Lake Superior
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Cover: A shaded relief image of digital terrain data for northeastern Minnesota, originally prepared by the U.S. Defense for Mapping Agency, and bathymetric data for Lake Superior, prepared by the National Oceanic and Atmospheric Administration’s Great Lakes Environmental Research Laboratory. Lake and stream locations were part of the Minnesota Land Management Information System’s (MIMIS) water orientation database.

These dissimilar databases were merged into a single Environmental Planning Program Language (EPPL) raster file, each cell representing 40 acres. Using EPPL on a PRIME computer, this image was created by using a light source (the sun) at an angle of 35 degrees above the earth’s horizon from a due south position and calculating the reflectance values. The values are represented here in hues of blue and green. Please note that the vertical elevation has been exaggerated by a factor of 15. A 35mm slide of this image was created using a MATRIX film recorder. The slide was then used to produce two four-foot by eight-foot Cibachrome transparencies, which are on display at Split Rock Lighthouse Interpretive Center in Minnesota. (The Center is indicated by a red dot on the lower left side of the image.)

(The image was created for the Minnesota Historical Society with assistance from Steve Hall, formerly with the Historical Society, and John Hostal, State of Minnesota Land Management Information Center).
STATEMENT OF EDITORIAL INTENT

The refereed section of URISA Journal strives to share new knowledge in the technical, social, economic, and institutional subject areas that support information systems technology. It is the intent that this section of the Journal contain papers that are representative of URISA’s membership and the broader information systems community. We encourage the participation of system designers, implementors and users as well as the educational and research community.

We hope that the refereed section will provide reliable information and new insights resulting from experience, research and scholarship. We also hope that this section will link academia, industry and the user community through the sharing of critical investigations and organized knowledge. To this end, we are seeking three forms of work: (1) Reports of current research and development pertinent to the overall information systems community; (2) systematic literature reviews of research for the research and development community; and (3) systematic reviews of applications which explain successful systems and procedures to the overall information systems community.

The refereed process consists of a "blind review." After receiving a manuscript from an author, we send it out for review to three or more persons who have been identified as being knowledgeable in the topical area. The name and affiliation of the author are removed from the paper so the reviewers can give it an impartial review; likewise, the names of the reviewers are not revealed to the author. We ask the reviewers to respond to the following: (1) Is the thesis or purpose stated early and clearly; (2) is the significance of the paper stated explicitly; (3) is the thesis argued persuasively; (4) is the writing clear, concise, straightforward, interesting, and in the active voice, where possible; (5) is the paper tied in appropriate ways to relevant literature; (6) is the paper illustrated appropriately; (7) are the methods sound and appropriate to the paper; (8) are the methods explained clearly; and (9) is the paper interesting to many different types of URISA Journal readers?

If the manuscript is accepted and does not need revising, it is sent to the managing editor for comments and final editing. If the manuscript needs revision, assistance is provided by the editors. If the manuscript is not accepted, it is returned with an explanation by the editors. (For complete guidelines regarding the preparation of manuscripts and illustrations, see p. 131.)

Kenneth J. Dueker
Dynamic Delivery of Transportation Services with GIS

Jay Lee

Jay Lee is an assistant professor in the Department of Geography at the University of Georgia. His research interests include various aspects of geographic information systems in algorithm development and geographic information analyses methods.

Abstract: Geographic information systems (GIS) provide an enhanced environment for analysis, evaluation and decision-making in many areas of urban and regional planning. The emergence of GIS has enabled significant advances to be made in the storage, retrieval, processing and presentation of large amounts of geographically referenced data. However, in applying GIS to the delivery of transportation services, a great deal of additional research and development has to be mobilized to exploit the potential of GIS technology for routing transportation vehicles, especially in dealing with real-time inputs in dynamic settings. As the first step, this paper demonstrates the feasibility of adding functional modules to GIS in order to process on-line spatial information to update road networks, to locate them, to incorporate real-time inputs of the services requested, and to perform on-screen routing operations. Although still being limited to a single-vehicle/multiple-location case, a prototype computerized routing system is used to describe the structure of a hierarchical, integrated spatial data model for transportation networks; simple heuristic algorithms are used for handling simple, dynamic routings.

Service vehicles running on a transportation network can be routed by different methods. Static routings refer to the routes and schedules that service vehicles follow when the numbers and the locations of the requested services are all known prior to operations. Examples for static routings include routings for public or school buses, garbage collection trucks, scheduled ships and aircraft. Alternatively, dynamic routings refer to last-minute design and execution of routes for service vehicles that are on route. Examples in this case include taxicabs, dial-a-ride services, delivery trucks, unscheduled ships and aircraft.

There is no single algorithm to solve all vehicle routing problems. Appropriate algorithms depend on the types of service vehicles and their settings. For example, algorithms for routing school buses will not perform as well for routing garbage trucks or taxicabs. Because of this complexity, there exists a large body of literature on problems of vehicle routing. Good reviews are available in Lin and Kernighan (1973), Mole (1979), Bodin et al. (1983), Christofides (1985), Bott and Ballou (1986), Golden and Assad (1987).

Dynamic routing problems require special attention for processing real-time inputs and are more critical in time constraints than are static problems; thus they compose their own research area. Literature on dynamic vehicle routing problems can be found in reviews scattered in several related fields: Psaraftis (1980), Larson and Cdoni (1980), Brown and Graves (1981), Bell et al. (1983), Psaraftis (1983), Powell (1985), Sexton and Bodin (1985), Desrochers, Dumas and Soumis (1986), Bertsekas and Gallager (1987), Golden and Assad (1988).

This paper first discusses the basic differences between static and dynamic vehicle routing problems. Special characteristics and requirements for simple dynamic settings are reviewed as the basis for constructing a computerized system for dynamic routings. A hierarchical data model which integrates network and related information into a spatial database is described also for this purpose. As an example, a prototype system is presented to demonstrate the concepts developed in this paper. The dynamic
settings in this paper emphasize the handling of the real-time inputs.

It is, of course, impossible to include all types of service vehicles and various settings (such as time window, queuing considerations, driver work rules, vehicle capacity, etc.) in this discussion. However, this paper, hopefully, will initiate ideas and stimulate the construction of systems that deal with other real-world constraints in models.

**Dynamic Vehicle Routing**

Dynamic vehicle routings can be defined as the dispatching of vehicles to satisfy multiple demands for services that evolve in a real-time (dynamic) fashion. Vehicles in this category include taxicabs, delivery trucks, ships, aircraft, etc. Services by these vehicles usually include picking up, delivering and dropping off passengers (or goods) at some stops in a transportation network. Routes are represented by a series of connected network links, e.g., street blocks in a transportation network. Inputs to a dynamic vehicle routing problem include the nature of service, the locations and the time of services requested. Example networks may be street networks or voyage networks for ships or aircraft. Stops in a network to be included in the vehicle routes may be pre-fixed, or non-fixed. Stops may be known prior to routing operations or may not be known in advance. If not known in advance, they will become real-time inputs during route execution. The format of inputs to the vehicle routing system determines the nature of a routing problem.

If the assumed inputs, the numbers and the locations of the requested services, to a vehicle routing problem do not change, either during the execution of the algorithm that solves it or during the eventual execution of the route, it is said to be a static vehicle routing problem. Alternatively, inputs may (and generally will) change (or be updated) during the execution of the algorithm and/or the eventual execution of the route in a dynamic setting. It should be noted that algorithm execution and route execution are processes that evolve concurrently in a dynamic situation.

There are many differences between static and dynamic vehicle routing problems. In a dynamic situation, the time dimension usually is essential and the routing problems may be open-ended. Future information may be imprecise or unknown prior to routings or the execution of routes. Therefore, an efficient information update mechanism is essential. In addition to the time constraints, resequencing and re-assignment decisions may be warranted because of real-time inputs. Usually, fast computation speed and fast on-line access to the system and to the database are necessary.

A static routing system has the luxury of knowing all inputs, i.e., customer requests, cancellations, etc., in advance. Solution speed is less critical, however; in a dynamic setting, the routing system is subject to imprecise or unknown inputs as well as greater time constraints. In many situations, a dynamic routing system would be forced to adapt heuristic procedures (mostly local re-routings) to accommodate real-time inputs for quicker solutions which are sometimes not as optimal.

**Human Interaction and Re-start Capability**

To incorporate the real-time input setting, a dynamic routing system needs to be interactive with its users (for example, vehicle dispatchers). A static routing system may be run in batch mode but a dynamic routing system needs to have human interaction, or even intervention, not only because of real-time inputs but also because of greater system control by the human. Some obvious "quick-and-dirty" routing executions may be performed by experienced dispatchers to avoid otherwise lengthy computation time. A system may become "hanging up" with an extreme situation, e.g., a request that is located geographically far away from all other requests. If it would be excessively unprofitable for the system to include this request at a particular time, it would be deferred (or denied) by the system operator indefinitely so that other requests may be served more efficiently. "Human in loop" would allow system users to overwrite a computer at will and to re-start the system whenever it is necessary. It is also necessary that dynamic routing systems have the capabilities of efficiently updating any routes and schedules.
Hierarchical Data Structure and User-Friendly Interface

Besides the need for human interaction and the re-start capability, a hierarchical data structure and a user-friendly interface of a routing system are also extremely important for a dynamic routing system. In a dynamic setting, the first step in routings is usually to identify the locations of the service requests within the transportation network. A hierarchical data structure allows the routing system to search for the location of any service request only through those relevant data (of the specific level of aggregation). It would drastically reduce the computation time required. Data links, i.e., street blocks, and point data are usually pre-processed and organized into different levels within the hierarchy. When performing routing operations, relevant data links or locations can then be identified with quick and direct searches.

