, and at a more general level, the scheduling of people's activities in both time and space (Parkes and Thrift 1980). A recent call for "spatiotemporal planning" is a case in point (Mey and ter Heide 1997).

The unique feature of the time-geographic framework is its explicit treatment of the time dimension. From this standpoint, human activities, also known as *activity programmes* (social, economic and recreation events) can be seen as having a given duration, and occupying a given location in time and space (Janelle et al. 1988). These locations are determined by a series of constraints which inhibit movement and hence participation in activities (Hägerstrand 1970; 1975). Many kinds of constraints exist in the real world, but this research will consider only the *physical constraints* that limit the ability of individuals to participate in activities and utilise services.

Using Hägerstrand's physical language, it is possible to trace individual movement paths through time and space. Essentially this involves collapsing three-dimensional space into a two-dimensional map, and using the third dimension to represent time. Seen from this perspective, movement is translated into geometric form, which allows us to examine unique individual movement paths or *life-lines* through the day, week, month and year (Parkes and Thrift 1980). The space-time prism is an extension of this concept, which, in 2-dimensional space delineates the total area or 'action space' which is available to an individual within specific space-time constraints. In three dimensions, the prism models the *volume* of space accessible between fixed markers (Miller, 1991). Many studies have used time-geographic concepts in a theoretical or semi-quantitative way, as Parkes' and Thrift's (1980) classic overview illustrates. Recent work has focused on creating ways of developing appropriate techniques and data structures for routinely describing individual patterns digitally. Proposals for a descriptive language or syntax for working with these concepts for modelling have also been made (Forer 1997).

The fundamental outputs from the space-time aquarium approach of Hägerstrand relate to where individual people are or could be at any time. They provide for an individual a statement of what can be accessed (spatially) at what cost (temporally). They also provide useful indications of potential interactions between individuals or facilities. The primal concepts of access and distance are central to the individual's situation, as well as to what might be derived from aggregate patterns of choice and constraint.

Actual data on real life-lines are rare, due both to the intrusive nature of the subject and to the large data collection costs for those willing to submit to the intrusion (Janelle et al. 1988). A number of time-geographic studies have consequently worked with surrogate activity patterns based on stereotyped presumptions of the actor's constraints, or with very small sample sizes. Central to all of these exercises has been the concept of the 'marker' episode, a high-priority event which places particular spatial and temporal constraints on the individual in terms of when the episode begins and ends. Examples of markers include the need to be at work on time for a given duration, to be at home when young school children present after school and to attend a lecture. Most studies to date that use surrogate activity patterns have specified a typical set of constraints (marker episodes) for a hypothetical person, and then examined the opportunities/constraints available to the individual in the remaining prisms of discretionary time. This strategy allows the researcher to identify a full range of locations that could be visited under different mobility assumptions, and the time that could be spent at any of them. It can, of course, be extended to consider the *likelihood* of visiting different places (based on proximity or other factors). This then begins to incorporate ideas of spatial choice rather than constraint (Table 1), and the generation of probable life-lines rather than available volumes of space-time. As a further step it is possible to consider an individual's action in the light of interaction with others, a process which may itself redefine certain marker episodes. There is certainly a steep research gradient when we move from the possible to the (variably) probable, and consequently attempt to populate any prisms with more precision. One attractive approach at any level of complexity is to utilise computational agents of varying sophistication to identify likely individual choices and/or interactions within a given structure of marker episodes and transport infrastructure. In this paper we concern ourselves solely with the first row of the matrix, predominantly with the top left cell, and less demanding methodologies.

Table 1: Options for deploying Time-Geographic concepts for modelling mundane activity choices

	In isolation	*Interactive*
Possible choices	Simple rules and space-time	*Plus* interactive rules and/or space-time syntax

	models	
Actual choices	Complex agents and behavioural modelling	*Plus* loosely coupled decision choices

As noted, the most promising way of advancing an understanding of real world lifelines and constraints/opportunities is to identify or model marker episodes. The more it is possible to identify the conditioning structure of a person's day, the more reliable is the estimation of what can be done with discretionary time. For this reason, amongst others, university student life styles represent excellent subjects. In many cases they juggle three key activity/location pairs: domestic activities at home base, studying at university and working at a work location. The studying component features a significant number of documented marker episodes, and other data (including student questionnaires) can be used to augment these.

To summarise, the time-geographic approach provides a well-documented but not fully exploited framework for examining fundamental issues of human activity and interaction. New tools have provided means of making these concepts operational to varying degrees, and domains exist where large scale surrogate data sets (20,000 individual records plus) can provide a useful platform for experimental analysis of individual life lines.

