Using GIS for Visual Simulation Modeling

*By **Michael Batty**, associate director of the National Center for Geographic Information and Analysis, 301f Wilkeson Quad, State University of New York, Buffalo, NY 14261-0023; e-mail, geobatty@ ubvms.cc.buffalo.edu.*

If you watch expert GIS users at work, soon you will discover that they use the software for many graphical tasks other than strictly GIS applications. Graphs and charts can be constructed, even simple calculations effected; the GIS is a *visual environment* for many types of computation. Equally, a GIS does not provide users with immediate applications, but simply a platform that can be tailored to a wide range of tasks. Users need to know their problems thoroughly and be proficient in the software before relevant applications can be developed. Moreover, there are limits posed by the emphasis on GIS in two dimensions, and these constrain possible applications despite the ingenuity of users. The functions available in proprietary GISs are limited to those that can be generalized most easily to a wide array of problems. For specific tasks, therefore, users must apply various macros to access external files and programs needed to customize applications.

This is unsurprising, as GIS essentially is concerned with spatial representation. Although there are some rudimentary analytic functions in most software, applications based on other processes such as modeling or design must be somehow fashioned from or adapted to the software in hand. GIS is not, for example, structured around processes of simulation or optimization, so modeling functions must be built anew when applications are developed. Thus, using GIS as an environment for organizing such processes is an attractive strategy, because proprietary GIS applications are likely to remain broad-based as vendors seek to maximize their markets. While GIS's adaptation to a host of decision-making processes is only just beginning, I will focus on applying the technology to spatial simulation modeling.

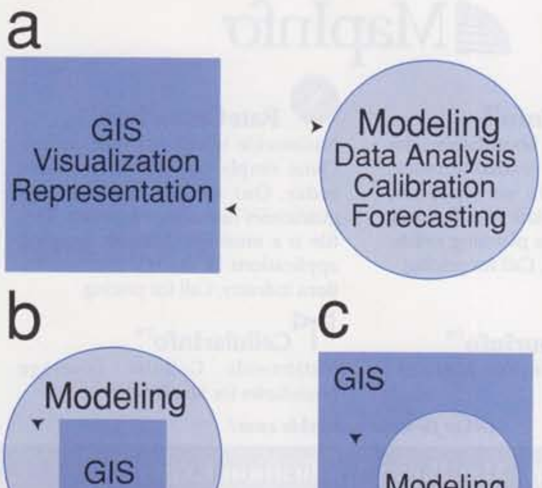

Figure 1. Linking models to GIS

First Steps

The most elementary strategy for linking simulation (modeling) to representation (visualization) is through a weak coupling of respective programs. Spatial data, either as observations or model outputs, can be imported or exported between these programs as Figure 1a implies. This strategy may suffice if all that is required is passive visualization, but if the user must respond immediately and continuously to the visual quality of data or model results, then a stronger coupling is needed. Two extremes exist: (1) components of GIS might be explicitly drawn into modeling as in Figure 1b; and (2) models might be built inside GIS as in Figure 1c, with many possible variants in between.

Figure 1 illustrates a generic form of this interaction based on diverse software. For example, visualization might be through proprietary GIS or it might be through packages from drawing to image processing. Modeling software, too, might range from spreadsheets or databases to one-off programs, while modeling processes may be data-driven, simulation- or design-based. Either component might contain elements of the other.

GIS Inside Modeling

GIS can be embedded into modeling software in many ways, as implied in Figure 1b. Building distinct GIS functionality inside modeling software has several advantages. Visualization is in effect immediate, graphics can be customized and spatial data structures can be directly tailored to model structures. In short, when a small number of generic GIS functions are required, this strategy reduces the need to use systems that pride themselves on offering a wide range of functions, many of which may never be used for a particular application. The disadvantages all relate to the absence of GIS functions that have been perfected within proprietary software. For example, graphical layouts often are well-designed in proprietary systems whose efficiency has been maximized by professional programmers. Functions such as zoom, overlay and search are fast and direct. The components of comprehensive GISs, however, rarely

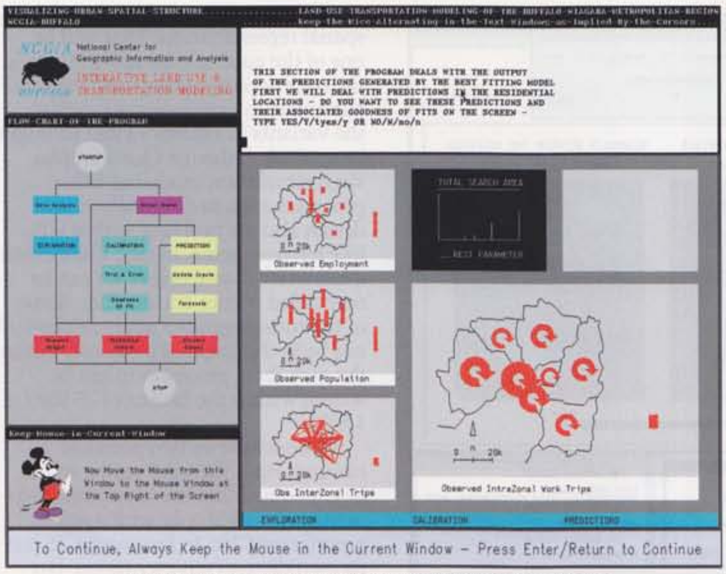

Figure 2. Using a purpose-built visual environment for modeling.

can be dissembled and used at will within other software; thus, these advantages are hard to realize.