In practice, the hierarchical data structure can be implemented in many formats. A simple example for implementing this concept is to utilize GIS editing routines to attach each network link (e.g., street block) with a hierarchical code: the freeways and the major arterial routes are associated with higher hierarchical codes and local street blocks are associated with lower hierarchical codes. Additional criteria such as number of lanes can be used to further classify link codes. For routes of shorter distances, local street blocks are used. Routes of longer distances (e.g., covering a large metropolitan area) can be computed on a system which includes only the freeways and the major arterial routes and then connect the requests for services by locally loading the location to the nearest arterial routes.

A user-friendly vehicle routing system implies a system that is easy to operate; for example, a system with graphic display to assist users in constructing spatial interrelations among information used in the system will be preferred to a system with only text output. Static routing procedures typically are not organized in an interactive environment as they usually run in batch mode with fixed input/output formats. Routing procedures in a dynamic setting, however, are very different and require a higher degree of interaction between the system and the operators.

Several unique features of an interactive system describe a user-friendly dynamic routing system. First of all, a graphic display is a must in a dynamic routing system so that users can quickly and visually construct spatial relationships among all information used. Decisions such as arranging priority of requested services by their relative locations to an existing route can be simplified through visual inspection. Otherwise, lengthy computation may be necessary for this purpose, and therefore prolong the response time by the system. Secondly, flexible input formats are also much preferred in a dynamic routing system as they reduce the input preparation time.

Different ways to input service requests can significantly affect the efficiency of the routing system. For example, by pointing to points on screen with a mouse rather than by typing in coordinates of the points will obviously result in tremendous savings in both preparation time and computation time. Finally, a menu-driven system interface is much preferred if compared with a command-driven system. The format of a menu-driven user interface does not require users to memorize many command formats and parameters. Options of operations are usually listed in the menu for users to make decisions. Training time for using the system is therefore drastically reduced.

In dynamic vehicle routing procedures, the information management and user interface issues are much more important than in static routing procedures. An efficient dynamic routing procedure implies more than just an efficient core routing operation. Actually, the core operation itself must be designed in such a way that the above features concerning human interaction, re-start capability, and user-friendliness can be easily implemented.

If more advanced features are to be included, an interactive user interface can be used to improve the user's decision-making process during routing operations. For example, a system may suggest alternative routes to users after analyzing routing information. The users could choose among them.
According to their purposes and experience. Moreover, route evaluation is possible when a system allows users to dramatically change a pre-set route and then evaluate the changed route against the optimal route. Users of such systems would be able to learn from the experience.

In summary, static and dynamic routings differ in how inputs are processed, in system response time, in system design and requirements. With these differences, one can expect the algorithms for dynamic routings to be unique from the static routing algorithms. However, there have not been enough dynamic algorithms developed for general dynamic routing purposes. In practice, dynamic routings usually adopt some of the static routing algorithms and run them in iterations to accommodate real-time inputs. Specifically, a static routing algorithm is used to generate an initial solution, and then the system relies on repeated operations for all subsequent input updates. In the next section we will discuss two ways to adopt static algorithms into a dynamic setting.

Algorithms for Dynamic Routings

Most dynamic vehicle algorithms were developed for vehicle allocation rather than specifically for routing purposes. In practice, a dynamic vehicle routing system usually adopts static routing algorithms and run them again every time a real-time input is received. Usually, the adopted algorithm must undergo a significant degree of re-design, most of it heuristic, to be tailored to the nature of the dynamic scenario.

Adoption of Static Routing Algorithms

The first and the most common approach to adopt static routing algorithms into a dynamic setting is to re-run the static routing procedures virtually from scratch each time a (significant) revision of the input occurs. For example, a new input or request appears, or another one cancels the request, or a vehicle breaks down, etc.

This approach may approximate more optimal solutions than the heuristic approach (to be described later) but will certainly accumulate more computation time. This will lead to delay in response time from system to users. Depending on the types of routed vehicles and the size of the transportation network, delay may range from insignificant to very significant. But in general, for a dynamic system which routes real-time inputs, this delay of responding time may be very undesirable.

Dynamic Routing with Heuristic Algorithms

An alternative and more realistic approach to the adoption of the static routing algorithms would be to handle dynamic input updates via a series of "local" operations, applied via the execution of an insertion/deletion heuristic (possibly followed by an interchange heuristic), after the static core algorithm is run. This would involve running the static algorithm just to initialize the process (for example, once a day), and rely on "local" operations for all subsequent input updates.

Local operations provide a reasonable way to handle dynamic input data. The principal advantage of local operations is the execution speed. Because it only revises established routes locally, it avoids wasting computational time to check other parts of the transportation network that are not relevant to the current input. It should be noted, however, that local re-routings work well when the number of new service requests is relatively small with respect to the number of service requests included in an existing route. But as the number of new requests increases relative to the number of known points for the existing route, the performance of local re-routings will be deteriorated. Furthermore, the spatial density of the service requests also affects the performance of local re-routings. Lower density transportation networks usually are more suitable for local re-routings. Also, the local re-routing algorithms work well for the situation of single-vehicle/multiple-location route, but may not work as well for multiple-vehicle/multiple-location situations.

Another issue concerning the heuristic approach of using the local re-routing algorithm is the tradeoffs between computing time saved and the possibility of obtaining optimal routes. For example, the local re-routing algorithm can be modified to allow users to specify different numbers of points on the existing route to be included for re-routing. One extreme is as the
aforementioned situation wherein a single new request is inserted into an existing pair of points. Another extreme is to include all points in the re-routing. This implies a total re-routing and naturally will require more intensive computation. Users of such systems will have to make decisions in terms of the trade-offs between saving computation time and obtaining optimal solutions, according to their own objectives.

**Dynamic Routing With GIS**

A vehicle routing system is currently being tested by the author based on concepts described so far. The earlier version of the system was designed for county-level governmental entities for various static-routing purposes: school buses, garbage collection trucks, etc. Later it was modified and enhanced to process dynamic routings for service vehicles such as delivery trucks. This system is described here as a demonstration. In its current version, the system is capable of routing one vehicle at a time with real-time inputs. The local re-routing algorithm uses only one point at each side of the new request for modifying an existing route with respect to a real-time input. Although it is capable of performing both static and dynamic routing operations, it is primarily developed for simple dynamic routings for delivery vehicles. Dynamic routings with other constraints, such as time windows, vehicle capacities, and others, will require further efforts to customize the system in the future.

The prototype system consists of a database and several modules: a NETWORK database which integrates both spatial and non-spatial data for the routing system; other modules for routing operations include ROUTE BUILDER, ROUTE MODIFIER, and ROUTE REPORTER. All routing modules share the spatial database, NETWORK.

**An Integrated Database**

The data required by the prototype dynamic routing system can be classified into two broad categories: graphic (spatial) and tabular (non-spatial) data. Graphic data refer to coordinates and their spatial relationships in a transportation network. Each data link represents a street block in the network. A series of coordinate pairs describes the positions and directions of the link. The spatial relationships among data links refer to how these links are interconnected in the network.

Tabular data refer to the information associated with data links in the transportation network. Each data link can be associated with a number of attributes such as number of lanes, one/two-way street, traffic flows, the distance of the link, number of houses located along the link, the range of their addresses, and others.

Graphic and tabular data, which may be stored in separate files, can be integrated into a GIS. GIS provides an enhanced environment for analysis, evaluation and decision-making in many application areas by integrating both tabular and graphic data. Once the data are organized into a spatial database, functional modules can be added to the GIS to carry out tasks. In our case, the functional modules added are the ROUTE BUILDER, the ROUTE MODIFIER, and the ROUTE REPORTER.

Using GIS, other tabular data for fleet management also can be incorporated into the database if desired. Maintenance records, fuel-consumption records, personnel records and other scheduling information can also be integrated.

**NETWORK Database**

The database, NETWORK, integrates both graphic and tabular data of the transportation network. GIS editors are used to input, edit, append, sort, or display data. An interface establishes the linkages between two groups of data. The structure of the database of the prototype system is given in Figure 1.

In the prototype database, a transportation network is stored by links. Each link is stored as a record in the link file. Each record contains link identification, coordinate pointers, hierarchical codes, and other attributes. While each link is defined by an "ID," its positions and directions are defined by a series of coordinate pairs. Coordinate pointers, recorded as two attributes for each link, point to the beginning and the ending positions of coordinate pairs in the coordinate file. A series of coordinate pairs can be
Functional Modules for Routings

The actual routing procedures can be conducted by adding function modules to a GIS. In addition to GIS editors, which may be used to input and edit street networks, the design and modification of routes in the prototype system is achieved by adding three modules: a ROUTE BUILDER, a ROUTE MODIFIER, and a ROUTE REPORTER. The structure and functions of these three modules are shown in Figure 2. The routing procedures begin by a static routing with the ROUTE BUILDER. Using information (of service requests) initially available, an initial route is established. The execution can be started any time after this point, depending on the arrival of real-time inputs. Upon receiving real-time inputs, the system switches to the ROUTE MODIFIER to perform “local” re-routing and re-sequencing. Real-time inputs are incorporated accordingly. A new request can be inserted to the existing routes and any cancellation can be deleted from the existing routes.

The algorithms used for local re-routings perform quick insertions or deletions on existing routes. They are not designed to re-route the entire set of updated requests with the entire transportation network. As the local re-routing algorithm deals with only part of the entire transportation network, the response time is dramatically reduced. However, it should be noted that routes designed in this manner some-

extracted from the coordinate file to describe the link’s position and direction. The hierarchical codes of the network links provide means for routing at various “resolutions.” Experience suggests that higher, hierarchical network links can be used to construct route segments between distant service requests. Many features can be recorded as additional attributes for each link. In the prototype system, each link record contains link (street) name, link’s length, address ranges, etc.
times are not always optimal if compared with the routes designed by applying static routings from scratch every time a new request is incorporated.

