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Review Article

What is GIS and What is Not?

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Abstract

As the title implies, this review of GIS (both GI Systems and GI Science) talks about boundaries – what is "in" and what is "out". In order to do this, the discussion itself must have some boundaries. A Canadian prime minister once described his country as "too much geography and not enough history". Here we will try to minimize both the history and the geography, and see how GI Science (the discipline) impinges on a variety of other disciplines, from Astronomy to Zoology perhaps. In other words, the boundaries of GI Science are becoming much less clear-cut, and fuzzier. It is important not merely to look at the traditional "Geo-" disciplines, but at other subjects which can contribute by overlapping with GI Science. In many cases this overlap may be more a question of mutually useful technology than similarity of applications – so even the distinction between GI Systems (the technology) and GI Science is a fuzzy one. This review is just one opinion, and a brief one at that, of where GIS fits at one moment in time. It will inevitably conflict in parts with the opinions of others. In outline we will look briefly at the initial situation, and see that historically the technology slowly became a new discipline. Since the question – What is GIS and what is not? – involves comparisons, we must look at the boundaries between the "ins" and the "outs", initially for the discipline and then for the technology. Inevitably these boundaries will be fuzzy, with lots of overlap. We will then attempt to use these overlaps to suggest where things might go in the near future.

1 From System to Science

In the old days GI Science was fairly easy to define – it involved putting maps into computers (see Coppock and Rhind (1991) for a historical overview.) The System was the Science. Implementing this idea took many years to complete satisfactorily, both because of the software development and because for any real project the data collection and validation was a major undertaking. We are now in the situation that this kind of automated

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cartography is routine, although the preparation of base maps is still a significant effort. The need for answering spatial "what-if" questions introduced the equivalent of physically overlaying plastic map coverages, and produced the traditional "analysis" functions (buffer zone, polygon dissolve, overlay). The need to query the attributes of the spatial objects produced the current marriage of spatial mapping and databases – GI Systems.

A more recent direction concerns the dissemination of the resulting large quantities of data. Thus much recent work has been concerned with Web-based map display, availability of data files, and with the necessary indexing of all of the data types and geographic regions that are available. This has led to the current interest in Metadata.

However we are now finding that the needs of the people who work with spatial information are not fully satisfied by these available tools and data sets. We are starting to see demands for yet more advanced techniques to assist in the analysis of spatial information. Rather than just static analysis, users are starting to demand simulation of various geographic processes. And rather than attempting to live with a two-dimensional "vertical" view of the surface of the globe people are demanding three-dimensional visualizations. The System is no longer enough. It has broadened into Science. We need to look further (Goodchild 1992).

Nevertheless, the Science cannot be divorced from the System, and we therefore have two aspects: the domain of the discipline ("the Science"), and the domain of the technology ("the System"). We will start by looking at the domain of the Science – and attempt to avoid as far as possible the issues of "What is geography?" by focusing on the types and scales of information implied by "Geo-" or "Geographic". We will then look at the overlaps between the System and related technologies.

2 GI Science: The Boundaries

2.1 Space

Let us assume that GIS relates to the manipulation of geographic data. Geographic data, while containing attribute information such as color, is assumed to have some form of geographic location – that is, some location in space, some reference system. It is normal that this is Euclidean space (either 2D or 3D) but this need not be an absolute requirement. Referring to geographic space implies some range of scales, but there is no reason why GIS techniques may not be applied to molecular or atomic structures, or to stellar or galactic distributions. Put in a human framework, most GIS work will apply to scales where the human observer moves around within the spatial model. It does not apply to scales where a selected motion causes movement of the model (e.g. CAD systems) or to scales where human motion has no discernible effect on the view (e.g. astronomic models, although we may invoke science fiction to override this!) This affects the design of any system manipulation tools – mouse movement appears to change the viewer's position, rather than changing the model's location or orientation.

This gives us some boundaries: GIS works with spatial data, at scales where it is reasonable to change the location of a human observer. While traditionally 2D, due to the fact that gravity encourages objects to accumulate at some particular datum, there is nothing inherent that eliminates working with the third (counter-gravity) dimension. Scale is also important in terms of detail – the level of data collection, or generalization, depends on the application. (At a human scale knowledge of each blade of grass is usually irrelevant.)

2.2 Dimensionality

Within the embedding spatial dimensionality, objects or features may be of the same or lower dimension. In a 2D map we may have 2D polygons, 1D boundaries and 0D points. In a 3D model we may have 3D volumes, 2D faces, 1D edges and 0D points. A 2D map may be the boundary face of a 3D volume (that is, mathematically, a 2-manifold) – as in geography it must be. However, our output devices are almost exclusively 2D, so direct representation of volumes is not possible, and we must resort to bounding volumes, 2D contour surfaces – the equivalent to 1D contour lines on a 2D terrain surface – or other representational tricks in order to view our model. Thus our model may be 3D but our display is only 2D, although improved economical methods for navigating within the screen depth may reduce this limitation. For example, Figure 1 shows a 3D isosurface generated from the visible data points.

