Interoperable GIS and Spatial Process Modelling

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1. Abstract

Recent developments in GIS have focused on the need for technically unrestricted interchange of both spatial data and traditional GIS operations and analysis. In this paper it is asserted that while research in these fields are well advanced, parallel developments in the area of collaborative spatial process modelling development are becoming more reliant on free exchange of both data and models. It is suggested that as these two fields of research advance, the distinction between the two will be blurred. A proposal is put forward for the construction of a system-independent spatial process modelling tool capable of integrating the transfer of data and operations as well as other process modelling functions to complete desired outcomes.

2. Introduction

The development of techniques for access and utilisation of remotely distributed spatial databases via global networks is potentially a 'great leap' for the GIS field (Thoen 1995). The potential benefits of research in this area are the construction of platform independent methods of spatial analysis incorporating the convenient and transparent integration of disparate data sets, and real-time display of queries. In addition to the clear benefits of research in this area, further use of closed proprietary vendor formats is being seen by many organisations as a restrictive practice adding to the desire for open systems (Ayers 1995).

Many current transfer problems stem from the existence of the legacy file formats and complex data transformations required for usability. A similar inefficiency and duplication can be seen in GIS functionality (Astroth 1995). Because of these limitations, Astroth argues that the potential for the further integration of spatial resources has been restricted. While the current developments of the Open GIS Consortium (OGC 1996) in particular would appear promising, the extent of this problem suggests that much more work is required. In this paper, a brief overview of Open GIS will be given followed by the highlighting of some developments in the area of data and process transfer. The papers will then focus on some recent research findings in spatial process modeling before proposing the development of a process modelling tool that attempts combine the two fields.

3. Open GIS: Transfer and Interoperability

The vision of the Open GIS consortium is '…the full integration of geospatial data and geoprocessing resources into mainstream computing and the widespread use of interoperable, commercial geoprocessing software throughout the information infrastructure' (OGC 1996). The proposal is made that GIS software development take the form of 'plug and play' modules leaving the user free to select the best component to solve a specific problem (Glover, 1995). The principal thrust behind the Open GIS

	Transfer	Interoperability
Scope	Data, no Process	Data and Process
Data Unit	Dataset	Object (Dataset or Lower)
Communication	Blind (One Way)	Negotiated (Two Way)
Integration	In Target System	In Server or During Communication

Table 1 – Differences Between Transfer and Interoperability from (Glover 1995)

initiative is the development of GIS interoperability (transfer of data and process) rather than just the transfer of straight data. Table 1 details the differences between the transfer of data and interoperability.

'Interoperability' allows for the analysis of data in addition to the straight exchange. The transfer of these two components (data and process) will now be examined with discussion on some of the related issues, and the most promising route for future research.

4. *Transfer of Data*

"Data are the raw facts entered into the computer" (Shore 1988, p10). In GIS terms, data has traditionally been viewed as the 'raw facts' in the structure of fixed proprietary vendor formats. These formats have resulted from the general evolutionary nature of GIS development itself. Because of the 'barriers' (Glover 1995) created by use of different non-interchangeable vendor formats, efforts to overcome these differences have traditionally been time consuming, difficult and resource intensive. While the development of interchange standards such as the Spatial Data Transfer Standard (SDTS, USGS 1996) are useful for bulk transfer, their use is very limited when attempting online transfer (Ayers 1995). This is because the use of a standard '….requires an extra step, can lose data and create inaccuracies, and requires a lengthy import process….' (Ayers 1995, p60).

Recent developments, possibly spurred on by the Open GIS initiative (OGC 1996) have seen some software vendors starting to tackle this problem (Strand 1996). The GeoMedia product launched by Intergraph in March 1997, features limited data access to other vendor formats, through the data warehousing capabilities (Intergraph 1997).

One solution to the current proprietary format exchange problem, is the use one of a growing number of spatial data interchange software package such as FME (1997) or Blue Marble (1997).

> '*The Feature Manipulation Engine (FME) is a sophisticated configurable spatial data processor and translator. The FME facilitates powerful interoperability between diverse systems, and can be used as the backbone of an on-demand mapping system.*' (FME 1997)

If this type of development is a prelude to future initiatives by other solution providers, and more particularly, GIS providers, then this is evidence to suggest that vendor driven data integration research is progressing favourably. This is consumer driven and reflects a changing attitude towards the importance in sharing data resources (Marr 1996).