Both insertion and deletion procedures perform local re-routing by the following steps (also shown in Figure 2):
1) Locate the request in the path sequence of the identified route;
2) Identify the two neighboring stops (closest to the location of the request) in the path sequence;
3) For insertion:
   a) Compute the shortest paths from the request location to the two neighbor stops;
   b) Delete the path between two neighbor stops from route;
   c) Replace with two shortest paths (from the location of request to two neighbor stops);
4) For deletion:
   a) Delete the paths between the location of request to two neighbor stops;
   b) Compute the shortest path between the two neighbor stops and add it to the route;
5) Ready for the next real-time input.

In addition to the ROUTE BUILDER and the ROUTE MODIFIER, a ROUTE REPORTER is implemented to produce output in both graphic and tabular forms. A map on which the designed routes are highlighted can be plotted on screen. Figure 3 demonstrates an example from the prototype system. Street links included in the route are highlighted by a different color. Function keys offer various options a user can select during routing operations. Route statistics, e.g., lengths, number of service requests covered, number of U-turns, left turns included, also can be reported. If preferred, a listing of street names can be generated to accompany the graphic reports (Table 1).
Conclusions and Future Research Issues

In recent years, major developments have occurred in two areas: geographic information systems, and vehicle location and tracking. Both are expected to impact routing and dispatching significantly. Without GIS to provide an interactive, integrated environment for vehicle routings, routing procedures are limited to mostly static settings or their simple iterations. Processing tabular and graphic data with GIS, dynamic routings become feasible and have the potential for a wider range of applications.

In the preceding sections, several key differences between static and dynamic vehicle routing problems are discussed. In general, solution-speed time constraints in a static setting are less critical than that in a dynamic setting. Dynamic routing problems in some situations have different emphases than those of static routing problems. As a result, routing procedures are also conceptually different. For a dynamic routing system, achieving routings in less time while satisfying certain profit-driven criteria seems to be more important than achieving an optimal route of the least operation cost as in the case of static routings.

It should be noted that in applying these concepts for practical applications, a computerized routing system would have to be tailored to meet the specific settings for each particular application. This involves incorporating specific constraints into the computerized routing systems. A number of possible constraints in routing systems have been treated to various degrees of success in the literature of operations research and transportation management. These constraints include time windows, driver work rules, vehicle capacity constraints, and

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TABLE 1. Prototype Dynamic Routing System (Tabular Output).

<table>
<thead>
<tr>
<th>Street</th>
<th>From</th>
<th>To</th>
<th>Side</th>
<th>Stops</th>
<th>Next turn</th>
</tr>
</thead>
<tbody>
<tr>
<td>BRADLEY</td>
<td>AV</td>
<td>JAINA_BV</td>
<td>left</td>
<td>0</td>
<td>right</td>
</tr>
<tr>
<td>CONWAY</td>
<td>BV</td>
<td>CONWA_DR</td>
<td>right</td>
<td>0</td>
<td>right</td>
</tr>
<tr>
<td>CONWAY</td>
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<td>CONWA_DR</td>
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<td>0</td>
<td>right</td>
</tr>
<tr>
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<td>DR</td>
<td>CONWA_DR</td>
<td>right</td>
<td>0</td>
<td>right</td>
</tr>
<tr>
<td>CONWAY</td>
<td>DR</td>
<td>CONWA_LN</td>
<td>right</td>
<td>5</td>
<td>U turn</td>
</tr>
<tr>
<td>CONWAY</td>
<td>LN</td>
<td>CONWA_DR</td>
<td>right</td>
<td>25</td>
<td>U turn</td>
</tr>
<tr>
<td>CONWAY</td>
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<td>CONWA_LN</td>
<td>right</td>
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<td>right</td>
</tr>
<tr>
<td>JALNA</td>
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<td>CONWA_DR</td>
<td>right</td>
<td>26</td>
<td>U turn</td>
</tr>
<tr>
<td>JALNA</td>
<td>BV</td>
<td>CONWA_LN</td>
<td>right</td>
<td>5</td>
<td>ahead</td>
</tr>
<tr>
<td>JALNA</td>
<td>BV</td>
<td>CHESW_CI</td>
<td>right</td>
<td>19</td>
<td>right</td>
</tr>
<tr>
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<td>DR</td>
<td>CHESW_CI</td>
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<td>8</td>
<td>right</td>
</tr>
<tr>
<td>SARAH</td>
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<td>SARAH_CR</td>
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<td>1</td>
<td>right</td>
</tr>
<tr>
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<td>CR</td>
<td>SARAH_CR</td>
<td>right</td>
<td>24</td>
<td>right</td>
</tr>
<tr>
<td>SARAH</td>
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<td>right</td>
<td>4</td>
<td>U turn</td>
</tr>
<tr>
<td>SARAH</td>
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<td>SARAH_CR</td>
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<td>7</td>
<td>U turn</td>
</tr>
<tr>
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<td>SARAH_CR</td>
<td>right</td>
<td>7</td>
<td>right</td>
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<td>SARAH_CR</td>
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<td>SARAH_CR</td>
<td>right</td>
<td>18</td>
<td>ahead</td>
</tr>
</tbody>
</table>

---

FIGURE 3.
Prototype Dynamic Routing System (Graphic Display).

F1: All on  F2: All off  F3: Auto  F4: Manual  F5: Backup
F6: New Route  F7: Jump  F8: Plot  F9: Print & Save  F10: Quit

Information
Left Turn: 1
Right Turn: 14
U Turn: 7
Steps in Beat: 1461
Steps Collected: 394
Distance in Beat: 24594
Distance Covered: 4529
Total Turns: 22

Cursor at: 280 1130
Status

Keys Activated:
F1, F4, F8 to F10
others. What constraints and how to incorporate them into a dynamic routing system are indeed pragmatic issues for future research.

Another direction for future research is to improve the system so that routing information can be analyzed and presented to the user in a form that will facilitate improved decision-making. For example, the computerized routing system will suggest alternative routes; the users can choose one that best serves the user's purpose and experience. Another option will allow users to alter a pre-set route dramatically. The system could evaluate the change against the final chosen route (after the dynamic modification) or against an optimal route computed post hoc and show how the route could have been improved. A wide range of similar conditions can be easily identified for future research.

In summary, the use of GIS in a dynamic routing system allows the routing efforts to be performed with a hierarchical structure, and that dramatically improves the computation speed of routings by bypassing the irrelevant parts of the network. In addition, the ability of GIS to process geographic information, together with tabular and graphic information, allows users to enter, edit, and to display transportation networks efficiently. Interaction among system and users via GIS graphic displays makes routing systems more user-friendly with quick realization of spatial interrelationships for the system operators. Finally, adding functional modules to GIS not only enhances GIS functionality but also expands feasible application areas for GIS.

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Data Structure Design for Surface Water Resources Information

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Abstract: Computer information systems designed to support the management of surface water must 1) maintain flow relationships, 2) reference point, line, and area information along the linear dimension of fluvial features, 3) distinguish the locations of these features with respect to stream bank, and 4) enable hierarchical basins to be specified for data analysis and display. This paper describes a set of principles enabling water resources information to yield data structures that will support these functions. They are consistent with computer models and graphic displays to support water-related decision-making. The principles are derived from consideration of data organization problems that are inherently associated with the representation of surface water features in computer systems. Finally, because of the diverse types of thematic data that must be present to support decision-making for water resources, we describe strategies for integrating existing data sources into a database.

Information systems for surface water resources have unique data structure and retrieval requirements that should be handled efficiently and accurately in operational systems. Design of the Illinois Streams Information System addressed these requirements by focusing on generic types of hydrologically structured retrievals and a data structure specific to streams data. This paper describes and evaluates strategies for structuring streams data so as to: maintain flow relationships; reference point, line, and area data along the linear dimension of fluvial features; distinguish locations of these features with respect to stream bank; and analyze data by hierarchical watershed.

Problems And Query Types

An information system must be designed with a set of problems and planning objectives in mind to ensure its long-term functionality. Systems designed to solve simple problems, or which have insufficient flexibility to adapt to changing problem environments, are destined to have short lifespans. Effective systems, therefore, must adapt to changing requirements. One strategy for dealing with dynamic problems is to identify their primal elements. At a primal level, simple boolean queries and queries designed to extract data from a database for input to models or for generating graphics are often used to:

- Retrieve thematic, locational, and topological information about a place;
- Select places meeting a specified set of thematic, locational, or topological characteristics.

In some respects, water resources information is no different from that collected to support other environmental decisions. For example, when questions are focused on basins, area-based GIS technology has been applied appropriately (e.g., Moore et al. 1983). In other instances, groundwater is the focus and, thus, three-dimensional (x, y, depth) point data and sampling strategies are often the main concern of system designers (Rajagopal 1986). In systems designed to support decisions about surface water, however, it is important to be cognizant of several distinguishing characteristics of the problem domain that must be considered at the database-design stage. Because impacts arising from the introduction of substances into the fluvial network are felt downstream, a capability for supporting directional (e.g., upstream of) queries and analyses based on flow must be provided. Streams also usually have hierarchical flow relationships and
form-nested basins, and a capability for efficiently retrieving information about basins is often required in regional assessment and planning activities.

Sinuosity of streams, except for channelized reaches, makes the measurement of length along streams and the specification of the relationship of other objects to such linear features difficult. Scale, resolution, and topology must be considered when computing lengths and relationships among objects in such circumstances. Within the information system, therefore, it is essential to provide efficient support for determining the following fundamental set of stream flow relationships (Hopkins and Armstrong 1985):

- Upstream
- Downstream
- Tributary
- Distributary
- Flow distance between
- Bank (left, right, both) or in stream

In the case of a hydrologic system, places may be points, lines, or areas on or in relation to streams, or may consist of stream reaches, entire streams, or sets of streams making up basins. For these reasons, information systems designed to support surface water resources decisions have design requirements that are different from those of area-based GIS. Although other flow networks, such as highway networks (Nyerges 1990), share some of these features, many are unique to stream networks.