Another distinction must be made in the case of 2-manifolds. At the full-model level these must be complete and have no breaks or boundaries, although in practice we may well need to cut them up. As our GIS display is 2D, we can only display part of our 2-manifold at one time (the front part). In addition, many of our operations on this manifold (e.g. triangulations, polygon construction) assume a 2D plane, so construction of 2D manifolds directly is often not yet possible. This is an active research area.

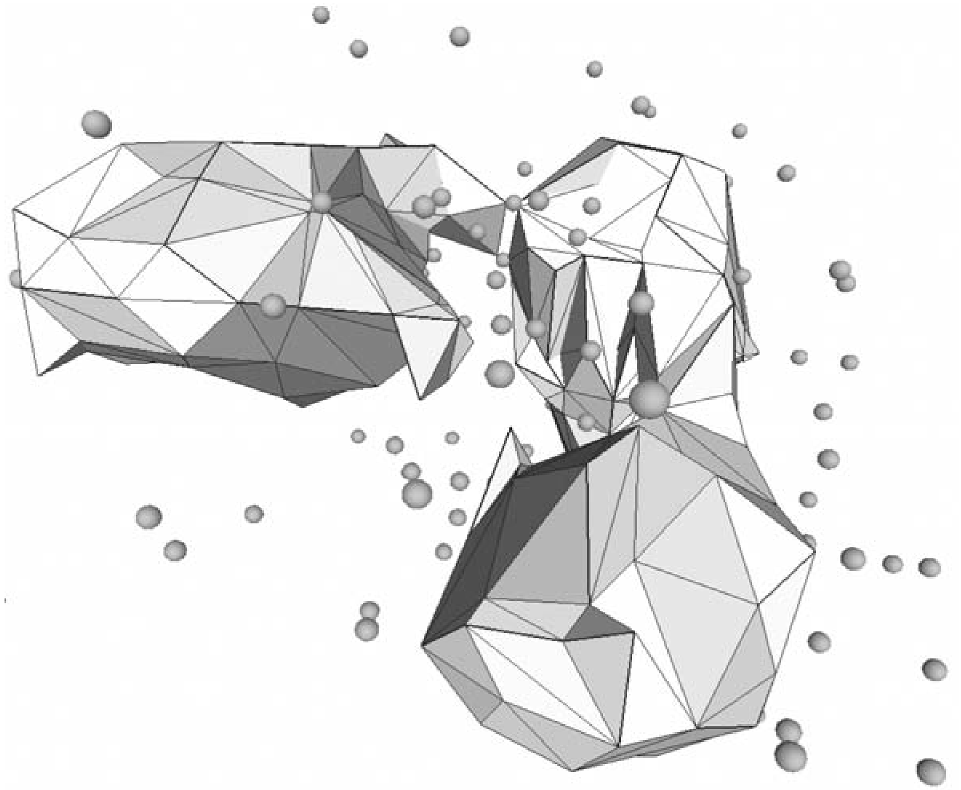

Figure 1 Isosurface extraction from 3D point data

2.3 Connectivity and Topology

For some applications the connectivity of spatial objects is critical, as in terrain models, tessellations and networks. In others it is less important, as in the cartographic representation of buildings or benchmarks. Nevertheless, the increasing demands for advanced analytical and simulation tools is encouraging the trend to fuller topological connectivity. From the early days of GIS the step from discrete entities (e.g. digitized boundary segments) to a topologically connected structure (e.g. a polygon map or a road network) has been particularly difficult.

This is directly in conflict with the world of non-spatial discrete data entities, such as drivers' licenses, which fits easily into the discrete world of databases, where each object has an ID and may be stored in its own little piece of the hard disk. There is no denying the spectacular development of relational databases, but the challenge of storing the links between for example, polygons, polygon boundary segments and polygon nodes, is not yet resolved in a satisfactory fashion. Since these relationships are relatively easily handled with the techniques of object-oriented programming, perhaps the development of object-relational databases will simplify some of these problems. Nevertheless, the management of attribute data associated with geographic information is less problematic than the spatial components. There are no particular boundaries to the attribute management of static geographical information. (A clarification must be made here: the frequent need for connectivity at the science level does not imply that it is necessarily implemented at the database level. It may be stored explicitly, but equally well it may be generated from discrete objects on the fly as required.) Software issues of connectivity include, but are not restricted to, questions of topology.

Location change is readily achievable for discrete entities by using a relational database. However, the relocation of objects, such as the diversion of a road, leads to problems of potential overlap and collision. Collision is fundamentally a topological question, as in principle it should not occur in a network of adjacency relationships without some of the previous relationships becoming false. However, in practice simple geometric tests may suffice in the majority of cases of cartographic feature displacement. The main problem of spatial change arises when it occurs in a topologically-connected system.

The 2D "topology" we are discussing here is the preservation of a connected graph on a 2-manifold (think: road network or polygon map). What happens if a node (junction) or point (intermediate position on an edge) is displaced? Often the result is still valid, but sometimes an edge will cross another edge forming (since this is a planar graph) new intersections and nodes – which means we are not preserving the graph. If we keep on going, we might move an edge so that it moves completely from one side of another edge to the other – which would break the topology rule that the order of edges around a node must be preserved. (Basically, manipulation of 2-manifolds involves ordinary graphs with the addition of this topological rule.) Thus spatial change needs to detect these collisions before the topological connectivity changes. One possible approach is to preserve spatial relationships in the form of Voronoi diagrams (Figure 2).