3. Individual life-lines, activity scheduling, and accessibility

We tend to consider an individual's ability to access a facility as a measure of mobility, while the ability of one or more individuals to get to a place to be a measure of the place's accessibility. In time-geography these distinctions become rather blurred, but the physical separation of people and activity sites, translated into travel time, remains as the fundamental element of accessibility and interaction. However, as an operational concept, accessibility is usually used as an aggregate concept, which in time-geographic terms can be seen in one light as a reflection of people's ability, en masse, to spend useful discretionary time at a place. Accessibility in this light is a higher order product derived from individual time geographies. The core of this paper is concerned with providing descriptions of those individual geographies and then the means of aggregating them in such ways as to describe both accessibility and personal interaction potential. The domain for this is the lifelines and life styles of tertiary students at the University of Auckland. If we can model their individual life-lines and prisms in a reasonable way, we can look with some hope at producing significant aggregate patterns from these.

At the most basic level, almost all human activities are scheduled and structured in time and space, and resulting activity patterns are the manifestation of individual desires and responses to these constraints. In practice, the ability for people to interact with one another or to gain access to the services and facilities which they require depends upon the careful trading of time and space to create sequences of activities which meet personal needs, whether optimally or otherwise (Kivell and Forer 1981). The key issue in building actual lifelines, as well as surrogate ones, is that of scheduling a number of activities in a prioritised way, subject to mobility-determined constraints. Procedures that translate activity needs or agendas into practical sequences are critical to the enterprise.

Lifelines and markers define prisms, and prisms essentially define individual action spaces and activity volumes. For any individual these are the regions of the space-time aquarium which can be physically accessed by that person. Anywhere else is inaccessible to them. Elsewhere we have used the term 'mask' to refer to these volumetric structures.

The ability of individuals to gain access to the services and facilities which they require is often referred to as 'reach' (compare Pirie 1979, Pooler 1995, Dijst and Vidakovic 1997). The 'reach' of an individual is determined by the overlap of the their mask with the masks of others or of specific facilities. This overlap shows where the necessary combination of people and/or facilities can coexist. In keeping with the geometric view of urban space-time adopted in this paper we can define accessibility as a characteristic of an activity place relating to potential use, or, in this case, the potential time that can be spent at a location by a person or group of individuals. This is readily derived from the properties of the intersection of different masks.

Student life lines and prisms represent an interesting phenomenon for study, particularly for metropolitan universities. Being naturally active, students increasingly face the challenges of coping with full time study, work and leisure in the context of rising fees and, often, transport or housing problems (George 1997, Rae 1997). In spite of recent developments in 'virtual technologies' and other initiatives aimed at distance learning (Peters and Roberts 1998), University students still require physical access to university resources for a number of reasons: attendance at lectures, labs, tutorials, access to research materials (those not yet available on the Web), and face-to-face interaction with peers, for both academic and social reasons (Forer 1998). Their lives are simultaneously both fragmented (Boswell 1995) and structured by lectures and other formal academic markers. Lecture timetables and the accessibility of campus sites dominate the activity patterns in the daily lives of students (Tomlinson et al. 1973), at a time when financial requirements to work put additional pressures on their daily schedules. Students are therefore faced with a number of issues that involve making the best use of their time between the fixed study markers in their day, so as to allow both leisure and work.

In this paper we take advantage of the fact that we are able to model a number of components of the student lifeline relatively easily. We know two of the three key spatial locations for their marker episodes (University and home), and can probably make a reasonable estimate of where work may take place. We also can make reasonable assumptions about the start and end times of their days, although with the more bohemian individuals these could be wildly inaccurate at times. Furthermore, we can identify quite closely (through time tables) their marker episodes associated with mandatory presence at lectures, labs or tutorials. Given appropriate assumptions in certain areas we can derive individual life lines and prisms, i.e. the masks of individual students. From these we can move on to derive aggregate measures of access and potential interaction. We report in sections four and five an initial exercise in generating these masks for substantial city area. As noted, the sample on which the modelling in this paper is based consists of 20 students. These have been selected at random from the Commerce component of a total student database of some 20,000 records. The sample size precludes any concrete conclusions being drawn at present, but it provides a test-bed for further model development.

Generating operational life lines and prisms based on the known parameters of students' lives requires three components. One is a data structure in which to model 'known' life lines and prisms in a way, which allows manipulation, aggregation, and query. Another is a working approach to the scheduling of core activities that define these life lines. The last is a routine to build masks, given marker episodes and mobility capabilities as inputs. The next section suggests means to achieve these goals.