Generic queries related to surface water resources can take the following forms:

- What streams are downstream from a specific point on a given stream? Queries of this type are needed to determine sites that could be adversely impacted by noxious material introduced into the system (e.g., hazardous spill assessment).
- What streams are tributaries of a given stream? This query type enables the determination of the set of streams upstream from any given location. Such information is needed to plan for basin-wide impacts (e.g., water intake protection—identify all places from which contaminants might reach this point).
- What points are downstream within a given distance from a point? This information is typically needed when evaluating whether to protect locations from adverse conditions introduced upstream (e.g., water intakes and toxic spills).
- On what bank is a particular activity or feature? Such information is critical for evaluating impacts and for planning access to locations (e.g., the bank for a boat launching site must be known to confirm road access).
- What is the linear extent of a bankside feature on each bank? Linear measurements are required for summary descriptions of streams and basins (e.g., disturbed bankside landcover).
- What features are upstream and downstream from a point within a given distance? Information about the neighborhood of a location is needed to mitigate problems that can result from proposed intrusions (e.g., what features are near a proposed bridge site?).

The relationships and query types described above must be supported by a data structure that enables their efficient representation and use.

Note, however, that there are two fundamental operations that must be performed repeatedly and which may cause problems: length measurement and the specification of network structure. In the next two sections of this paper we describe problems associated with supporting these relationships and strategies for overcoming these problems. The remaining sections address integration of multiple data sources and system implementation issues.

The Problem Of Length Measurement

Mathematicians and cartographers have long been aware of the knotty problem of measuring a “true” length of a linear feature. Steinhaus (1954) asserted that linear measurements were paradoxical, and similar observations formed one of the bases of fractal geometry (Mandelbrot 1982). The essential problem is that for any given irregular feature (e.g., a stream), as more points are sampled, the resulting length estimate tends to increase. The problem is ubiquitous in surface water databases because streams are rarely straight for distances greater than ten channel widths (Leopold et al. 1964) except along channelized sections.

Linear Features Measurement

A general theory of cartographic lines, which is pertinent to the treatment of line complexity, was articulated by Peucker (1975). Chrisman (1982) also contributed to the theory of error in digital spatial
representations and, in work related to transportation networks, Armstrong (1987) enumerated several error sources that occur in the context of network measurement. Dueker (1975) described similar problems encountered when area features are encoded. Recently, Maling (1989) provided a comprehensive overview of problems associated with making measurements from maps. Much of the discussion reported by Maling that pertains to length measurement, however, focuses on coastlines and lakes (e.g., Mandelbrot 1967; Hakonson 1978) and political boundaries (e.g., Richardson 1961). Though there are important lessons that can be learned from these lines of inquiry, other, often neglected, factors assume importance when surface water features are considered.

**Source material error.** If error is present in the original source document, and if the document is assumed to be correct, then the best outcome that can be obtained is the reproduction of error with a high degree of fidelity. Errors are introduced into source documents during the data collection and compilation stage, and may also result from manual production problems such as misregistration.

**Scale of the source material.** An additional conundrum is introduced when map scale is considered. As the scale of the source material increases, the amount of the detail that can be represented grows because of cartographic generalization practices, and thus length estimates tend to increase. This, in turn, will influence the sinuosity of streams, and will also affect the stream order of the smallest streams included on a map (e.g., Mark 1983). In each case the availability of information is partly controlled by scale. Furthermore, because sinuosity is controlled by scale, distance measurements also vary with scale.

**Sampling density.** When digital estimates of length are made, digitizing can be done in several modes: point (point selected by user), time (points recorded at each time interval), and distance (points recorded at each distance interval). In each case, the replication of the form of the line is affected by the mode of data capture. It is difficult to transform a continuous, sinuous feature such as a stream into a single, discrete, digital representation that is suitable for different applications that may vary in their need for accuracy or precision. Although every effort is normally made to abstract the stream into a sequence of straight segments, this process of abstraction is contingent upon the capabilities of the technician. These capabilities also may vary among personnel, which introduces further uncertainty into the sampling process. Assuming that point sampling is adopted, the length of the stream will be determined by the selection of points to be used in calculating the distances; higher sampling densities yield increased stream lengths.

**Data capture error.** Digitizing linear features is a boring task because it is repetitive and the tangible rewards are low. Different kinds of errors will creep into the measurement process including overshoot and undershooting of meanders, and glitches attributable to the physiological and psychological composition of the digitizing technician (Jenks 1981).

**Data storage and processing error.** Although such errors are not always encountered, round-off, truncation, and other errors associated with improper numerical precision sometimes occur. Chrisman (1984) described the effect of precision on the representation of coordinate data in geographic information systems. The limited numerical precision of computers affects either the size of the study area or the degree of spatial precision that can be handled by the system.

**Topological error.** Topological errors occur when elements of a network are incorrectly connected, or disconnected. If flow relationships are required, topological structure is a key element; error in topological connectivity disrupts networks and plays havoc with determining flow relationships and hence, with length estimation. This is especially problematic for stream networks because redundant paths normally do not occur except in braided channels. In such cases an expert determination of the main channel may be required. Such determinations should be based on the logic of hydrologic flows.
Braided channels can be incorporated by encoding distribu-
tory (a stream that flows out of another stream) relationships as
inflows to tributaries, thus these streams have an inflow at one
end and outflow at the other.

User error. Beard (1989) identified user error as an additional
element in the traditional carto-
graphic error taxonomy, and ad-
vocated designing systems to
discourage misinterpretation by
users. Direct encoding of rela-
tive positions along linear fea-
tures, network topology, and
right or left of line topology en-
courages use and interpretation
of data based only on intention-
ally coded and, therefore, accu-
rately represented relationships.
For example, if geographic coor-
dinates are not given for a sin-
nuous line—only relative posi-
tions along its length—then
different users will not be able
to compute different lengths be-
tween positions. Similarly, if
bank positions are encoded di-
rectly, different users will not
derive them from coordinates
that may be encoded from maps
with different levels of line
generalization. Graphic representa-
tions can then be generated spe-
cifically for display purposes.
This discourages use of graphic images for data manipulation,
which prevents users from mak-
ing interpretations not sup-
ported by the level of accuracy
represented in the data (Hop-
kins and Armstrong 1985).

Measuring Linear Surface
Water Features.

The following problems
arise from the characteristics of
linear surface water features and
the storage and encoding of
data about such features. De-
signers of surface water data-
bases must address these issues.

Dynamic process error. Dy-
namic fluvial environments can
create significant errors because
fluvial environments undergo
continuous morphological
change. For example, if a dis-
tance along a river is measured
on an outdated map, a new
meander cutoff would alter the
distance, making distance esti-
mates obtained from the map
incorrect. More subtle changes
in length also occur continu-
ously as stream courses evolve.

Water feature width. This
problem is related to the scale
at which features are displayed
and also depends upon the
symbolization method that is
used to represent objects at a
given scale. Rivers, for example,
may be represented as a single
line at one scale, or as an areal
symbol within cased lines at an-
other. In the latter case it is nec-
essary to establish the linear di-
mension of an areal feature
before digitizing can take place.
While this may be straightforward for some features (e.g., an
essentially linear, narrow stream
channel), for others it is com-
plex and requires the arbitrary
specification of a center line,
which usually approximates the
medial axis of the water feature.
This requirement may, of
course, be obviated in the case
of reservoirs, where topographic
maps sometimes show new
water features by applying an
overtint to the topographic con-
tours. In those cases, the origi-
nal channel can be determined
and encoded. This can be ar-
gued to represent the line of
water flow through the reser-
voir, which is usually the ap-
propriate logic for length measure-
ment of streams and reservoirs.
One way to proceed when the
channel cannot be determined is
to approximate the reservoir... "by selecting portions of the
reservoir through which straight
lines can be drawn that appear
equidistant from both banks.
These lines can then be con-
ected to make an approximate
center line for the lake." (ISIS,
1986) The problem with this
approach is that channels are hy-
pergeneralized into straight line
segments and, although flow
length measurements within the
lake may thus be inconsistent
with flow length measurements
obtained from streams, no supe-
rior method is available. Note,
however, that the length of flow
within the reservoir can be
identified so that differences be-
tween reservoir flow and chan-
nel flow, for example, could be
distinguished in a routing
model.

Islands. Whenever a channel is
bifurcated by an island (or is-
lands), a decision must be made
about the path used to measure
the linear dimension of the
stream. A second channel can
be included as a distributary,
but one channel must be chosen
for stream distance calculations.
In some instances, the solution
is obvious. In other ambiguous
cases, a method must be de-
volved to enable channels to be
consistently identified. Mueller
(1979) asserts that the channel
with greatest depth should be used. Note, however, that for some stream situations the channel through which the main volume flows may change during different flow regimes (Leopold et al. 1964). Furthermore, channel depth is impossible to determine on most topographic maps. If the strategy is to retain consistency with other data, measurement of each path may be required to determine which path has been followed previously.

**Referencing of bankside data.** Inherent in any water resources information system is the need to store information about characteristics of stream banks. If a system is designed to store information about changing conditions (e.g., change in the land cover on each bank of a stream), then the database must contain information about where changes occur with respect to the length along the stream. Noting where such changes occur by specifying a two-dimensional coordinate, even with extremely high precision, is often insufficient for placing changes along the stream in correct hydrologic relationships.

In a GIS, geometrical and attribute data often are encoded from several sources that have been compiled and printed at different scales with commensurate levels of generalization. When a generalized data source (e.g., Figure 1A) is used with a more detailed source (Figure 1B) confusion about the location of features with respect to bank can occur (Figure 1C). The correct placement often can be determined by available information about the feature, such as the point at which a boat ramp or discharge enters the stream, and encoded directly. The degree to which objects are incorrectly assigned to a bank is related to the sinuosity of the line as well as to the precision with which a point can be specified. Blakemore (1983) described a similar problem with respect to the assignment of a point feature to a polygon. The antecedent of this work stems from Perkal (1966) and Nystuen (1966).