2.4 Time

Just as for the spatial dimensions we consider GI Science to work within a "human scale", so the appropriate time scales should also be human. Thus work at the nanosecond scale

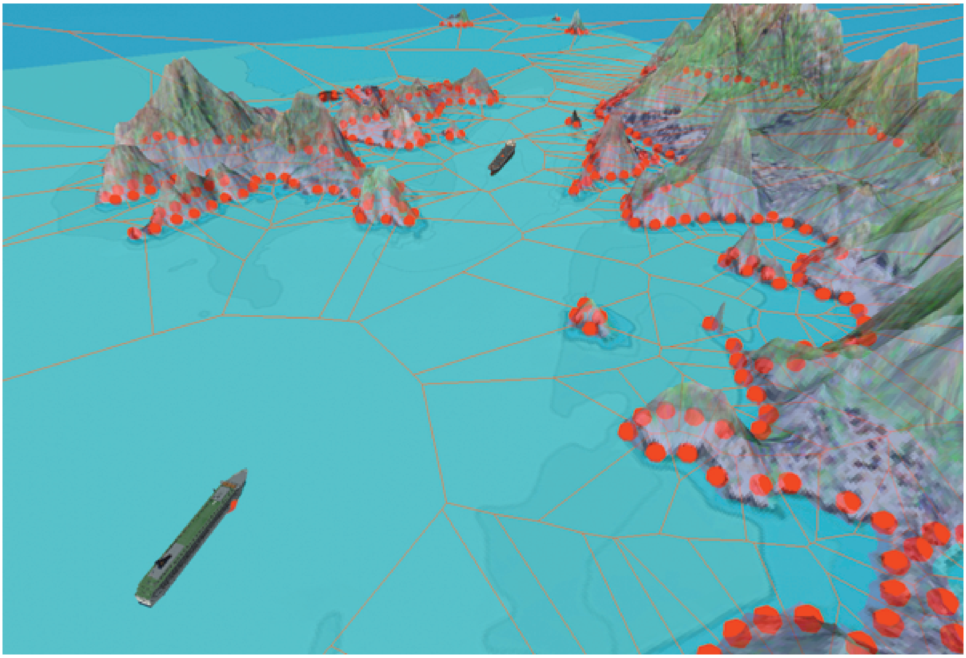

Figure 2 Voronoi cells used for collision detection in a marine GIS. This figure appears in colour in the electronic version of this article and in the plate section at the back of the printed journal

probably belongs to physics, and work in the millions of years belongs to geology or astronomy.

While three spatial dimensions for GIS suffice, the absence of time and change from the traditional GIS model is still a major concern (Langran 1992). Attributes of discrete entities may change abruptly – in which case a traditional relational database may manage the change, along with a date stamp and an archival copy of the previous value. A map may thus be constructed for any specified date. If the change is gradual, some formula needs to be applied in each case in order to construct a map for some desired date. The same is true if the change is cyclic – e.g. summer and winter conditions. Thus managing attribute change for discrete entities appears feasible.

2.5 *Fields, Objects and More*

GI Science is perhaps unique in its concern with the fundamental types of information being manipulated. "Fields" imply the existence of a value throughout the study area (show me a place with no land elevation, or no temperature). But we cannot store continuous fields without breaking them up into discrete pieces. "Objects" are discrete, but they must be embedded in space, and therefore have at least implicit relationships with other objects, arguably making a continuous field with discrete attributes. (Point randomly at a map of houses and the result is "house" or "nothing". Point at a proximal map of these houses and the result is always "nearest house".) This dichotomy has been recognized for many years. Mark (1999) gives a good discussion of the issues in GIS. Even Einstein (1961, p. vi) contributes: “I wished to show that space-time is not necessarily something to which one can ascribe a separate existence, independently of the actual objects of physical reality. Physical objects are not in space, but these objects are spatially extended. In this way the concept of ‘empty space’ loses its meaning.” There is a variety of plausible spatial models.

One plausible answer is to treat all data sets as Voronoi diagrams – what Aurenhammer (1991) called “the fundamental spatial data structure”. (These may also be referred to as Dirichlet domains, Proximal maps or Thiessen polygons, as they have been rediscovered many times.) Thus discrete objects are the generators of Voronoi cells, giving topological relationships, and fields are represented as sets of tiles (often on a square grid) whose values may be either located at the centre or spread equally throughout the cell. In two dimensions we are still working with a connected graph on a 2-manifold.

2.6 3D is Different

Working in 3D has several differences from working in 2D. A primary concern is visualization (still restricted to 2D for most of us). Thus what we display will be one or more surfaces, in perspective view – perhaps one for the terrain and one for each building superimposed on it. Individually these exhibit 2D relationships, but the links between separate surfaces or shells is more complex. Internally we may be working directly with these surfaces, or else they may be extracted as required from a full 3D (volumetric) model.