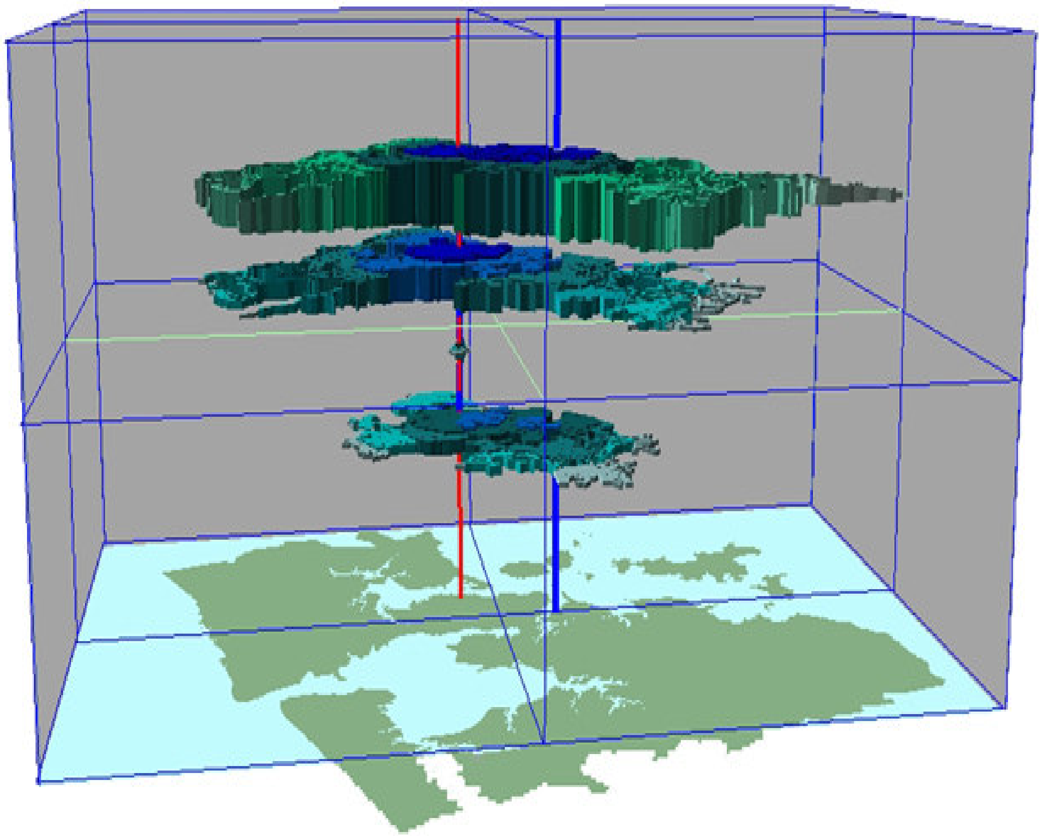


Figure 1: Student's life-line and action volume (markers and prisms)

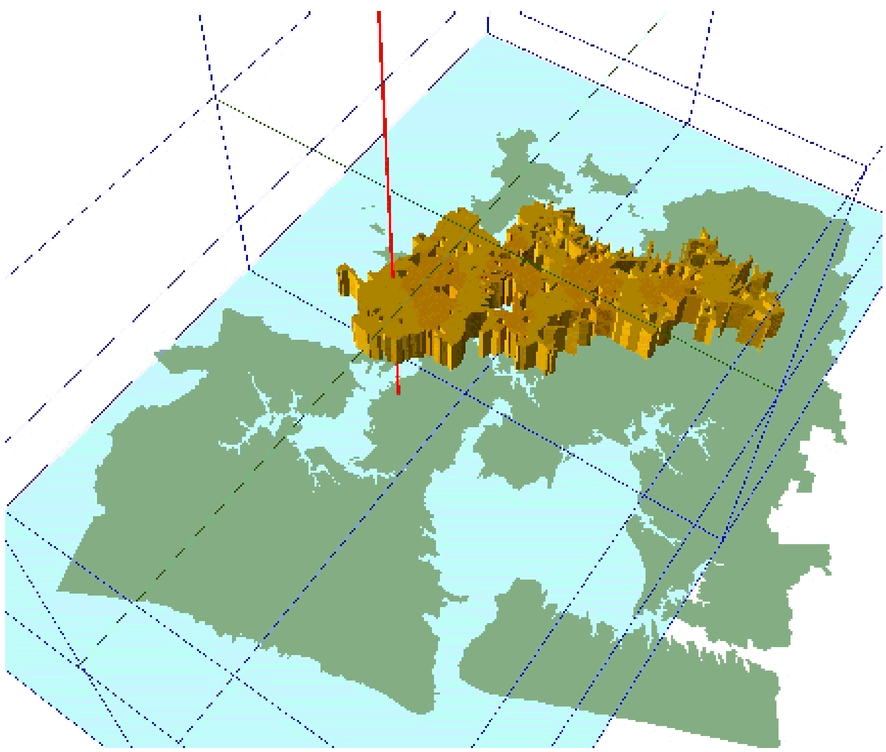


Figure 2: Potential interaction - intersecting prisms to find areas of common space-time

4. Implementing a model of student's daily activity schedules

4.1 A model for Time-Space in Space-Time

The question of how to incorporate time itself into GIS has been a key issue in GIS literature in recent years (Langran 1994, Pequet 1995, Egenhofer and Golledge 1997). In particular, the appropriate syntax for describing and querying events within relational databases has been the subject of much debate (Al-Taha et al 1994). One thing that is clear is that the current generation of GISs are still fundamentally lacking in an appropriate data structure which can incorporate the time dimension.