It is important to note that each of the above errors rarely operates independently; often, several error sources are present simultaneously, which further compounds the problem of measuring distances. Although it is conceivable that such errors could cancel out, our experience indicates that these errors must be acknowledged in any database. Most important, the choices made and procedures used should be carefully documented so that system users can interpret results appropriately.

**Stream Network Relationships**

Because of the hierarchical nature of stream basins, and the need to address environmental problems at the basin level, it is important that any surface water resources information system be able to retrieve data efficiently with flow rela-
tionships preserved. Furthermore, because impacts often propagate downstream (e.g., chemical spills), and dilution is measured on the basis of flow volume and flow distance from a problem, it is essential to be able to trace downstream basin outflows. Several strategies have been developed for encoding these flow relationships.

**Name Lists**

Names could be commonly used stream names, but these are generally not unique. There are, for example, at least 21 Indian Creeks in the state of Illinois; therefore a unique labeling must be created. This can be accomplished by adding an additional identification field to each stream record. This approach lacks intuitive appeal and may require users to adopt strategies for determining whether information retrieved is associated with the intended stream. For example, a program can be constructed to ask the user: “Do you mean the Owl Creek that flows into the Sangamon River?” Answers to such queries normally will ensure that data are retrieved for the correct stream, although they presume that the user has some knowledge of the basin.

Assuming that an identification strategy can be established, each stream then has a list of its tributaries associated with it. The number of entries in such a list will vary widely, and thus it is unwise to try to store it in a single record. The list should be normalized to produce a record type that consists of the main stream and a single instance of a tributary. This is illustrated as an entity-relationship diagram (Chen 1983) in Figure 2, and as a relation in Figure 3. If implemented as a relation, the name list approach may require a substantial number of joins if flow relationships for an entire basin are required for analyses. Such operations are facilitated by recursion (Schek 1988), but this feature is not available in all commercially available relational database management software. Joins are also performed when additional attribute information about each tributary is required. Selection operations are used to specify records that meet specified criteria; joins enable two tables to be linked on the basis of attributes held in common in each table. Given a table consisting of streams and tributaries, a selection creates a new reduced table in which only those tributaries of a specified stream are present. The tributary field of this new table is used to join with the original table to find those tributaries of the first tier of tributaries, and this process repeats until a join fails to find matches. At that point, a join to other tables containing needed attributes is performed.

**Hierarchical Stream Numbers**

In this approach, each stream is assigned a unique identifier that directly incorporates the stream network relationships. There are two major strategies that have been advanced: concatenated integers, and binary.

**Concatenated integers.** Armstrong and Hopkins (1983) describe a referencing strategy in which each stream is numbered

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**FIGURE 2.**
Entity-relationship diagram for name-list method of specifying flow relationships.

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Stream has Tributaries
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**FIGURE 3.**
Example relation showing name-list method.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Tributary</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sangamon R</td>
<td>Owl Cr</td>
</tr>
<tr>
<td>Sangamon R</td>
<td>Indian Cr</td>
</tr>
<tr>
<td>Sangamon R</td>
<td>Hunter Br</td>
</tr>
<tr>
<td>Sangamon R</td>
<td>Rawlings S1</td>
</tr>
<tr>
<td>Sangamon R</td>
<td>Duck Cr</td>
</tr>
</tbody>
</table>

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upstream from the outflow of the river system. The stream numbers consist of groups of digits which serve as counters for the number of tributaries upstream from the outflow. These counters are then concatenated as the basin flow structure is constructed (Figure 4). Each group of digits can yield additional information, for example, by using odd identifiers for tributaries flowing in from the left facing upstream. In addition, the groups can contain null entries (or zero values) to permit future additions to the sequence. Such additions may be required if the scale of the system is changed to include small order streams, or if a small stream that otherwise would not be included in the system has a distinguishing characteristic that warrants its inclusion (e.g., a hazardous waste site). Finally, streams may need to be added because they were inadvertently missed during data collection.

The concatenated numbers must be parsed to produce information about flow relationships and basins. For example, if a stream is identified as 102030, and two digit groups are used for each stream, it can be determined that the stream is the third tributary of the second tributary of the outflow stream (10). Parsing, in this case works from right to left. In addition, information about basins can be retrieved by processing only records with identification numbers within a given range. Continuing with this example, if information were required about all tributaries upstream from 1030, all stream records with identifiers from 103000 to 103099 inclusive would be accessed. The major limitation of this approach is its sensitivity to the depth of the network; as smaller and smaller tributaries are enumerated, the required number of digits grows linearly.

A related method uniquely identifies each reach rather than each stream. At least two instances of this approach have been implemented: The United States Environmental Protection Agency’s Reach File and Minnesota’s Common Stream and Watershed numbering.

The EPA reach file (U.S. Environmental Protection Agency 1982) builds on U.S. Geological Survey hydrologic units. A hydrologic unit number identifies a watershed and a reach number identifies a portion of a stream, usually delimited by two confluences. These numbers are sufficient to identify parts of streams uniquely, but all hydrologic flow relationships must be provided through pointers that indicate the outflow destination and inflow sources of each reach.

In the state of Minnesota’s Stream Inventory and Data Retrieval Systems Program (Thornton 1981), the intent is to provide support for representing each minor watershed within a basin. Each Common Stream and Watershed (CSAW) identification number is also a non-unique basin identifier (Brown, Anderson and Gersmehl 1987). A set of terminal streams is identified in the first stage of the process of assigning identifiers to streams, and then tribu-
taries of these streams are numbered consecutively upstream from the mouth. These base numbers are augmented in the second stage with a set of new codes that provide information about the relative location of each watershed along the stream. Taken together, the numbers uniquely identify each basin within each major drainage basin in the state; the numbers, however, are not unique for the entire state because several watersheds can be the fourth basin on the third tributary of a major stream (Brown, Anderson and Gersmehl 1987:10). A similar approach was developed by Hopkins, Armstrong and Belford (1981) for the state of Illinois. Their reach-based system, however, was later discarded because it was unnecessarily cumbersome when information about an entire stream was required. And reaches can be calculated from the hierarchical stream numbering system described above if the locations of tributaries are maintained as an attribute of each stream.

Klein (1982) described a numbering system in which a total of four digits provides a unique identification sequence. In this strategy (the right-hand-turn rule), as the tributaries upstream from the outflow are reached, an arbitrary decision is made to always turn right at the confluence. The next step is to form a number in which the first two digits are the identifier of the stream to the right, and the second two digits count the number of segments which lie upstream from the confluence (Figure 5). In this approach, however, each stream reach has a unique identifier, and thus, a list of reaches must be built and processed if information about the main axis of an entire stream is needed. This problem is exacerbated if information about an entire basin is required.

**Concatenated bit-strings.**

Beran (1982) uses a series of concatenated bits to store network structure. This representation is parsimonious, yet is able to capture the richness of stream tributary relationships. The identification number is calculated at each confluence by assigning a 1 for the right branch, and a 0 for the left (Figure 6). Thus, a stream numbered 110 is the first tributary entering from the left of the first right-hand tributary of the main stream in the basin. It suffers from the same affliction, however, that the right-hand-turn method does—it breaks streams into reaches at confluences. To retrieve information about an entire stream, a list of reaches must be traversed. This approach also suffers from the limitation of the long sequences ascribed to the concatenated integers approach described above. Although the increment of accumulation is smaller because only single digits are being accumulated at each level of the hierarchy, identification sequences tend to grow quickly because each reach (rather than each stream) has an identifier. Thus, identifier lengths increase rapidly in areas with dense stream networks.
An additional feature of this strategy is that each binary identifier can be converted to base ten to ease human use of the system—a bit string is inherently difficult for most people to recall and use. It is important to note, however, that even with this conversion, each of the strategies described here, including the name list with its non-unique stream-names problem, will normally require a human interface to translate between human cognitive naming schemes and their database representations. One way to implement this is to build an additional list or relation that specifies the correspondence of commonly used names and database identifiers. Such lists are rarely easy to construct because of non-unique names that require additional identification.

Database Integration

Databases designed to support water resources decisions must contain a wide variety of thematic information types because of the interdisciplinary nature of water problems. This raises the issue of data acquisition for numerous attributes of streams. For example, if information is needed to support a decision about issuing a permit to construct an intrusion on a stream, a topological framework, such as that described earlier is required. Associated with this framework is a need for information describing a diverse set of natural and constructed features related to the location of the proposed intrusion: bridges, dams, and land cover types are common examples. Costs associated with manual data entry are high, however, and so whenever possible existing databases are often used to provide needed information. But within these existing databases, each thematic element may have been originally collected and organized with a different purpose in mind; thus a mechanism must be developed to translate from the original database domain to the stream database domain. Database engineering provides a set of frameworks for the systematic treatment of such transformations (Navathe et al. 1986).

Database engineering concepts

Nyerges (1989) has defined this process as "...the bringing together of information parts into a working whole, controlling redundancy where appropriate." A key issue that helps to guide the process of integrating diverse information about surface water resources is the provision of a method for ensuring use of a common strategy for making distance measurements and a common strategy for specifying flow relationships. Existing databases almost always have some locational attributes, and thus the mapping from the original domain to that of the target database is an important task. In addition, system designers must ensure that other identification schemes (e.g., sort keys) are commensurate. This is best accomplished with records that are fully normalized in the relational database context. Navathe et al. (1986) specify a multi-step process for information integration begin-
ning with the user view of the database. The first step is pre-
integration in which naming conventions are established for
objects and attributes. This step is eased if a thoroughly speci-
fied data dictionary is available. Problems, of course, will occur
if ambiguities exist in variable names and if units of measure-
ment are not specified. Keys are also identified at this stage. This
enables entities to be uniquely identified. When this is known,
Navathe et al. (1986) suggest that the domain of entity classes
can be determined to be:

- Identical: Domain (A) = Domain (B)
- Contained: Domain (A) ⊆ Domain (B)
- or
- Domain (B) ⊆ Domain (A)
- Overlapping
- Disjoint: Domain A ∩ Domain (B) = Null

In a surface-water resources database, identical do-
main would occur if each database contains the same set of
streams. In cases where only a single basin is contained in one
database, the second condition would hold. Overlapping do-
main would occur if some of the streams in two databases are
held in common, whereas the final condition would hold if no
stream is held in common in each database. The problem of
naming conventions is particularly important in this case, be-
cause, as noted earlier, stream names are not unique. Thus, the
determination of set coverage is difficult to automate as a prac-
tical matter.