A 3D surface GIS model implies one or more 2-manifolds which, unlike a terrain model, need not necessarily project well onto a plane (i.e. be monotonic in X and Y), and may have overhangs, holes and handles (bridges). Connectivity consists of graphs embedded in these 2-manifolds, implicitly or explicitly, expressing tile adjacency, road or river connections, etc. See Figure 3, and Tse and Gold (2004) for applications in urban modeling.

3D topology may be similar to the two dimensional case if we are only concerned with the exterior of particular “shells” or of the overall terrain model. Irregular volumetric models are best handled using the 3D Voronoi diagram, as the geometric construction rules, as in 2D, enforce a consistent topology in all but the most degenerate cases (and even there the problems are with the precision of computer arithmetic and not with the methods themselves – see Ledoux and Gold 2006).

A 3D volumetric GIS model implies partition into 3D tessellations (implicitly or explicitly) for either field or object data. However, for the 3D volumetric case connectivity is a graph showing the adjacency of 3D cells with a common 2D face, as well as the connectivity associated with the shared faces, edges and nodes, expressed by the dual graph (Figures 4 and 5, and Ledoux and Gold 2006). Interpolation implies a form of connectivity, as 2D or 3D local interpolation is a space-filling function based on the relationships of the query location to the nearby data objects.

2.7 Change

If we intend to model Change with time, then we are starting to look at aspects of “simulation” that are not necessarily part of traditional geography. By “simulation” here we may mean modeling the change over time of our attributes (e.g. within a population density map organized as polygons), change over time of the spatial location of our objects (e.g. marine navigation) or change over time of our connectivity