Figure 2 shows a typical example of a modeling process that has been developed within a purpose-built visual environment. The model in question simulates the interaction between homes and workplaces through a journey to work. The modeling process — beginning with data exploration/ analysis, model calibration and then prediction/ forecasting — is used to structure the visual layout with the main portion of the screen given over to maps of data and results that pertain to these three stages in the process. Moreover, these maps are drawn as bar charts to indicate population and employment at different locations. Interzonal and intrazonal flows can be visualized directly, whereas such types of flow maps are difficult to customize and display quickly in proprietary GISs.

Of course, the problems lie with the absence of interactive functions such as zoom and the way these are controlled with pointing devices such as a mouse. Although a rudimentary zoom (aggregation) facility was built into this particular program, this is limited and any attempt to replicate the efficiency of proprietary systems would, in effect, be replicating GIS. The interactive modeling process implied by Figure 2 comprises less than 3,000 FORTRAN statements and, as the user is so close to both the graphics and the model, changes to the visualization can be made at will. Nevertheless, the system has to be so closely tailored to the city in question that even changing the problem's size — from eight to say 80 zones — causes major changes in the visualization that necessitates reprogramming. Using proprietary GIS avoids this.

Modeling Inside GIS

The alternative approach involves building simulation models using GIS to visualize data, model results and make predictions as in Figure 1c. Such a system enables the user to tap the immense power of GIS in terms of its graphics, allowing many problems to be handled directly without reprogramming, and it provides common standards for spatial data. The disadvantages are that its graphics are limited to those of the GIS, and analysis and simulation remain remote from both data and their visualization.

To illustrate such an application, consider a modeling process consisting of data analysis, model calibration and prediction as a set of relations embedded within a GIS, as illustrated in Figure 3. The system uses the GIS as the display medium, but also uses the software as the organizing frame for the sequence of analysis and modeling operations accessed as links to the outside world through system macros.

The advantages of using GIS to structure simulation modeling is that the GIS is neutral to its data sources. Once data analysis functions such as those in Figure 3 are set up, they can be applied to observations, model results, forecasts and designs. Data functions dominate the system while GIS functions are minimal. In short, although the GIS acts as the framework, most of its functions never are used. Yet the structure of its software forms the essential organization of the application. Figure 4 shows a typical frame from an application that uses ARC/INFO software from Environmental Systems Research Institute, Inc., Redlands, Calif., to model residential location based on population density in the Buffalo, N.Y., region.

In the ArcPlot frame, the popup-pulldown menuing window at the top shows the sequence of modeling operations. Each modeling element is accessed through the Arc Macro Language link to other program modules, while the results of these operations is the GIS itself. In the screen in Figure 4, the model already has been calibrated and thematic maps of observed data, model predictions and residuals are shown. There are many other graphical features such as three-dimensional surfaces, scatter plots and dynamically linked or "hot" windows in the system, all accessible through a hierarchy of menu items (Batty and Xie, 1994).

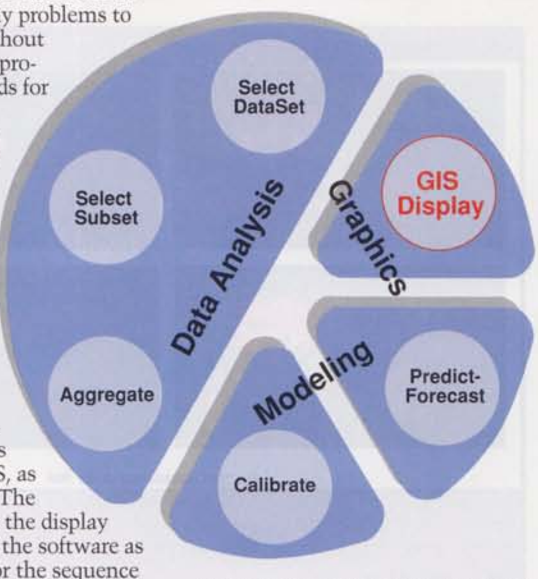

Figure 3. Adding data analysis, model calibration and prediction to GIS.