The following steps should be followed to smooth integra-
tion of disparate databases associated with surface water resources:

- Establish a naming convention for streams, stream identifiers,
  entities and their attributes.
- Establish the correspondence among these features.
- Establish candidate keys and do-
  mains for object classes.
- Establish a mapping among
equivalent attributes of object
classes.

A similar approach based on Navathe et al. (1986)
was described by Armstrong
(1990) for a groundwater data-
base integration application.

The Illinois Streams Information System

The implementation of the Illinois Streams Information System (ISIS) raised many of the issues addressed here. The
approach to the length measurement problem was also part of
the database integration problem, because data from diverse
sources must be interpreted appropriately. Given the severity
and pervasiveness of length measurement problems, a strategy
was formulated to minimize the adverse effects of error on
system performance. This example is predicated on the exist-
ence of a set of distance benchmarks encoded along the
feature at clearly defined points (e.g., at bridges across streams)
between which new estimates can be made. This serves to re-
duce error effects, which tend to accumulate as distance along a
linear feature increases, including dynamic process effects.

The benchmark distances used by ISIS were measured by the
USGS (Healy 1979) and constituted an accepted set of
known and identifiable points,
known as a River Mile Index
(RMI), upon which to base new measurements. In the USGS
data set, most bridges, USGS
gauging stations, tributary con-
fluences, and county boundaries
were encoded. Because each
confluence is included in the
ISIS benchmark data, cumula-
tive error cannot propagate bey-
ond the length of a stream. In
practice, however, errors do not
normally propagate very far
along any individual stream be-
cause bridges and tributaries
also are included; and most
streams are bridged by roads on
a regular basis because the road
system in Illinois is based on
the rectangular U.S. Public Land
Survey (USPLS) survey system.
Given these benchmark data,
additional data encoded by ISIS
staff included such items as sec-
tion lines, topographic con-
tour line crossings, and intakes and
outfalls along streams, among
approximately 25 additional
variables.

Information was encoded to the nearest one-tenth mile
from USGS 7.5-minute topo-
graphic quadrangles. This
means, for example, that if a
stream meanders into a section
for less than one-tenth of a
mile, the section is not entered
into a list of sections through
which the stream flows. Also
note that any given RMI indi-
cates only that the feature de-
scribed is within 0.05 mile on
either side of the point that cor-
responds exactly to that mea-
surement (Figure 7).

The ISIS database uses
7.5-minute quadrangles
(1,240,000) as its primary data
source for all measurements that
were required to supplement the
existing RMI data. This scale provides an adequate level of generalization for making length measurements for a state-wide database because it enables measurements provided in the original benchmark data (Healy 1979) to be replicated consistently. In addition, this map series depicts almost all of the streams that were needed in the ISIS database. When published 7.5-minute maps were unavailable because of incomplete coverage in Illinois at that time, either preliminary versions of 7.5-minute maps or 15-minute series quadrangles were used. These source documents have well known characteristics and conform to National Map Accuracy Standards. Note, however, that this standard applies only to well-defined points, and does not apply to irregular features such as stream meanders (Thompson 1982).

RMI digitizing was performed by graduate assistants who received training about the goals of the project and the methods that were developed to accomplish these goals. When needed, new measurements were interpolated between known points to minimize cumulative error. To determine an interpolated value for a required RMI (RMI<sub>n</sub>), two distance measurements are made. The first is from the nearest-known downstream RMI (RMI<sub>0</sub>) to the new point, and the second is between RMI<sub>n</sub> and the nearest-known upstream RMI (RMI<sub>0</sub>). If the sum of the two new distances (RMI<sub>n</sub> to RMI<sub>0</sub> and RMI<sub>n</sub> to RMI<sub>0</sub>) is within two percent of the benchmark distance (BD) between the known points from the existing database, then the new RMI is:

\[
RMI_n = RMI_0 + \frac{(RMI_0 - RMI_n)}{(RMI_n - RMI_0)} \times BD
\]

Since the known distance (BD) is assumed to be correct, the new distance is adjusted to be in the same proportion to the known length, as the measurement to the new point is to the total measured distance.

If the difference between new and old measurements was greater than two percent, the new measurement was confirmed and used. Differences between measured RMI values and those in the existing database occurred from measurement errors in the original data capture process, and from errors that occurred because of dynamic fluvial processes. The new distances are likely to be a more accurate reflection of the environment because the newest available maps were used. Thus, channelization, meandering, and meander cutoffs not detected in the original database, but which exist in the field, are captured. The ISIS approach changes the RMI values if significant channel changes occur so that the index can be used for distance calculations. If, for example, the U.S. Army Corps of Engineers wants to extract data with respect to its river mile posts, these could be entered as a data item.

Nyerges (1990) suggests the reverse strategy for highway networks, maintaining road mile markers as the index for data and including a separate distance attribute for distance calculations. This distance can then be modified if the road is realigned without changing the mile markers. This strategy may be more appropriate for roads because the mile markers exist on the ground as reference points, but with the exception of a few navigable streams, such markers do not exist for streams.

The ISIS database made extensive use of existing digital data sources to minimize data entry costs and error. Data were obtained from various state and federal agencies (e.g., USGS and Illinois Department of Transportation). Each agency, however, had a unique method for organizing its database; in each instance a conversion from the existing database to the ISIS referencing scheme needed to be performed.

Bridge information, for example, was obtained from two sources. The USGS database (Healy 1979) contained the RMI for each crossing and in most instances the crossing was identified by name or highway number. Thus, each bridge was identified by the water feature it
crossed, how far upstream the bridge was from the mouth, and a descriptor. The stream and RMI data were integral to the ISIS database, but each bridge record also needed an assigned stream number. Bridge descriptors (e.g., highway designations) were standardized to ensure uniform interpretation and to allow identification by highway and highway network route mile. Detailed information about the characteristics of each bridge were obtained from a specialized database about bridge characteristics compiled by the Illinois Department of Transportation (IDOT). Because the quantity of information about each bridge provided by IDOT exceeded that which was required by ISIS, the number of fields on each record was reduced substantially.

The Illinois Streams Information System has now been completed based on the design described above. Data included are documented in Hinrichs et al. (1991) and the database is documented in Johnston et al. (1991).

Conclusion

Surface water resources information systems have unique data organization requirements because they must efficiently support flow relationships, particularly the dominant hierarchical structure. Problems arising from the need to assign features along the linear dimension of a stream also must be addressed. Although there is no theoretical solution for deter-

mining length along a sinuous line, operational procedures can be implemented. Those adopted for ISIS illustrate one feasible approach. Designers and users of such systems, however, must be cognizant of the potential for data error and user misinterpretation. With the proliferation of digital cartographic and attribute data, developers of surface water resources information systems must be attuned to the need to integrate existing data into their systems. Database engineering methodologies can be fruitfully applied to support these tasks.

Notes

1. Although we recognize the importance of using internationally accepted units of measurement, for reasons related to ease of implementation and user acceptance of the system as described throughout this paper, miles rather than kilometers are used. A mile is a unit of length in common use in the United States; each mile is approximately 1.6 kilometers.

Acknowledgements

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References


Land Information Systems Network in the Puget Sound Region
Thomas Nolan and Timothy Nyerges

Thomas Nolan received his masters degree in geography from the University of Washington, with an emphasis in geographic information systems (GIS). He is currently working for the city of Seattle as project manager of the city’s “Joint Automated Mapping Project.” Research interests include municipal GIS, and regional GIS integration efforts.

Timothy Nyerges earned a Ph.D. in geography from Ohio State University. Currently an assistant professor of geography at the University of Washington, his research interests include GIS as it applies to land records management and transportation issues.

Abstract: Many public and private organizations are generating land information and maintaining land records with little awareness of each others’ activities and responsibilities. Although this current institutional arrangement is caused by separate mandates, it nonetheless leads to a duplication of efforts and inconsistent data. This paper examines the problems and potential for implementing a “land information systems network” (LISN) in the Puget Sound Region of Washington State.

Although many local agencies collect information about land, e.g., land descriptions, value, ownership, parcel size, location, use, restrictions, and zoning, land managers continue to face major problems with managing land information. The Larsen Report (1976), which is best known for its estimation of costs of land information, also provides an extensive list of problems concerning the management of land information:

- Accessibility
- Availability
- Duplication
- Aggregation
- Intergratability
- Confidentiality
- Institutional

A variety of land-records management procedures have evolved in response to organizations’ needs and mandates for information. “The irrationality that characterizes our present land records system is not the result of irrational behavior; it is the outfall of rational, but uncoordinated behavior.” (Portner and Niemann 1984, p. 96)

Many current land records systems and operations have evolved in response to inefficient manual data collection and storage methods. However, today’s versatile software and affordable hardware is making automated systems more widespread and efficient, making them more practical and accessible for local governments and organizations (Dueker 1987).

An unfortunate result of the rapid computer automation is the creation of multiple, separate systems and record collection procedures that are incompatible with each other (Comptroller General 1982); mostly because they follow organizational perspectives of the past. There is a need for a systematic and more holistic approach to land records modernization; otherwise continued financial commitments in isolated single-purpose systems will make integration and information sharing less likely.

In the past few years, several concepts have been proposed that should help ameliorate land records management.
problems. Among these are: the multipurpose cadastre (MPC), geographic information systems (GIS), land information systems (LIS), and the concept of land information systems networks (LISN).