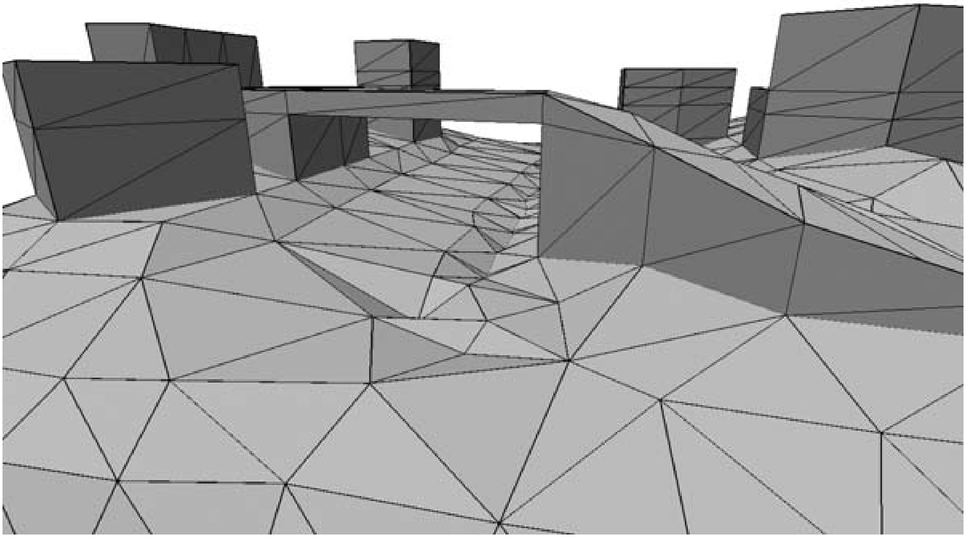

Figure 3 Integration of bridges, holes and buildings within a terrain model

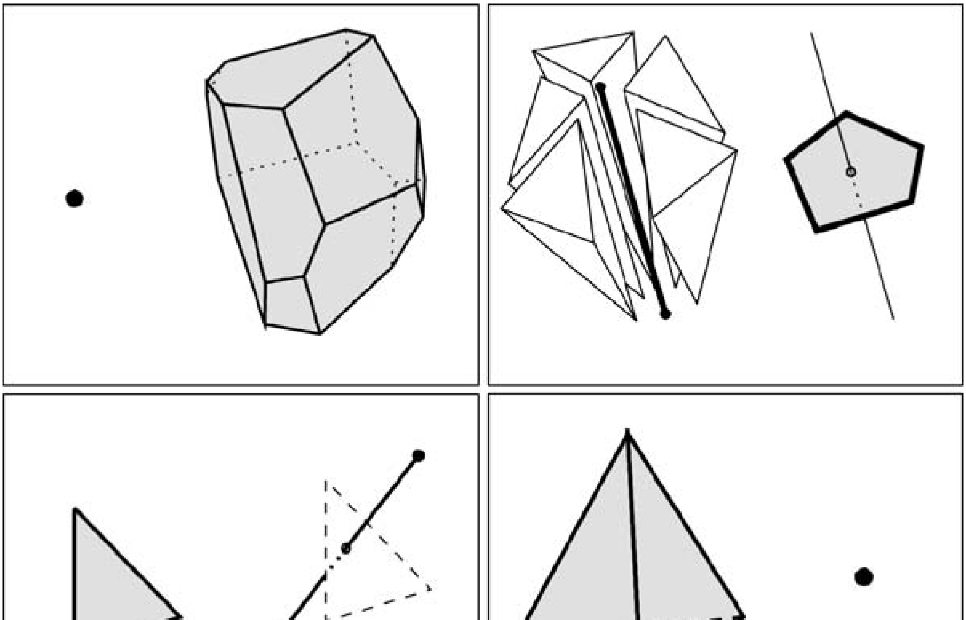

Figure 4 Duality in 3D: point/volume; edge/face; face/edge and volume/point

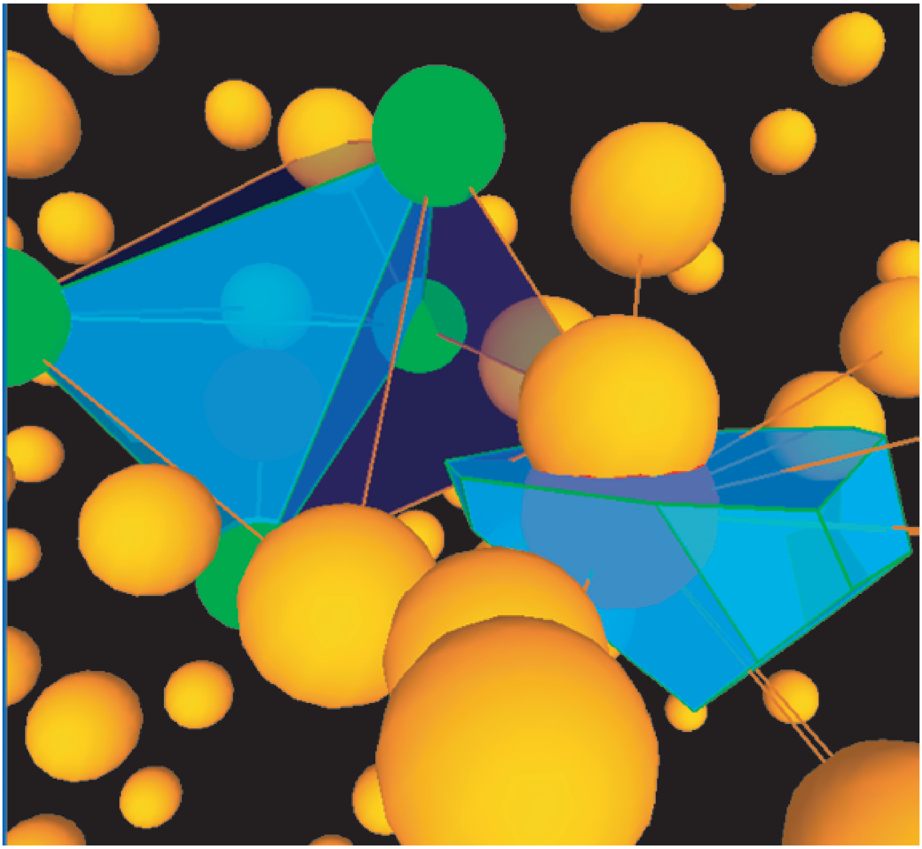

Figure 5 A Tetrahedral element on the left, and a Voronoi cell on the right. This figure appears in colour in the electronic version of this article and in the plate section at the back of the printed journal

(topology) (e.g. the movement of a foam of bubbles). By "simulation" we may initially mean entering the changes by hand on a paper map (e.g. population after each census), followed by computer automation of the procedure (and of the visualization), or full simulation by defining some mathematical function that attempts to describe the behavior of the process, and letting this drive the previously-described automation.

It should be noted here that "change" does not necessarily mean attribute change over time (dz/dt) – it could also mean attribute change over space (dz/dx), spatial change over time (dx/dt) or even their inverses. Examples of these include forest growth within stands (dz/dt), height change over the landscape (dz/dx) and polygon boundary migration over time (dx/dt). These changes may be continuous (as in a smooth landscape or steady forest growth) or discrete (as in a cliff, a forest fire or a manual map update). For details see Gold (1991). All of these types of change are forms of simulation (and this idea classifies terrain surface interpolation as simulation of attribute change with changing location – which is reasonable). All of these may fall within GI Science, although they have often been used, and developed, within other disciplines.