5. *Transfer of GIS Operations*

Albrecht (1996,p36) derives a 'conclusive list of Universal GIS Operations' shown in table 2. According to Albrecht, these operations represent the building blocks from which more complex operations may be constructed. These operations were identified by Albrecht from the processes commonly found in existing GIS software and have each been defined algebraically. Algebraic specifications were chosen because they are relatively easy to implement by a functional programming language, and provide unequivocal function definitions.

Once these operations have been defined in this manner it is suggested by the authors that a major step has been made towards the free exchange of GIS operations. Since mathematical definitions exist for GIS operations, a good foundation has been made towards the creation of systems for the remote control of these primary operators

Search	Interpolation; Search-by-region; Search-by-attribute; (Re-)Classification
Locational Analysis	Buffer; Corridor; Overlay; Voronoi/Thiessen
Terrain Analysis	Slope/Aspect; Catchment/Basins; Drainage/Network; ViewShed
Distribution/Neighbourhood	Cost/Diffusion/Spread; Proximity; Nearest-Neighbor
Spatial Analysis	Multivariate analysis; Pattern/Dispersion; Centrality/Connectedness; Shape
Measurements	Measurements

Table 2 – Universal GIS Operators from (Albrecht 1996)

on host spatial databases. Alternatively, mechanisms may be put in place to send locally stored operations to act on the remote data assuming security is not compromised. This is analogous to the use of Java applets, but are too restricted in their operations on the client machine.

6. *Spatial Process Modelling*

There are many actual and potential applications for spatial process modelling, and as such, research into the construction of generic process modelling tools and methods with maximum useability and flexibility are preferable. Parks (1993) recognised that the majority of recent spatial modelling research has focused on environmental issues. This appears to have resulted in a bias towards environmental modelling development as presented in the literature. It is argued here that much of the work reported has general application and thus no distinction is made.

There is great potential for modelling software that integrate the benefits of GIS with the process analysis capabilities of modelling software (Abel *et al.*, 1997; Bennett, 1997). Parks (1993) argues that with appropriate planning, modelling and GIS technology may '...cross-fertilize and mutually reinforce each other' (p31) and that both will be made more robust by '...their linkage and coevolution' (p33). According to Abel *et al.* (1997), this integration in the past has been technically difficult to achieve. Abel *et al.* (1997, p5) argues that many examples of GIS and modelling systems integration '...are typically specific to the component subsystems and to the narrow application focus of the integrated system'.

Ball (1994, p346), defines a good model '...as one that is capable of reproducing the observed changes in a natural system, while producing insight into the dynamics of the system'. This implies that the model has two functions. First, to simulate and predict based on observed processes, and second, provide detailed understanding of the inter-relationships among variables and processes described by the model. Simulation modelling must '...describe, explain, and predict the behaviour of the real system' (Hoover *et al.*, 1989, p5) and '...requires that the model indicates the passage of time through the change in one or more variables as defined by the process description' (Ball, 1994, p347). Ideally, in an integrated geographical modelling system (GMS), as described by Bennett (1997, p337), '...users should be able to visualize ongoing simulations and suspend the simulation process to query intermediate results, investigate key spatial/temporal relations, and even modify the underlying models used to simulate geographical processes'.

The limited development of these models in the past is according to Maxwell *et al.* (1995, p247) due to '...the large amount of input data required, the difficulty of even large mainframe serial computers in dealing with large spatial arrays, and the conceptual complexity involved in writing, debugging, and calibrating very large simulation programs'. An accepted method of reducing program complexity argues Maxwell *et al.* (p251) involves '...structuring the model as set of distinct modules with well-defined interfaces.'. Maxwell *et al.* suggest that the use of a modular hierarchical approach permits collaborative model research, and simpler design, testing, and implementation. Bennett (1997) and Maxwell *et al.* (1995) advocate the use of modelbase management systems to store, manipulate, and retrieve models. Bennett (p339) states that 'by managing models like data, model redundancy is reduced and model consistency is enhanced.'

Maxwell *et al*. (1996) suggest that one way to develop simpler process model design tools, is to construct suitable graphical interfaces for the display and manipulation of structure and dynamics. Albrecht *et al.* (1997, p158) suggest the use of a '...flow charting environment on top of existing standard GIS that allow the user to develop workflows visually.'. In addition Bennett (1997) and Parks (1993) assert the need for artificial intelligence, expert systems, and agents to guide non-expert users in the appropriate handling of these tools and reduce the need for the writing of complex computer code.