A MPC is defined by McLaughlin (1984) as "a large-scale community oriented land records system designed to serve both public and private agencies, and individual citizens by: 1) employing a land parcel as the fundamental unit of spatial organization; 2) relating a series of land information records to this parcel; and 3) providing ready and efficient access to these records."

A GIS is defined by Dueker and Kjerne (1989) as "a system of hardware, software, data, people, organizations, and institutional arrangements for collecting, storing, analyzing, and disseminating information about areas of the earth."

Dueker and Kjerne define a LIS as "a geographic information system having, as its main focus, data concerning land records."

Finally a LISN is defined by Palmer (1984) as a confederation of LISs that work together for the benefit of each, and for the benefit of the whole, without having to be in the same organizational unit, e.g., local government. In summary, a MPC is implemented using LISs and GISs linked together in a LISN.

A LISN would rely primarily on institutional, organizational, and cooperative arrangements in order to take advantage of rapidly developing LIS/GIS technology. Consequently, the nature of a LISN results from the needs, experience, and intuition of the involved organizations.

The purpose of this paper is to examine the potential for a LISN in the Puget Sound Region. For some years, members of several local organizations have talked about a regional database. A LISN addresses that interest. The paper's goals are:

1) Explore the regional interest level in the LISN concept.
2) Assess available resources among possible participants.
3) Identify the major problems that need to be overcome.
4) Provide recommendations for the implementation of a successful LISN in the Puget Sound Region.

RESEARCH APPROACH

Determining which organizations to include in this project was a multi-step process. A list of potential participants was compiled by consulting literature sources such as the National Research Council Report of 1980, and the Geographic Information Management Systems Standards (GIMS) report, 1988.

The next task was determining how to contact appropriate respondents within each organization. Mailing lists from the now-defunct Washington State Mapping Advisory Committee (SMAC) and Northwest Computer-Aided Mapping Association (NWCA-MA) were used to contact likely participants; then questionnaires were mailed. This process took six weeks. The questionnaire determined:

1) The extent to which organizations and agencies have automated (or plan to automate) their land records systems;
2) Which groups produce and utilize land information by type;
3) Which groups are interested in additional land information.

The next step included interviews with key survey respondents. It was felt that in-person interviews could add background on both existing land record management systems, as well as those being planned. An additional set of questions was asked to determine the most important issues involved with land information sharing.

SURVEY RESULTS

The survey results confirmed that the major problems to be overcome before and during LISN development encompass complex institutional, economic, and technical issues. Although the issues and problems can not always be placed into a single category, three categories provide a convenient framework for discussion.

Institutional Issues and Problems.

Many survey participants identified a lack of coordination and cooperation among land information-using agencies. This is a serious obstacle to the development of a LISN. The term cooperation basically describes "one-on-one" ventures between organizations. Often this coop-
eration is a result of good intentions by individual agencies. Coordination refers to a method of "managing cooperation," to insure that many organizations are cooperating with one another in a more efficient manner.

Insufficient cooperation among organizations collecting, using, and storing similar land information results in duplication of efforts. Lack of a means to coordinate and share land information, and distribute the associated costs, hinders cooperation and coordination. Confidentiality and liability constraints also tend to reinforce separation of land information activities.

Cooperation within the Region Cooperative ventures are by no means a new idea in the Puget Sound Region. Of the 40 organizations responding to the questionnaire, 88 percent stated that they are presently engaged in some type of data-sharing arrangement involving the exchange of land-related information. Clearly, government agencies are creating links where needs exist, and agreements can be forged. However, almost all respondents indicated they could benefit from cooperating with more organizations.

Coordination within the Region Perhaps the greatest obstacle to large-scale coordination among organizations is a difficulty in finding commonality among organizational mandates. Also, there are no organizations that have within their mandate, a specific responsibility to directly coordinate information sharing within the region.

Coordination often evolves out of the need for a solution to a specific problem. Several survey respondents stated that many potential cooperative agreements probably do not materialize because organizations know too little about their counterparts. With this in mind, increased coordination of efforts (as well as information and/or application development sharing) may be more likely to evolve if it is established which organizations in the region engage in similar land information applications (see Table 1).

The primary advantage of such a grouping is probably "application sharing" because applications may be similar even if geographic areas are not overlapping. The possible exchange of ideas and discussion of issues relating to new or improved applications could also lead to more coordination of efforts within the region.

Although a grouping of organizations by application category obscures the details of individual organizations, some common data interests can be determined. "Application-categories" that utilize similar land information are documented in Table 2.

Groups that promote data, cost, and application sharing, as well as educating others of the needs and advantages for integrated land information systems in the Puget Sound region are listed in Table 3. These common interest and coordination groups could become the focal point for the creation of new arrangements as well.

Confidentiality and Liability Constraints Seventy percent of participants reported that they do not produce or use any information that is not available to the public. These organizations feel they have no "confidentiality" constraints that would hamper their ability to enter data-sharing arrangements.

The related issue of "liability for information provided" is a more sensitive topic. Although no survey participant reports any recent problems involving liability issues with their data-sharing agreements, several individuals believe that a methodology for resolving potential incidents, especially in regard to digital data, is needed.

Economic Issues and Problems.

The following list contains the most frequently mentioned economic "hurdles" that must be cleared before LISN development can be initiated successfully.

1) Availability of Funding for LISN Development
2) Cost of Additional Geodetic Control
3) Need to Justify Automation/Integration Costs

LISN Funding Availability

The major economic issue concerning LISN development is the problem of how to obtain adequate funding for conversion to digital methods in a coordinated manner. In order to acquire funding for new cooperative projects, decision-makers must be convinced of the importance of such projects, especially if there are extra costs as-
TABLE 1.
Respondent Organizations Listed by Organizational Focus

<table>
<thead>
<tr>
<th>RESOURCE MANAGEMENT</th>
<th>SERVICE MANAGEMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>USGS: Water Resources Div</td>
<td>Seattle Police Department</td>
</tr>
<tr>
<td>WA Dept of Natural Res</td>
<td>Tacoma Police Department</td>
</tr>
<tr>
<td>WA Dept of Wildlife</td>
<td>Seattle Fire Department</td>
</tr>
<tr>
<td>WA Dept of Ecology</td>
<td>Tacoma Fire Department</td>
</tr>
<tr>
<td>Puget Sound Wtr Qual. Auth.</td>
<td>King Co. Emergcy. Medical Serv</td>
</tr>
<tr>
<td></td>
<td>METRO (Transportation Div)</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>FACILITIES MANAGEMENT</th>
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<tbody>
<tr>
<td>Port Authority of Tacoma</td>
</tr>
<tr>
<td>Port Authority of Seattle</td>
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<tr>
<td>WA Dept of Transportation</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>Public Works Departments</th>
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<tbody>
<tr>
<td>King County</td>
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<tr>
<td>Pierce County</td>
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<tr>
<td>Snohomish County</td>
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<tr>
<td>Thurston County</td>
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<tr>
<td>Bellevue</td>
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<tr>
<td>Everett</td>
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<tr>
<td>Kent</td>
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<tr>
<td>Renton</td>
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<tr>
<td>Seattle</td>
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<tr>
<td>Tacoma</td>
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<table>
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<tr>
<th>Public Utilities</th>
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<tbody>
<tr>
<td>METRO (Water Quality Div)</td>
</tr>
<tr>
<td>Seattle City Light</td>
</tr>
<tr>
<td>Private Utilities</td>
</tr>
<tr>
<td>Viacom TV Cable</td>
</tr>
<tr>
<td>US West Communications</td>
</tr>
<tr>
<td>Puget Power Electric</td>
</tr>
<tr>
<td>Washington Natural Gas</td>
</tr>
<tr>
<td>US West/Cellular Phone Division</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>DEMOGRAPHICS</th>
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<tbody>
<tr>
<td>U.S. Bureau of the Census</td>
</tr>
<tr>
<td>King Co. Dept of Election</td>
</tr>
<tr>
<td>Puget Sound Council of Govts</td>
</tr>
<tr>
<td>METRO (Transportation Division/s)</td>
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<tr>
<th>PLANNING</th>
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<tbody>
<tr>
<td>Municipal</td>
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<tr>
<td>Seattle</td>
</tr>
<tr>
<td>Everett</td>
</tr>
<tr>
<td>Tacoma</td>
</tr>
<tr>
<td>County</td>
</tr>
<tr>
<td>King Co.</td>
</tr>
<tr>
<td>Regional</td>
</tr>
<tr>
<td>Puget Sound Council of Gov'ts</td>
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</tbody>
</table>

<table>
<thead>
<tr>
<th>LAND TAXATION/EVALUATION</th>
</tr>
</thead>
<tbody>
<tr>
<td>King County Assessor</td>
</tr>
<tr>
<td>Stewart Title Company</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>LAND USE AND DEVELOPMENT</th>
</tr>
</thead>
<tbody>
<tr>
<td>King Co. Land Development Information System</td>
</tr>
<tr>
<td>King Co. Building and Land Development</td>
</tr>
<tr>
<td>Seattle Master Builders Association</td>
</tr>
<tr>
<td>King and Snohomish Multiple Listing Service</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>ADMINISTRATIVE</th>
</tr>
</thead>
<tbody>
<tr>
<td>City of Seattle Administrative Services</td>
</tr>
<tr>
<td>City of Tacoma Data Processing Department</td>
</tr>
<tr>
<td>King County System Services</td>
</tr>
</tbody>
</table>

The use of general funds also eliminates the difficult problem of attempting to divide the costs of cooperative projects between individual user agencies. However, general funds are difficult to justify and obtain and user-fee financing is frequently used.

"User fees" is a financing alternative that charges users in proportion to benefits received. Quasi-user fees are property taxes and property transfer taxes used to create digital parcel layers. Property owners and purchasers are deemed to be users of the system. This last approach would require new legislation and political support however.

Survey participants also listed possible incentives to LISN development. This list included: new market mechanisms and new state legislation allowing an LISN to be built profitably, the further development of federal and state standards to provide goals to shoot for, and a "data-giveaway" scheme to promote application-development sharing.