To implement a model which explicitly incorporates the temporal dimension, the authors have proposed a discrete, geometric model, described in more detail elsewhere (Forer 1997). This approach seeks to circumvent many of the limitations imposed by both vector GIS treating time as a continuous space and database queries based upon time as an attribute. Geometric models adopt a dimensional rather than an event-based view of space, with the advantage being that temporal querying is performed upon the immediate properties of a data model rather than its attribute data. This actually makes certain types of query, and the provision of certain key derivative outcomes (such as action spaces and isochrones of maximum visit duration) far simpler.

The framework adopted here utilises a discrete 3-dimensional partitioning of space-time: in effect a cellular aquarium, retaining Hägerstrand's dimensional conventions. For each mask, each cell in the matrix is either empty (inaccessible) or has a value denoting either presence or potential presence. This structure is clear from closely examining figures 1 and 2.

In figure 1 we see a perspective view from above Auckland, showing a typical student life line and prisms. The vertical axis is time, with the framed box around the map representing the day (the mask). The green cross lines within the box are noon. The red vertical line, provided for reference, represents the University campus location through time. The strong azure vertical line sequence emanating from the map shows the student's life line for a day, commencing and ending at their home. There are three periods of lectures at the University, and the large shaded volumes represent the student's prisms, i.e. the volumes of discretionary space-time they can actually access.

In figure 2 there are two prisms shown, representing two students. As the sequence shows these are interleaved, the common volume representing times and places where both can meet. The vertical extent of the conjoint space at any point represents the time available for a meeting at that point.

It should be noted that the ability to be present in a cell is itself a property of travel time from an origin, or more generally of time-space (Janelle 1968). These properties can be derived from a traditional network analysis. By defining separation for individuals in terms of travel times, but embedding these separations within the matrix of Euclidean cells, the nature of time space can be preserved within a tractable model of space-time.

In line with previous discussion, the geometric objects termed masks are composed of cells, which can represent *actual presence* (the known lifeline or marker episode) or *potential presence* in space-time (the prism). Each object is defined by a volume of cells, which represents its possible presence in space-time. All (urban) phenomena have their characteristic masks, which can be broadly generalised into the four categories illustrated in Table 2. Typically static facilities are represented by vertical rods of cells, lifelines by more complex trails of cells, action spaces by (not necessarily contiguous) clusters of cells and mobile facilities such as mobile libraries by vertically fragmented rods.

Table 2: Classification of spatial processes as objects and events

	Actual presence	***Potential presence***
Intermittent events	Static facilities and amenities	Mobile services and facilities
Continuous events	Individual lifelines	Action spaces

There are various ways to model and visualise such a view of the world, but necessary tools include both raster and network modelling options, the former for coping with the cellular structure and the latter for deriving action spaces within transport constraints. This work is based largely on modules of ARC/INFO 7.1.2., although some work on compressing and querying volumetric structures has been undertaken in C. Geometric space-time is modelled as a three-dimensional array of grid cells, treated as two spatial dimensions and one orthogonal time dimension. The methodology developed so far (Huisman et al. 1997) requires the following inputs to generate action spaces (modelled as volumes):

- Cell size
- Time interval
- Space-Time budget (specifically the temporal limits of marker episodes and related locations)
- Mode(s) of transport

The resolution issue, the choice of cell size in terms of spatial and temporal granularity, is clearly critical, and the choice of the most appropriate values will almost certainly vary depending on the specific context. In this instance the chosen parameters are a 200m spatial resolution and 10 minute time interval. Mode of transport is significant, but can be modelled in a number of ways. In this example only two modes are considered: by foot and by car, with the choice being made largely on the basis of available discretionary time. Deriving the space-time budget is more complex. The aim is to define marker episodes from known constraints and timetables as accurately as possible, so that the discretionary prisms can then be generated. The methodology of computational agents is briefly discussed as a means of achieving these goals, although in this case a simple rule-based system is employed to generate the twenty sample lifelines.

4.2 Agents, scheduling and the estimation of life-lines

Future modelling initiatives will investigate agent-based simulations (ABS) to model lecture attendance and scheduling choices for students. Research in the field of Artificial Intelligence (AI) has traditionally been at the forefront of ABS (see Jeffrey 1997), although simulated agents are being increasingly used in both the Social Sciences and Information Technology to study complex problems such as decision processes and complex behaviour (Smith & Mackaness 1996, Dibble 1996). There is as yet no universally accepted definition of 'agenthood', but it is possible to identify a set of general characteristics, which an agent is considered to possess (Bura et al. 1996):