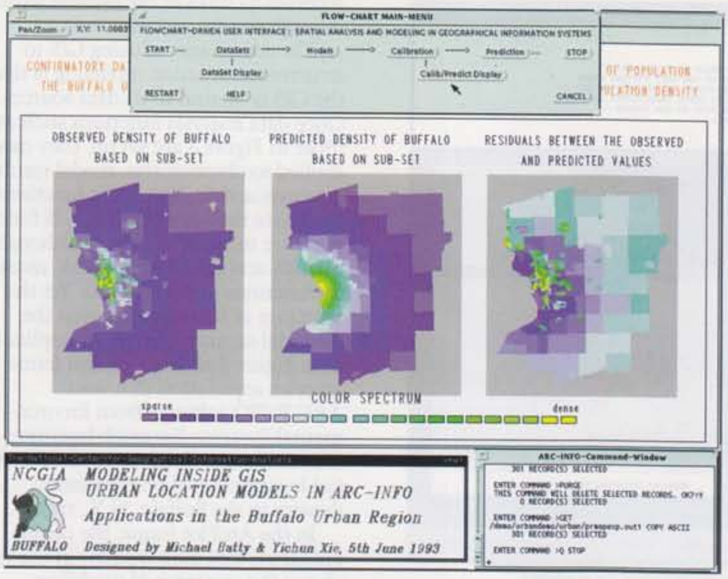

Figure 4. Modeling urban population density distribution in the Buffalo, N.Y., region.

The great advantage of this kind of interface is its generality. Other different geographical models are being built using the same ideas. Figure 5 illustrates a typical screen from a global economic trade model of trade flows between countries during a 20-year period for four commodity sectors. The application also enables gravitational models to be calibrated to the data, similar to those used in Figure 4. Figure 5 shows how users can select a country — the United States in this case — and look at its exports (or imports) in each of the four commodity sectors for a given year. The use of GIS rather than a purpose-built, visual environment does, however, constrain the graphics in that a GIS does not enable the representation of flows. These can, of course, be built into the software, but it is difficult because so little of the graphics are under the user's control.

Next Steps

Only recently have GIS vendors begun to develop ways their software can encompass processes other than spatial representation. That will be one of the cutting-edge applications in the next decade, as users and vendors alike start to explore ways in which the variants in Figures 1a and 1c might be applied. Although I have emphasized simulation modeling, other processes such as data analysis and design also are evolving within GIS-like environments. In fact, there exists a hierarchy of processes that can be embedded within one another. Some of the most ingenious applications will not be in the graphics produced, but in the way these processes might be woven within the fabric of GIS (Batty, 1993).

I'll conclude on two points of caution. First, the wary reader might be concerned that the ideas sketched here are possible only with a few proprietary GISs. In fact, each GIS has its own distinct representation, but there is great convergence among systems. More problematic is the way GISs treat their interaction with the outside world. However, most systems are acquiring interfaces that enable users to bring in data and software from many sources. Second, in the future, GISs are likely to break up into individual components that reside on the desktop as a loose coalition of software that can be drawn hither and thither into different constellations. That will hasten the merger of Figures 1b and 1c with GIS inside modeling blurring into modeling inside GIS. When that transition begins, GIS will evolve new forms with representation merging into simulation.

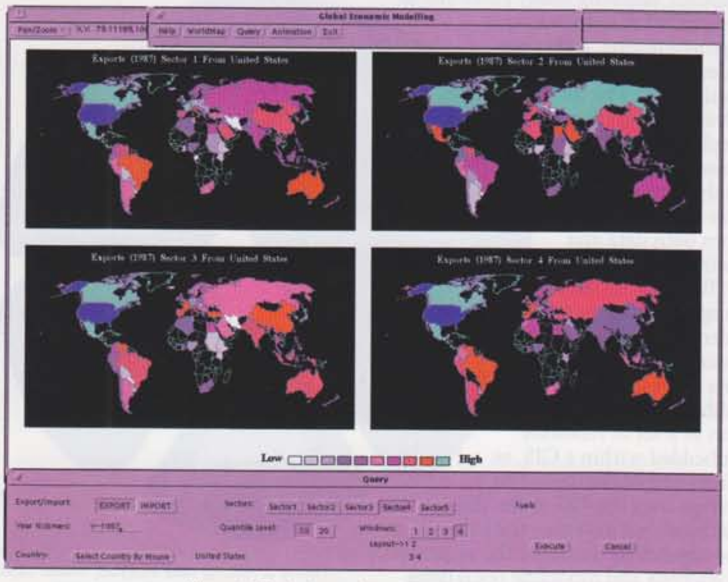

Figure 5. Exploring and modeling world trade

References

Batty, M. 1993. **Using Geographic Information Systems in Urban Planning and Policy-Making**, in M. M. Fischer and P. Nijkamp (Editors) *Geographic Information Systems, Spatial Modelling and Policy Evaluation*, Springer-Verlag, Berlin, pp. 51-69.

Batty, M. and Xie, Y. 1994. **Urban Analysis in a GIS Environment: Population Density Modeling Using ARC/INFO**, in A. S. Fotheringham and P. Rogerson (Editors) *Spatial Analysis and GIS*, Taylor and Francis, London, pp. 189-219.

Acknowledgments

This work is supported in part by the National Science Foundation under grant SES-88-10917. Debbie Buffamanti, Sam Cole, Frank Xia and Yichun Xie helped with the graphics.