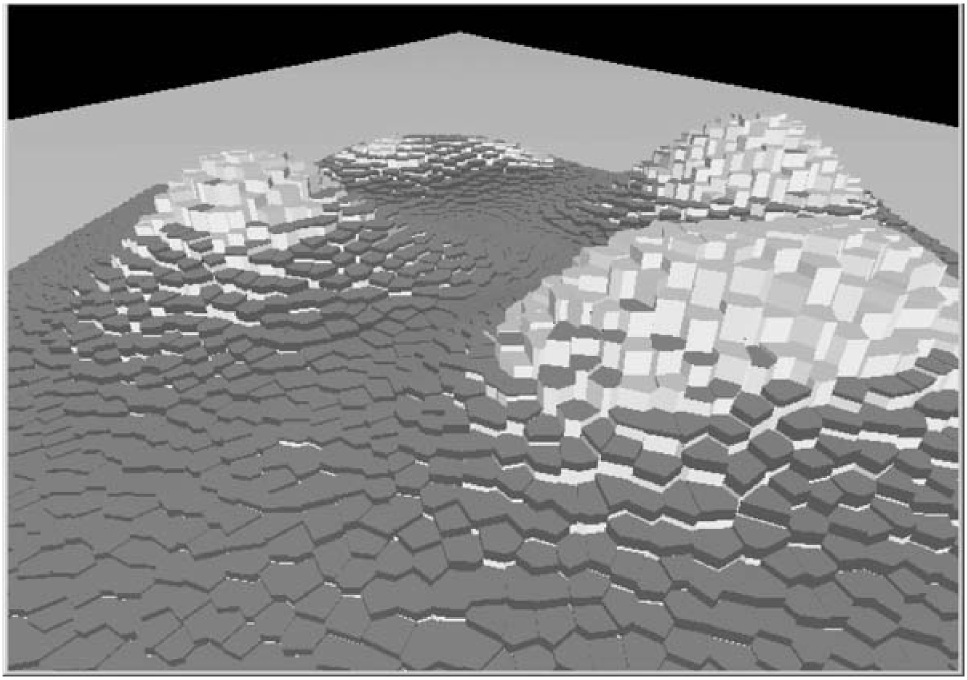

Figure 6 Surface water runoff: Eulerian flow between fixed irregular cells

"Managing Change" can therefore be applied to many problems. The simplest in concept is map updating: read a "log file" ordered by date, and insert or remove the features that have changed. The log file can be read from the beginning to any specified date, giving a map for that time. However, this is often not easy to achieve. In particular, if there is any topological connectedness then it is often not obvious how connections are to be re-formed automatically after adding a single element. Updating of attribute values alone, however, is often feasible with this approach. Movement of topologically connected objects, such as Voronoi cells around moving objects in a collision-avoidance system, requires a dynamic topology maintenance system – and most topology-constructing systems are static. (A dynamic system allows local updating of the connection changes, but typical static systems rebuild the whole network for each change.) A good illustration of the two is to compare Eulerian and Lagrangian fluid flow modeling. In Eulerian simulation a network of cells (usually a regular grid or Voronoi cell structure) is initially constructed, and flow is assumed to be a transfer of fluid between adjacent cells (Figure 6). In Lagrangian simulation each node is assumed to be a fixed mass of the fluid, and their interaction produces movement of the nodes. In free-Lagrangian simulation the topology is capable of being updated as the nodes move – often by using dynamic Voronoi data structures (Mostafavi and Gold 2004). These methods may be implemented in 2D or 3D.

2.8 Interaction and Visualization

Intimately linked to "Change" are the issues of Interaction and Visualization. In 2D we may often want to edit our map or spatial representation, which requires a vertical view at the appropriate location and scale, as well as tools to edit the objects and, if necessary, the topology. In 3D the change in view is more complex, involving perspective transformations and the ability of the observer to navigate within the simulated world. This must involve an intuitive interface, as poor interfaces (especially for spatial movement) often disorient the user, rendering the system useless. Changing or editing the data requires an effective set of graphics tools to allow easy "picking" of the appropriate map elements within the 3D display, as well as allowing modification of the spatial data structure. (It is rare that a 3D model consists entirely of discrete objects.) Game technology is a basic resource for scene visualization and navigation, but it rarely permits all but the most basic editing or scene modification – usually by blowing the object up!

2.9 Conclusions: GI Science

We can therefore place tentative boundaries around GI Science. It concerns information with a spatial location. This space is Euclidean in metric, and associated with the Earth (the Geographic component), implying that the information is meaningless if it is moved to a different location. The spatial scale is human, in that it is possible to imagine the human observer moving around within its limits and obtaining different views. This information may be associated with fields or objects, but field information in practice is associated with discrete contiguous tiles, and discrete objects are implicitly associated with some form of adjacency network or tessellation. The space is fundamentally three-dimensional, but for many applications a projection onto a single two-dimensional datum, or perhaps onto a terrain surface, suffices. These are 2-manifolds, without boundaries, although in practice they often need to be partitioned.

GI Science is also concerned with the attributes associated with these objects, points or tiles. These may vary widely in type, but are associated with a spatially located object. In the object-oriented model these attributes (fields) may be simple values, or else pointers to other objects (which provide the topological linkages required to preserve the graph structure). 2D systems often require a graph embedded in a 2-manifold, but 3D systems often require more elaborate structures. Managing change in the world model is becoming an increasingly important issue, which means that GI Science is expanding into (or being taken over by) other disciplines, e.g. hydrology. Simultaneously, the demand for more realistic, and 3D, visualizations expands the shared features with game development, computer-aided design and engineering, to name a few. The future clearly involves more integration at a discipline level, as well as at the system design level – which requires more system, graphics and programming knowledge within the GI Science community.

3 GI Systems: The Boundaries

The boundaries of GI Systems are somewhat different from those of GI Science. Whereas GI Science is constrained by the "human" scale, some of the tools that are useful for manipulating spatial objects of any scale may also be useful for the human scale (e.g. CAD systems), and some GI System tools may be useful for other, non-human, scales (e.g. contouring used to map electron density, or cosmic background radiation). Another example is the technology of game development – surely the attraction of games demands some human scale, but it is rare that the landscape being modeled is part of the "real" world, although there are some exceptions. Thus, having some idea of the range of GI Science, we can look briefly at disciplines that might produce tools that could overlap with it. We can also look briefly at other disciplines where GI Systems might be appropriate. We will use the same categories as before to suggest appropriate directions.

