Raster versus Vector Data Encoding and Handling: A Commentary

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RASTER AND VECTOR data structures are two alternate methods for representing spatial phenomena. As models, they each have strengths and weaknesses for describing conditions in the real world. We use these models regularly in geographic information systems (GIS), yet perhaps we do not give enough consideration to the generic or intrinsic differences between these two methods of representing spatial data. We might well ask: Are technological developments favoring one or the other method? Is integration between them possible and practical, or is one method going to become dominant over the other? The answers to such questions are important to all who are investing in geographic information systems (GIS) technology, both as users and developers.

HISTORICAL CONTEXT

The vector method for representing spatial phenomena has, throughout history, been the most common. The development of cartography was based on the use of lines, or "vectors," to represent entities such as roads and streams, and to define edges between different spatial features such as land and water. Surveying and map-making techniques were founded on the principles of geometry and trigonometry which employ vectors.

We were, perhaps, from the beginning implicitly aware that such lines often imposed on the landscape a structure which was subjective and inexact. The introduction of aerial photography to map making, of course, made it patently apparent that much of the real world is not made up of distinct lines. Nevertheless, we continued to map with vectors. Complex optical/mechanical stereoplotters were eventually constructed to assist human interpreters in defining sharp lines and edges in essentially continuous photographic images.

It was only after the advent of computers that the raster data structure began to emerge as an attractive alternative for certain types of mapping. Because of the small memory and computational limitations of early computers, the raster maps produced tended to be quite coarse in comparison to conventional manually prepared (i.e., vector structured) maps. They were often perceived to be inherently inferior. However, it quickly became apparent that, while the spatial resolution of the raster approach was too coarse for some cartographic purposes, it presented some very powerful advantages in data encoding and applications which required thematic mapping and analysis. Performing multiple map overlays, for example, could be accomplished in a fraction of the time required by the vector approach.

In recent years new methods of capturing information directly with electronic sensors and raster scanners have contributed to expanded use of the raster method. Image processing and remote sensing have created a vast pool of information which is difficult to incorporate in the vector world. The proliferation of raster-based satellite remote sensing systems, having increasing resolution, has established a very large community of experienced raster data users.

INTRINSIC DIFFERENCES BETWEEN RASTER AND VECTOR STRUCTURES

The intrinsic difference between raster and vector data structures may be illuminated by drawing an analogy to two ways that physicists look at the properties of light. For understanding diffraction, the behavior of light can best be explained by treating it as a continuous wave. The photoelectric effect, on the other hand, can best be explained by treating light as parcels of photons. In physics, each of these models has validity, depending on the intended application. Similarly, the vector and raster models for representing spatial phenomena both have merit and utility, depending on what it is we need to accomplish.

Vectors work well when real world spatial conditions can accurately be defined as lines or edges. Example might include property lines, the face of a building, or the center line of a pipeline.

The representation of any truly linear spatial phenomena is, almost always, represented too coarsely in raster format. For example, the face of a building is a straight line, and should properly be represented by a line rather than a string of pixels. The problem of linear representation in raster format is exacerbated if the raster step changes with respect to the angle of the line to be encoded. In such instances the line takes on a jagged stair-step configuration.

The vector approach allows the user to capture important topological information difficult to achieve with the raster model. If, for example, a stream network is represented as vectors (i.e., arcs and nodes), the topological structure which results can be used to describe the contribution that each tributary makes to the overall drainage system.

Not surprisingly, then, the vector approach is quite effective in applications such as property mapping and utilities mapping and for preparing output maps which appear similar to those crafted by means of conventional cartography. The vector approach has, however, also been used in circumstances for which it is not ideally suited. When we look at an image of a region, we see many phenomena which have no sharp boundaries. When we impose lines (vectors) on the image to bound such phenomena, we introduce a highly precise interpretative element into the data which is misleading. In such situations the raster model may be a more appropriate model for both data encoding and handling.

It is, perhaps, useful to consider at greater length how we use vectors to represent transitional spatial phenomena. A photointerpreter who draws a line around a wooded area is using a subjective process which has limited accuracy. Two interpreters might well position the line quite differently. Branches of trees, for example, overlap one another. Overhang and overlaps can easily be several metres. Depending on the season in which the photograph was taken (i.e., whether or not the trees are in leaf), the boundary line may be drawn differently. Yet once the line has been drawn, it takes on a certain immutability.

An important consideration in determining the suitability of a particular data structure is related to the level of accuracy of the information being represented. A classic illustration of this issue is encountered when spot observations (point data) are interpolated to produce contour maps representing continua (e.g., precipitation, elevation of terrain).