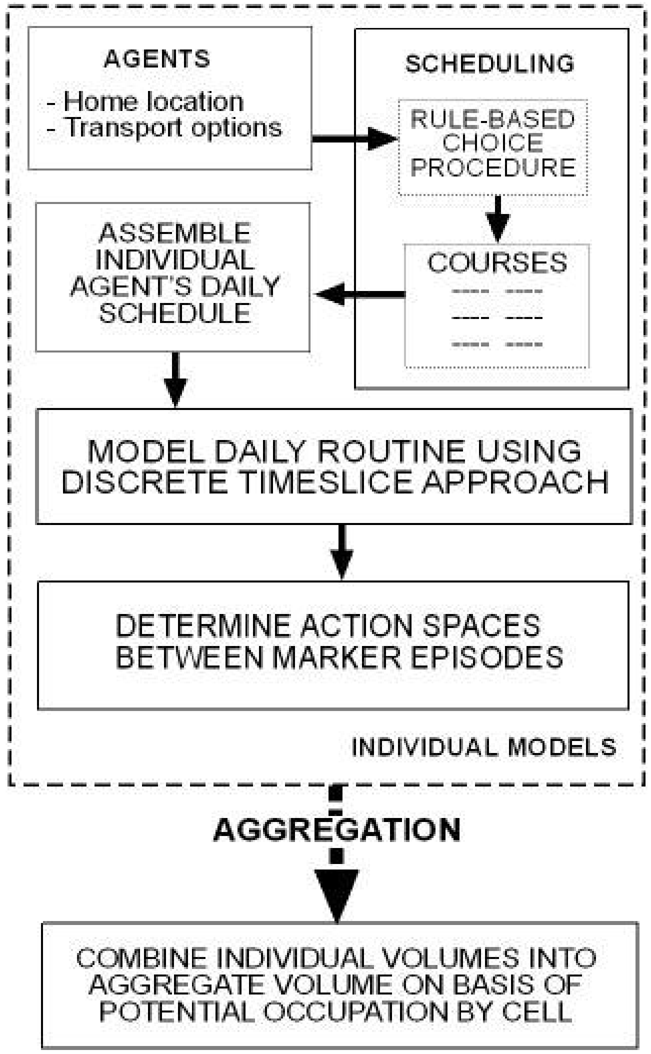
- Agents have intentions, capabilities, and obligations,
- Agents have the ability to make choices and decisions,
- Agents are resource constrained.

In a situation where we consider interacting lives and life lines, the necessary level at which to simulate intelligent behaviour is relatively high, and close parallels exist between classic work on artificial societies (Gilbert 1991) and artificial ecologies (Hubermann and Hogg 1988) (row 2 of Table 1). In the current context we have some strong evidence of necessary structures in the student lives, and the conception of agency used can be less idealised and more process-oriented than the existing AI models (see for example Sloman 1996). The agents conceived of here simply have a set of goals and limited resources with which to achieve these. They are required to make rational decisions about which events they should participate in, given their limited capabilities.

Each agent represents an individual student, who has a daily schedule of one or more lectures that s/he is required to attend. Moreover, each has a set of transport options, which are limited to car travel or walking. Some basic rules are applied to create a structure to their day that mirrors both markers and opportunities. For instance, it is assumed that students who live within 3km of the University will walk to University, and all others drive or are car passengers. It is also assumed that only if their time window exceeds an hour are the agents likely to take their car out of paid parking within Auckland and drive. The relative scarcity of parking facilities at the University of Auckland makes this a reasonable assumption.

The generation of activity schedules is illustrated in the figure below. Agents choose which stream (lecture time) of a given course that they will attend. This decision process follows a rule-based procedure (Vause 1997). First, the series of lectures an agent is required to attend are selected from a database table, along with the times at which those lectures are offered. It is assumed that agents will choose the first available lecture of a given course if this time slot is not already filled.

Figure 3: procedure for modelling marker events and action spaces



Each agent's daily schedule of markers is assembled using this iterative procedure, and action spaces between the marker episodes (lectures) are calculated based on the rules above and an underlying transport model. These prisms represent opportunities for interaction between students and their access to activity sites outside the university. The days currently start and end at assumed times for leaving home (7:00 a.m.) and returning for dinner (7:00 p.m.), although these can clearly be altered or randomised in some way to provide a more realistic model of aggregate behaviour.

4.3 Creating prisms

While almost universally represented as simple conic entities in the literature, the real geometries of operational prisms are highly complex, as even figures 1 and 2 reveal. To make any sense at all the prism has to reflect travel time of the individual; a phenomenon which is itself spatially complex and influenced by both the behaviour of transport systems and the access the individual has to specific modes of transport. In Auckland we should note that any model of travel time should include significant periods of congestion (affecting cars and buses) and student use of cars, while heavy, is far from universal. In the model presented here we restrict ourselves to the dominant mode (cars/motor bikes and walking) with assumed stable congestion levels over the day. We also model these modes as being networked along the same routeways. The latter assumption in particular has some distorting effects where substantial park areas exist which can be freely traversed on foot. Work is in progress on providing a more sophisticated model of transport space, incorporating continuous surface movements for foot traffic in open spaces, rush hour congestion loadings and public transport options.