3.1 Space

The biggest technological issue for GI Systems is the management of space, so we can probably eliminate subjects where this is not relevant. Traditional database management systems, for example, are not GI Systems. However, recent commercial developments make it clear that having a spatial component is a big advantage to many database applications – and so these are being developed. How much has to be added before these can be considered a GI System remains to be seen, but it should be noted that while effective databases are necessary components of most GI Systems, the technology transfer in the other direction has been more limited – databases remain preoccupied with discrete data elements, while space is inherently topological. Rapid reconstruction algorithms may be removing this obstacle for some applications (e.g. polygon shape files), but it is not obvious that this is appropriate in other cases (e.g. very large road networks or terrain models). It seems that storage and retrieval of large graphs remain important research questions.

Other space-manipulation systems seem to have a direct application to GI System development. Examples include CAD systems, flow modeling systems (e.g. ground or surface water modeling), navigation systems and game development tools. Disciplines having a direct impact on GI System development are mathematical subjects such as graph theory and topology, and computer science subjects like computational geometry and computer graphics.

3.2 Dimensionality

In 2D, drawing systems had a major influence on the development of automated cartography, and it is still common for cartographically complete maps to be exported to a paint program for final touch-up. Indeed, some modern GI Systems appear to add image analysis and image processing tools within their basic design. It would seem clear that, from the broad perspective of this review, image analysis and remote sensing form part of GI Science, even though their techniques are more concerned with manipulating fields than with defining objects and storing them in a database. (This second case, feature extraction, leads directly to transfer to a GI System.) However, 2D drawing systems do not usually have any topological structuring, which is now considered necessary in modern cartographic systems.

In 3D, GI Science is still relatively weak, and has a lot to learn from CAD systems (e.g. Lee 1999) and 3D modeling in computer graphics (e.g. Hill 2001). In both these cases the emphasis is either on manipulation of a connected surface model (b-rep) or on the superimposition of volumetric primitives (Boolean). Boolean modeling is not particularly useful in GI Systems, but the incorporation of b-rep models (graphs on the 2D manifold) within TIN modeling would greatly enhance the functionality of 3D GI Systems. At present the terrain and any added features, such as buildings, are not usually topologically connected, preventing applications such as navigation and flow modeling that might require knowledge of all potential obstacles (Tse and Gold 2004).

3D volumetric modeling requires solid cells, rather than surface models. Currently the major experience in this field comes from disciplines such as ship or aircraft design, geological modeling, and ocean or atmospheric modeling. Simple regular Eulerian cells (voxels or octrees) are the most common, but irregular cell models, e.g. Voronoi or tetrahedral, are becoming more common. The basic algorithms and data structures for many of these come from recent work in computational geometry, as there are many issues of arithmetic precision, data structures and complexity that require a specialist's experience (Ledoux and Gold 2006).

3.3 Connectivity and Topology

This has traditionally been weak in 2D CAD systems, fairly good in individual applications of 2D GI Systems, and good in 3D CAD systems and computational geometry research. 2D and 3D simulation, such as fluid flow, require good connectivity models. Simple systems work with 2D or 3D grids, depending a lot on the quality of the algorithms used to interpolate the grids from the original data, but systems that adapt to the real data distribution are now available in some more advanced software. It seems clear that any significant advances in 3D or simulation within GI Systems will require a more thorough understanding of the issues of generating a satisfactory set of connections between the data elements, and providing a generic volumetric data structure.

3.4 Time

In GI Systems, time is largely limited to snapshot maps compiled with considerable difficulty from time-stamped data – unless only attributes have changed. The problem of updating a topologically connected map is still considered difficult, even with modern object-oriented techniques. Similarly, the increasing demand for simulation is relatively easy to provide for flow between fixed cells, although this is rarely incorporated in GI Systems. Where movement of spatial entities, navigation, collision detection or cell movement is required, the development of kinetic spatial data structures is needed – still a research topic in 2D, although results from computational geometry are very good. The development of kinetic data structures and algorithms in 3D is just beginning. Finite element and finite difference simulation is well known in 2D and 3D, for example in surface runoff, groundwater flow, geological reservoir modeling, and others. Integration of these methods in a GI System is rare, and information transfer between the two applications is often difficult.

3.5 Fields, Objects and More

GI Science is perhaps unique in its concern with both fields and objects within the same project, but most current systems are limited to two views: "raster" for fields, and "vector" for objects. Most applications fall within one domain or the other – e.g. CAD object design, or atmospheric simulation. However, fluid flow simulation requires boundaries, which must be integrated into the mesh construction process. The integration of GI System tools with flow simulation packages would undoubtedly simplify many applications. A consistent set of data structures for both fields and objects would greatly simplify development – one approach is the 2D or 3D Voronoi model. Following Einstein (1961), cited earlier, all discrete objects could be considered as fields.