The contours (vectors) that define points of equivalent magnitude on a surface are usually calculated from a rectilinear grid or a random set of point observations.Isolines do not, of course, exist in the raw data, they are merely calculated by mathematical interpolation. Although such lines are drawn explicitly, the interpolation method itself may not support the accuracy that

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is implied by the uses of lines. Because of measurement uncertainty associated with the point readings and the assumptions associated with the interpolation method, there is always a plus or minus standard error associated with any interpolated line. Clearly, it can be argued that using a raster cell size which is smaller than one-half this margin of error will not materially decrease the accuracy.

Consider, too, that in vector format, a boundary which is distinct in the real world (i.e., a property line) is displayed with the same certainty as an edge which is ambiguous or vague. Such differences may be overlooked in the processes of analysis and overlay.

Perhaps the most serious limitation associated with using vector format to encode and handle thematic data in a GIS is the relative difficulty one encounters in performing Boolean and overlay operations on different data layers. Experience has shown that these operations can be performed more easily in raster than in vector format. The mathematics for overlaying data in vector format are inherently more complex.

IMPACT OF TECHNOLOGICAL DEVELOPMENTS

Technological developments for encoding and handling geographic data are occuring rapidly. It is likely that improvements in conventional computers (e.g., higher speed and greater storage capacity) will benefit both raster and vector approaches equally. Although still in the very early stages of development, advances in parallel processing will probably marginally favor the raster approach, because raster structured data can be more easily partitioned for multitasking.

Significant differences in the rates of development of raster versus vector data encoding technology are appearing. Small video cameras and desktop raster scanners are now available from a number of commercial vendors. As these products are combined with geometric correction software, users will be able to capture a great deal of geographic data directly at a fraction of the former cost.

Relatively little progress has been made towards automatically producing vector data. Manual digitizing has improved marginally. Line scanning techniques are available which can convert existing drawings to digital (vector) records but this is still costly technology. More importantly, these techniques require the existence of clean single-theme source maps and to considerable amount of human interpretation and interaction to be effective.

Developments in software capabilities have resulted in improvements in both vector and raster domains by means of integration of database concepts with graphical data structures. Recent advancements in the adaptation of hierarchical data structures (e.g., quadtrees) have produced more powerful and higher resolution options for representing thematic data. It is now possible to process and store raster data of greater volume and detail than was previously possible. In the future it is likely that we will be able to employ hierarchical data structures to more effectively represent linear data.

There are, of course, already methods for transforming data from vector to raster and raster to vector formats. Conversion from vector to raster is more clearly understood and unambiguous. For a given polygon defined by a set of vectors, one and only one raster representation exists for a given grid.

The converse is, however, not true. Given a raster representation of a contiguous area, it may be extraordinarily difficult to find the vector polygon which best represents it. A unique staircase-like vector polygon can be defined, but this is a simplistic solution. If an attempt is made to find a minimum set of straight lines, or smooth arcs, to best fit the raster polygon, a mathematical problem of some complexity is encountered. Solutions are generally not unique, because many polygons comprised of different line segments will reduce to the same raster.

This paradox may present problems for GIS users. It is possible, for example, that a vector polygon might be reduced to a raster format for one step in an analysis, then, in a later step, undergo retransformation to produce a vector polygon which is different from the original.

In recent years much work has focused on transformation of vector data into the raster format. The approach which has been adopted essentially can be characterized by representing a line (having infinitesimal width) by a one cell wide raster.

This method has produced graphically acceptable results, but must be recognized as merely a short term solution acceptable when working in the raster world, but completely unacceptable in the vector world. It should be noted that all methods currently employed to transform information from vector to raster, and vice versa, inevitably result in loss of information during the transformation process.

CONCLUSIONS

Given these developments, I believe that it is unlikely that one data structure will become dominant. Both raster and vector data structures have a place in GIS and will continue to prevail for many more years. Institutional inertia and restraint stemming from past investments in technology and data bases is great. The vector approach for representing spatial information will undoubtedly have many proponents simply because so much of our existing knowledge about the surface of the Earth is already stored in this way.

The vector approach will likely dominate certain applications such as in the areas of cartography, property mapping, and facilities management. On the other hand, I suggest that the dominance of the vector approach in resource management (e.g., forestry, soils) and environmental applications will be eroded by an expanding set of raster-like data structures.

During the next few years more elegant and efficient ways of integrating data formatted in these two different ways will be developed. Hopefully this information process will be intelligent and transparent to the user. In addition, some of the emerging hierarchical structures may also provide clues to the evolution of an integrated model which does not require the time consuming and error-prone translation of data from vector to raster and raster to vector.