The creation of prisms uses a combination of network and raster processing to identify travel times to all possible points, beginning from the time-space coordinates of the start and end of the prism period. At the end of one marker episode standard route-finding (allocation) algorithms are used to run routes outwards from the student's location at that time, for a duration of up to ***M*** minutes, where ***M*** is the known duration for the prism. Simultaneously, routes are created out (backwards in time, as it were) from the location where the new marker episode will need to start. Summation of travel times using the two route structures for each network segment provides the means to calculate the potential time available at any point, as well as when that time will start. This information is then used to populate a stack of grids from **t**1 to **t***n*, where **t**1 is the end of the first marker episode and **t***n* a period which terminates at the start of the next marker. The grids can then be treated individually or transferred as a single matrix for analysis.

5. Is there an improved view of access and interaction in all this?

5.1 Probable presence: access, opportunity and likely courses of action

The rest of the paper details some results to date and presents further graphic representation of the masks of single and multiple students. Behind this descriptive exercise, however, is the initial macro-goal of producing a useful means of linking a satisfying description of individual activity into statements of aggregate spatio-temporal behaviour. There are acknowledgments of structuration at work across both spatial and temporal scales in this situation. Somewhere within this larger goal too there is room to consider ways in which this approach yields effective means to query space-time properties of both individuals and aggregate groups. Individually the cellular masks which emerge from the analysis described above have a number of interesting properties which can be obtained from basic orthogonal queries of the stack of grids comprising them. These include queries of individual grid cells (can X be here at time T?), whole grids (how large is the activity space of X at time T?), and stacks (by drilling down we can identify the number of prisms, their duration and the time still available to an individual at a location at a specific time). By combining masks of several individual's we can answer queries about where and when and for how long meetings are possible. By combining infrastructural masks (those for facilities or events) with those of individuals we get insights into how structure and individual can interact. The syntax and capabilities of querying mask structures is being reported elsewhere (Forer and Huisman 1998). The remainder of this paper provides some examples of artifacts generated from operational masks, including comments on aggregation and the issue of 'probable presence'.

The discussion below is focused on extensions of the traditional view of prisms. In that they provide a statement of where people *may be* they have an intrinsic value of their own and help illustrate individual time geographies. The figures below are one more attempt to illustrate how dynamic students' life-spaces can be, and how these life-spaces can vary between students (Figure 4a and b). Compared to figures one and two they effectively re-map the third temporal dimension back into the time component of an animation to show available space varying over time. Basically figure 4 animates the 'reach' of two students over time using two-dimensional 'slices' through their prisms.

In this example the students are the same as those in figures one and two. When interpreting these figures we can note that a single point represents a marker event in progress, in their cases these are either lectures or home periods. Initial expansion of the point represents the start of a discretionary prism, which then expands until the maximum area of access is attained. Contraction follows, back to the point which represents the start of the next marker episode. The animated GIFs used for presentation in these figures are not synchronised, which limits any insights into the possible meetings of the two students used in this example. However, the figures do illustrate the asymmetrical nature of some of the action spaces for students quite well.

Figure 4a and b: Animated GIFs representing individual markers and prisms.

If we move beyond idea of single masks and the delineation of maximum access volumes we can consider two final aspects of masks. One is probable presence, and the other is further aggregation of multiple masks.

Traditional time-geographic studies have often been criticised for a failure to link the range of *possible* access to a place to undertake an activity with the *likely* occurrence of such an activity at a place. The *possible* is defined by the discretionary volumes of the mask, subject to a constraint on the minimum duration needed for certain activities. The *probable* is clearly a subset of this volume which involves many more trade offs and factors.

In standard two dimensional analysis at its simplest, distance is usually the major factor used to model interaction, usually through applying variants of rules which 'explain' the distance decay phenomenon. Three dimensional prisms give us rather more information from which to identify the individual's circumstance and the likelihood of their presence at a place. Combined with a suitable set of parameters, prisms could effectively generate a probability surface of an individual travelling to any point in an area, although we would expect the outputs to be couched in more aggregate terms in all respects. Moving from the prism to the mask it would be helpful to replace a binary definition with one involving some form of relative probability, or the likelihood of an individual's presence within specific cells. Potentially this would provide a way to move towards probable rather than possible action space, as well as generate more robust aggregate statements of activities. Arguably, the *possible* presence of people is really more the domain of emergency services, defence and urgent couriers. The *probable* presence could perhaps tell us more on general activity options and their interaction with urban structure. This is identified as an area for further examination. Realistically, we already know that the family of interaction models based on distance (in some metric) are subject to constraints on accuracy because of the complexity of human behaviour, and function for different purposes with different levels of effectiveness. We should expect no less with any understanding based more on space-time analysis, and only further research will show whether the richness of the conceptual framework will actually help or hinder positive outcomes.