3.6 3D is Different

GI Systems and GI Science practitioners have had little real experience of modeling and simulation in 3D. The techniques and data structures are much more complex. That, however, is not a sufficient reason to avoid the topic, as the demand from clients will inevitably increase, and many of the problems have already been addressed in other disciplines. GI Scientists really must start attempting to learn from more rapidly advancing disciplines, or else be left even further behind.

3.7 Change

Similar comments also apply to the management of time within the GI System. The study of change of discrete objects has progressed considerably, in conjunction with database design, but little thought has yet been given to the management of change in a spatial network, except for problems of map generalization. When such change is a direct function of world time, rather than of manual map editing, there are still few available resources except a little work on free-Lagrange methods for fluid dynamics, and recent studies on kinetic spatial data structures within computational geometry. Here again collaborative work with GI Science could produce valuable results.

3.8 Interaction and Visualization

The human-computer interface has received a lot of attention in recent years, especially for computer games and CAD systems. The first component is the specification of the relationships between 3D objects, and with the observer (or observers if there is more than one window). This has largely been resolved with recent 3D graphics cards, algorithms and languages – especially OpenGL and DirectX. The combination of matrix transformation techniques for relative object positioning and orientation, development of scene graph models, and vector algebra formulations of lighting, orientation, areas and volumes – together with object-oriented programming techniques – puts graphical software development within the hands of anyone who wishes to make the effort (Hill 2001). The second component is the direct interaction of the observer with the simulated world, allowing object modification or construction. This has been developed effectively for CAD systems and computer graphics modeling, but it needs to be modified somewhat for integration within a GI System, as the observer-object relationships are less clear (for example: if I move the mouse to the left, do I rotate the object viewed to the left, as in the case of a small carving, or do I move myself to the left, as in the case of climbing a cliff?) An interesting application is the idea of a "Marine GIS" (Figure 7; Gold et al. 2004). Some good work is being conducted in oceanography, but intuitive interfaces are still difficult (Ware 2004).

3.9 Conclusions: GI Systems

The emphasis in this section has been on the techniques, algorithms and data structures needed to continue extending the GI System towards a closer simulation of the 3D view of our simulated world, and towards the simulation of processes, such as water runoff, within that world. Inevitably this means speculating on the integration of GI System tools and those of other disciplines – geology, computer science, CAD, etc. Unfortunately

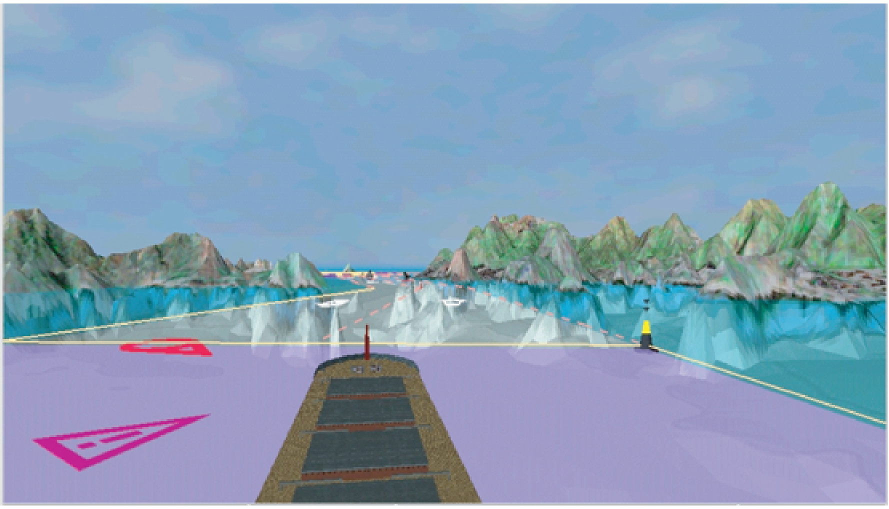

Figure 7 Navigation simulation with a marine GIS. This figure appears in colour in the electronic version of the article and in this plate section at the back of the printed journal

the spatial data industry has had relatively little experience in handling these needs. Simulation has traditionally been in the province of specific engineering and equivalent disciplines, and three-dimensional modeling and viewing techniques have largely been developed by the computer-aided design (CAD), computer graphics, computational geometry and game development disciplines. If the (geographical) spatial data industry wishes to respond to these needs it will largely have to look outside its tradition or skill base in order to develop the appropriate tools.

4 The Future

Inevitably the application of GI Science affects the definition of GI Systems and their implementation – databases, visualization, etc. Similarly, the functionality of GI Systems feeds back to the understanding and practice of GI Science. "The Science is the System" could be the epitaph for both, if by this we mean that we can only think about manipulating spatial data within the terms of the functionality of a particular system or approach – the Science comes from the System in this instance. Equally, "The System is the Science" is undesirable, as developing the GI System purely for the GI Science excludes those other disciplines that have developed their own insights and tools for the manipulation of spatial data, but which could contribute tools and methods to expand both the System and the Science. It becomes more and more clear as we progress that no discipline has a monopoly on spatial data, and that we all benefit from shared developments and insights. There is no longer any excuse for ignorance of others' work, of reading only "our own" journals. Success will largely come to those who learn about, appreciate, and use work from new and different places, outside the security of what we previously knew.

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