7. *Major Issues Spatial Process Modelling to be Resolved*

Besides the difficulties in linking GIS functionality to process modelling software discussed in the previous section, there are potential problems in the standardisation of process model description. This is highlighted by Abel *et al.*(1997) who recognises the need for compatibility with legacy models and identifies the requirement in many cases to 're-use' rather than 're-implement'. To promote internationally collaborative development of sophisticated modular process models as supported by Maxwell *et al.* (1995), there needs to consistency. More specifically, if there can be agreement on the format of a modelling language, then unrestricted development of modelling tools may take place. Other areas for further research include the need for transparent access for spatial modelling tool during operation to high performance computers, support for differing spatial representations, and temporal dynamic modes (Maxwell *et al*., 1996). In addition to these improvements, Bennett (1997) argues the need for developments in four-dimensional data structures, improvements in scientific visualisation, equation generation, and model validation and calibration.

8. *Spatial Process Modelling System II*

It is proposed to construct a system to design spatial process models, permit sharing of model structure, and execute the process model on user selected data.. The functionally independent components of the system will in the form of *services*. Services will initially comprise model design, model interpretation, GIS operations, data conversion, and visualisation. These self contained modules would be able to be enhanced and replaced as required without affecting the rest of the modelling system. This modelling system is viewed as a consolidation and extension of the SPMS modelling system (Mann, 1997).

For illustrative purposes, a very simple model representing a standard cartographic modelling process has been shown in Figure 1. The purpose of this model is to select suitable parachute drop sites given specific criteria relating to maximum ground slope, and proximity close to or away from, air corridors, access roads, and waterways. Figure 1 represents a screen shot of a non-functional prototype of a model design and construction interface and one of the services in the modelling system. The current version of this interface is written in Visual Basic, but is currently in the process of being converted to Java for maximum cross-platform portability. The data conversion service will be provided by FME (1997). To enable this, a specific interface will be constructed between this, and the model interpretation service. FME, does have the minor limitation in that it is platform dependent requiring Solaris or Windows95/NT, but it is believed that with the use of self contained services, future versions of the software may remove this limitation.

Using this object based interface, the user is able to place objects from the menu onto the modelling area. The object may take the form of data inputs, data outputs, spatial operators (defined by Albrecht 1996), and mathematical operators. In addition other specialised objects include time constraints and other sub-modelling components. Links are drawn between the objects, but these serve only to indicate the sequence of processing steps which may be forward or reverse (which provides feedback loops). In this example, the four inputs, slope, airspace, road, and hydro, are linked to either a buffer or overlay spatial operation, concluding in the desired output. The required parameters for each object may be specified by clicking on an object. These parameters vary according to the nature of the object.