If we are to populate the mask with probabilities, a number of ways suggest themselves. One option is to have declining probability with distance from the marker locations, assuming that people maximise their available free time by minimising travel. This could also be weighted by the total volume available in the prism in some way. We could go one step further and make probability a function of duration available at a point (the *travel time ratio* suggested by Dijst and Vidacovic 1997), which with non-symmetric prisms (the defining markers are at different locations) is not the same as distance. We could weight the cells by characteristics of their contents, for instance open shops. These are not straightforward to implement or validate. However, we present a simple example in which we assume the trade off between travel time and likely cell occupation will be linear with distance, resulting in a relative probability of occupance being generated. Future testing will experiment with travel time ratios as well as more 'traditional' exponential functions of distance decay.

Aggregation is the second issue that we identified. Suppose we wish to generate a volume of *probable presences*, which expresses the likely distribution of 'free' individuals (i.e. those at that time in a discretionary prism) over time. In what follows, we use aggregate masks to develop a picture of possible and probable presence at places in Auckland over time. It is possible to envisage any number of scenarios where such an artifact is useful, if not critical, for decision-making.

Figure 5 is a first step in the derivation of *probable* presence. The figure was generated from the aggregate time supply (in minutes) over a day, for all students in the sample (compare Oberg 1976). This figure illustrates the *relative* likelihood of presence for all free individuals over a day, based on the sum of their discretionary space-time relative to the total available free time (hence attendance at lectures is implicit). It shows a classic radial pattern, modified by Auckland's underlying topography. Of greatest influence in this pattern is the Auckland road network, notably the bridges and motorways which connect the various pseudo-zones of Greater Auckland, to the North, South, East and West of Central Auckland (the main 'landmass' in the centre of the figure).

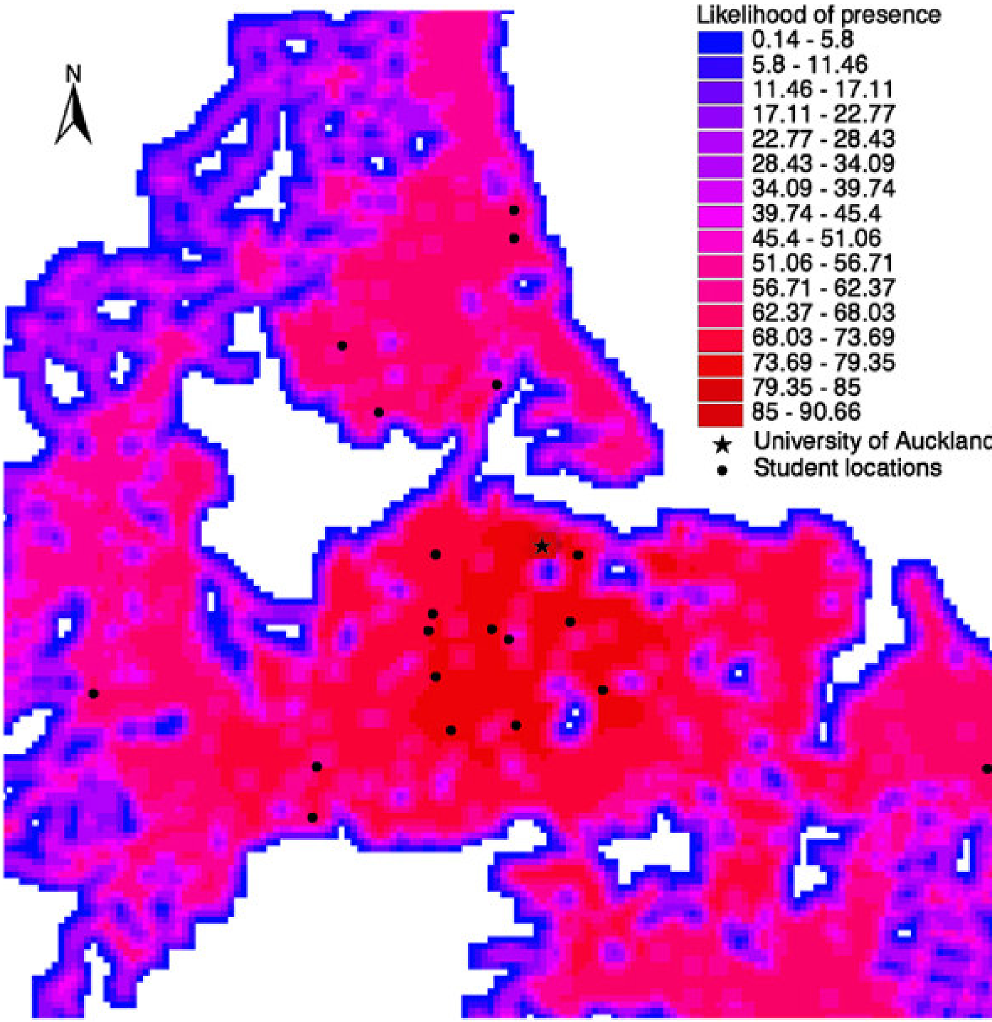


Figure 5: Probable presence for students with discretionary time.

Another example is where one needs to be able to investigate how long a group of individuals can spend in a certain area, not just be there, so we are attempting to illustrate this. The diagram below shows the aggregate picture of this phenomenon: the dynamics of possible presence in Auckland over a day. It was generated by combining all the daily life-lines and prisms for each individual agent into an aggregate surface. Aggregate surfaces were assembled for each time interval, creating a new stack, and an animation generated from these. The surface represents the number of person-minutes that can be spent at a given location by students in the sample. [Click on the picture for a larger view]

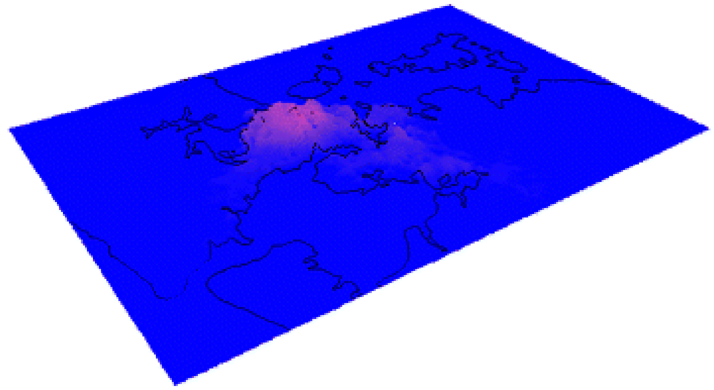


Figure 6: Animated surface representing the combination of individual life-lines and action spaces of students in the sample.

For visualisation purposes the value of each grid cell is used as the z-dimension, as well as being assigned a value from a colorramp from blue to red. A marker shows the time through the day. The red peaks indicate up to 200 person-minutes which can be spent at a given location at that time interval. The spatial and temporal resolution for this diagram is the same as those used previously: a 200m grid cell size and a 10 minute time interval.

The diagram illustrates the scalability of the geometric model for combining complex individual lifelines and action volumes into an aggregate structure. Questions relating to aggregate time use or potential occupation are handled with relative ease. There are various alternative artifacts that can be generated depending on whether the issue is one of possible presence, likely presence, presence for a specified duration, total numbers or total time. Both building and querying are straightforward, and while there are obvious limitations to what can be shown by an animation, recent developments in VRML and other web technologies provide further options for interactive visualisation of these patterns. One could envisage a variety of aggregate geometric representations as a basis for decision support.

6. Summary and conclusion

Despite continued research initiatives, the current generation of GIS and other spatial modelling tools are still currently lacking in a data-structure which will allow them to realise their full potential in terms of modelling the temporal dimension. This paper sets out to operationalise core time-geographic concepts within the current generation of GIS, adopting an alternative approach to the modelling of time. This involves adopting time as a co-equal dimension in a Newtonian framework that itself encapsulates a relative conceptualisation of distance (and then being very careful of the operations that are viewed as permissible).

The concept of agents was used to generate the activity patterns of student lecture choice and attendance at lectures during the day. From here, resulting action spaces were calculated and sets of potential opportunities determined. As illustrated in the previous section, these can be combined using simple algebraic and boolean operators to provide an aggregate picture of access and opportunities for interaction between individuals and groups, as well as with their immediate environment.

The title stresses that this is a preliminary investigation, and the paper has simply sought to identify preliminary problems in the approach, and to generate some initial patterns and analyses. In this it has achieved a number of goals in establishing a general procedure for creating masks and visualisng some individual life lines of students. It has also experimented with some initial ways of combining masks to deliver aggregate pictures of possible activities over space and time based on individual life lines. In the absence of an application domain to evaluate the results the reader is left to form their own judgments, although a knowledge of Auckland helps underline their worth.

Research over the next year is targeted at enhancing various stages of the process by which masks are generated, and establishing a much larger sample of student masks. We hope to generate a range of modules that enable the full range of routine queries to be answered from the masks, as well as experiment with different aspects of probable presence.

We believe that the approach described here has very wide applications. Specifically, however, the application domain of student life styles raises interesting issues of structure and process in an Auckland context. We acknowledge that students, individually, have increasingly problematic lives responding to structures around them. The research above begins to show us how these structures condition choice for them. Conversely, however, students, *en masse*, condition choice for everyone in Auckland and impact on the City's structure : the movement of over 40,000 students into central Auckland daily creates a perceptible traffic thrombosis during term time mornings, which in turn influences many people's life options. Much of this reflects the geography and timetabling of learning. One investigative area we hope eventually to turn to is the central issue of more flexible structures in students' lives: modifying the rigid place and time markers imposed by traditional tertiary delivery. The approach described above could perhaps be capable of assisting the effective development of enhanced structures in the system, as well as cataloguing the implications of individuals' compliance with existing markers as described here.

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