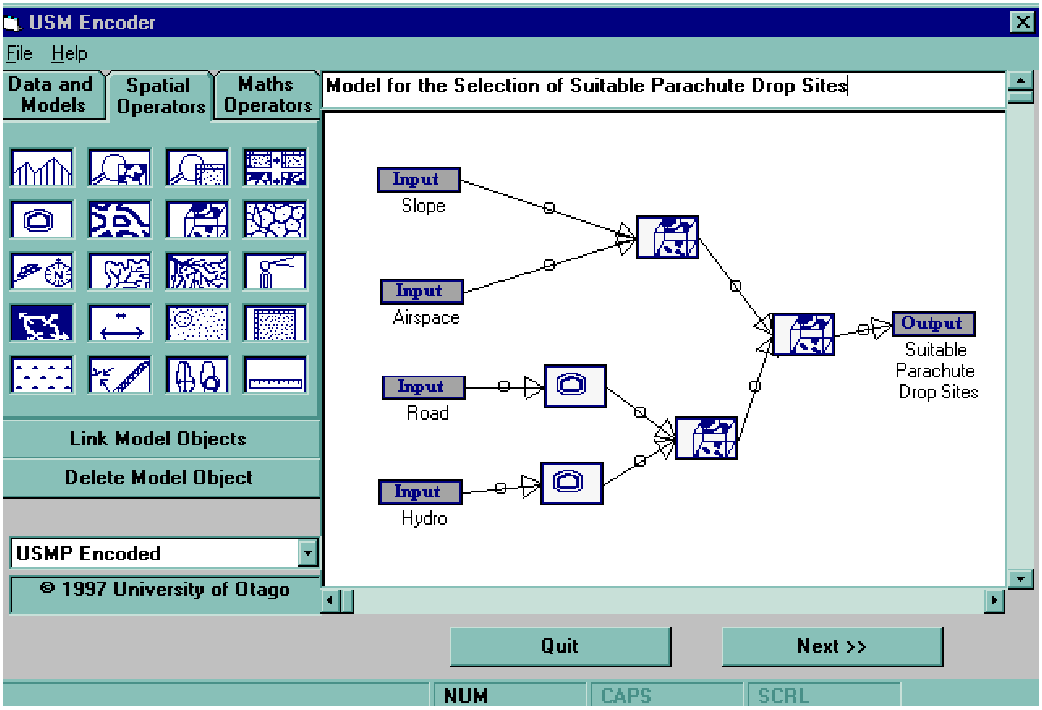

Figure 1 - Prototype Spatial Model Design and Construction Interface

Once model design has taken place, it is intended that the structure may be distributed widely and reused. A potential user may receive the model structure file, and either include it in their own model construction or send it to the implementation service. When opened the implementation service reads the file and determines the required inputs and outputs, before creating a dynamic interface for the specification of required data sources. Figure 2 is a non-functional example of such an interface as it would relate to the previous parachute dropsite problem.

In addition to the specification of data sources and destinations, the interface would also provide detailed model descriptions and limitations, and options for how the processing should proceed. This format will allow users to insert their own data for full utilisation of the model. There are a significant problems to be resolved such as data type specific processing, security, meta-data, and version control.

9. Conclusion

The development of highly sophisticated spatial process modelling techniques, involving the modular and distributed amalgamation of GIS and modelling software capabilities is progressing rapidly. At the same time research is continuing into GIS interoperability, representing the unrestricted exchange of data and process.

In this paper the role of spatial model interchange in relation to the transfer of spatial data and operations has been discussed. Analysis of the features of both suggest a blurring of the differences between interoperable GIS and advanced spatial process modelling systems. A potential conceptual strategy has been discussed, that would integrate some of the more recent research and tools, to advance the knowledge in this area. For the success of such a project it is recognised that ongoing work in the interchange of data and operations is paramount.

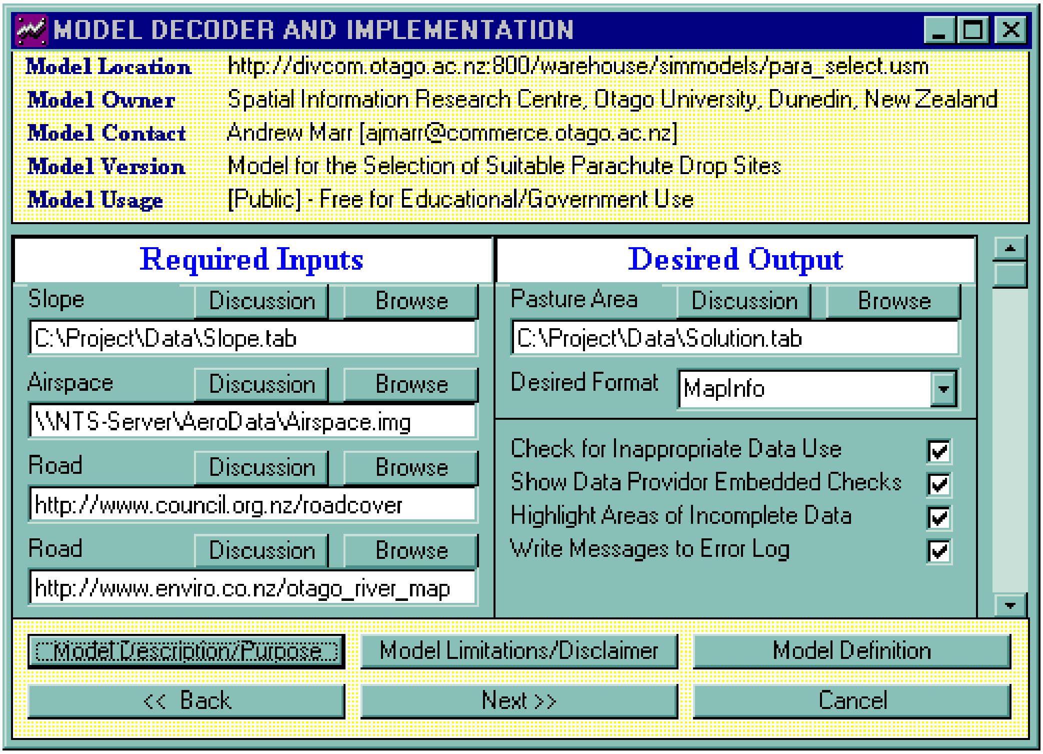

Figure 2 - Prototype Spatial Model Implementation Interface

10. *Acknowledgment*

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