**Costs for Additional Geodetic Control** The lack of adequate geodetic control to spatially register the region's land information databases is an often mentioned roadblock to LISN development. Cooperative arrangements are needed to distribute and share the associated costs of the improved geodetic control.

Geodetic control network-development time is also an issue. Organizations with lower accuracy requirements
may not be willing to wait or pay to construct a digital database acceptable for those with the highest accuracy requirements. Yet, geodetic control is crucial to register separately collected data.

Justifying Automation/Integration Costs The success of a proposal to improve land information systems in an organization depends heavily on the priority level it attains compared to other projects competing for the same tax dollars. In the United States, some of the most successful proposed or operating LISNs are the state of Minnesota (Robinette, 1984), Lane County, Oregon (Carlson and Bates, 1986) and the city of Indianapolis (Montgomery, 1990). Successful LISNs are born when systems are coordinated and supported by a wide variety of proponents.

Survey results confirm literature findings (Godschalk et al. 1985) that the major costs in constructing and eventually linking land information systems are in four major categories:

1) Investments in hardware and software
2) Conversion of data
3) Personnel
4) Operations and data maintenance

Survey participants reported the following tangible benefits:

1) Time savings in map production and map updating
2) Improved facility management and government administration
3) Quicker access to information
4) More current information available

<table>
<thead>
<tr>
<th>TABLE 2.</th>
<th>Land Information by Application Category</th>
</tr>
</thead>
<tbody>
<tr>
<td>Resource Mgmt</td>
<td>Service Mgmt</td>
</tr>
<tr>
<td>Parcel Boundaries</td>
<td>X</td>
</tr>
<tr>
<td>Street Centerlines</td>
<td>#</td>
</tr>
<tr>
<td>Hydrography</td>
<td>#</td>
</tr>
<tr>
<td>Right of Ways</td>
<td>#</td>
</tr>
<tr>
<td>Transportation</td>
<td>X</td>
</tr>
<tr>
<td>Contour lines</td>
<td>#</td>
</tr>
<tr>
<td>Subdivision Boundaries</td>
<td>#</td>
</tr>
<tr>
<td>Zoned Boundaries</td>
<td>#</td>
</tr>
<tr>
<td>Building Footprints</td>
<td>#</td>
</tr>
<tr>
<td>Physical Geography</td>
<td>X</td>
</tr>
<tr>
<td>Benchmarks, Control</td>
<td>X</td>
</tr>
<tr>
<td>Sewer Pipes</td>
<td>#</td>
</tr>
<tr>
<td>Utility Poles</td>
<td>#</td>
</tr>
<tr>
<td>Storm Sewers</td>
<td>#</td>
</tr>
<tr>
<td>Edge of Pavement</td>
<td>#</td>
</tr>
<tr>
<td>Easements</td>
<td>#</td>
</tr>
<tr>
<td>Water Pipes</td>
<td>#</td>
</tr>
<tr>
<td>Spot Elevations</td>
<td>#</td>
</tr>
<tr>
<td>Soils</td>
<td>#</td>
</tr>
<tr>
<td>Parcel Centroids</td>
<td>X</td>
</tr>
<tr>
<td>Sidewalks</td>
<td>#</td>
</tr>
<tr>
<td>Manholes</td>
<td>#</td>
</tr>
<tr>
<td>Electric Lines</td>
<td>#</td>
</tr>
<tr>
<td>Gas Lines</td>
<td>#</td>
</tr>
<tr>
<td>Telephone Lines</td>
<td>#</td>
</tr>
<tr>
<td>Other Planimetric</td>
<td>#</td>
</tr>
<tr>
<td>Address Ranges</td>
<td>#</td>
</tr>
<tr>
<td>e = 50% or more of organizations in the category use this information</td>
<td></td>
</tr>
<tr>
<td>x = 25 - 50% of organizations in the user category use this information</td>
<td></td>
</tr>
</tbody>
</table>

Intangible benefits also were mentioned, but are less quantifiable:

1) Improved decision-making
2) Improved community planning
3) Less time devoted to projects
4) Increased spatial modelling possibilities

Survey participants also were asked to respond to a broad question, “Can you provide a rough estimate of the costs necessary to accomplish your mandate in regard to land information?” Responses indicate that approximately 18 million dollars will be spent for the management and automation of land information in the region over the next five to ten years. If these dollars are to be spent wisely on automation projects, the need to identify duplicative efforts, and possibly reduce the duplication through some form of LISN, should be important to those spending the money, and those paying the costs.

Data Layer Supply and Demand Several studies suggest
TABLE 3.
Land Information-Oriented Professional Organizations

Northwest Computer Aided Mapping Association (NWCAMA)
Washington State Geographic Information Council (WA-GIC)
Northwest Land Information Systems Group (NWLIS)
GPS Users Group
ACSM/ASPRS State Chapter
Research and Data Interest Group, sponsored by PSCOG
Northwest ARC/INFO Users Group, sponsored by ESRI
Northwest Synercom Users Group, sponsored by Synercom.

TABLE 4.
Most Valuable Data Layers to Provide

WA Dept of Natural Resources—PLSS control information
King Co. Tax Assessor—Current parcel-based maps, parcel ID’s, and street
address linkage, taxpayer name, and assessed value per site
King Co. Planning/LDIS—Plats, building permits and recently rezoned area
information
King Co. Dept of Elections—County-wide, up-to-date address based information
King Co. System Services—County land and building characteristics
King Co. Emergency Med Services—Automated “Geocode System” for recording
and modelling service management data
City of Everett Public Works—County-wide “base map” for private utilities
City of Everett Public Works—City-wide infrastructure information

that successful LISNs usually develop on an incremental basis
(Godschalk et al. 1985; WLRC 1987). High-priority data-sharing
arrangements often evolve from immediate needs. High-priority
data layers that organizations could provide are presented in
Table 4. On the other hand, high-priority data layers that or-
ganizations would like to receive from other organizations are
presented in Table 5.

Analysis of Tables 4 and
5 is difficult, but some linkage
possibilities seem to emerge:

- There is an indication that county
tax assessors, elections depart-
ments and administrative depart-
ments should attempt to create
and link digital parcel and ad-
dress-based information.
- It appears that municipal service-
management organizations (po-
lice, fire, and EMS) should join
with planning agencies to obtain
digital address-based information,
as well as population information.
The U.S. Census Bureau’s
“Tiger files” could act as a fram-
ework for address-based informa-
tion.
- Municipal and county public
works departments, in conjunc-
tion with public and private utili-
ties, should create linkages be-
tween infrastructure databases by
means of geodetic control to
achieve spatial registration, data
transfer standards, and common
data models.

Technical Issues and Problems.

Technical Issues The study in-
vestigated all ongoing land in-
formation modernization in the
region. Sixty-five projects/pro-
grams/activities, that we char-
acterize as “development phases”
are being undertaken within or-
organizations (Table 6). The
larger number of development
phases than organizations indi-
cates that some organizations
are involved in multiple proj-
ects, possibly at different stages
of development.

It is also interesting to note that a total of 72 percent of
the activity is in local govern-
ment (municipal—46 percent, and county—26 percent). The
type of system developments are listed in Table 7. Most are
in the planning or design stage, although a large proportion are
operational. Thirty-four (85 per-
cent) of the 40 responding or-
ganizations say that they already
have or are planning to auto-
mate their land information
functions.

A question about collec-
tion units resulted in parcels
being listed as the most com-
mon unit (Table 8). However,
only 31 percent of the organiza-
tions reported the parcel unit as
their most important unit of in-
formation collection. These re-
sults reinforce the need for a
geodetic geo-reference fram-
work, and an LISN’s need for
linkages capable of dealing with
a large variety of possible
analysis units. Chrisman and
Niemann (1985) also argue that
positional overlay is superior to
using parcel units for data in-
tegration.

Technical Problems Although
the most difficult roadblocks to
LISN development are probably
institutional and economic prob-
lems, there are also several
technical problems that must
TABLE 5.
Highest Priority Data Layers to Receive

| WA Dept of Natural Resources—Rural transportation and hydrography |
| King Co. Tax Assessor—Linkage to county construction and development permit issuance |
| King Co. Planning/LDIS—Census tract population and housing information |
| King Co. Dept of Elections—Direct updates of annexations, jurisdictional and school district boundary changes |
| King Co. System Services—County levy and bond information in automated form and parcel number-address linkages |
| King Co. Emergency Med Serv—Population information |
| Snohomish Co. Public Works—Improved geodetic control |
| City of Everett Public Works—Snohomish Co. assessor maps |
| Seattle Police Dept—Up-to-date address-based information |
| Puget Power—“Land Base” of Puget Sound Region, with land features and geodetic control |
| Washington Natural Gas—Multi-layer, underground construction map, including all utilities |

The technical aspect of digital base-map compilation is an area of concern to many organizations that wish to share data. Although a base map for facilities management contains many of the same layers necessary for a base map useful for other applications, some organizations are not willing to pay the higher costs associated with an engineering-quality base map which requires positional accuracy equal to one to five feet (with respect to true measured position on the earth). Yet sharing of data requires that the data be compiled with equivalent positional accuracy. These issues of accuracies can be handled by documenting the needs of organizations and searching for similarity. The paper takes a step in this direction by documenting the range of map-scales used by participant organizations (see Figure 1).

Because the region is served by land information systems from several vendors, spatial data transfer is a problem. A solution to this problem as developed by the Digital Cartographic Data Standards Task Force (DCDSTF 1988) is known as the National Data Transfer Specification (SDTS).

SDTS "...is an attempt to meet the recognized requirement for easy transfer of spatial data from one spatial data handling system to another with both systems possibly residing on computer hardware and operating software of different makes" (DCDSTF 1988, p. 17). The SDTS was submitted to the National Institute for Standards and Technology in May 1990.

TABLE 6.
System Development—By Institution
(Number of reported development phases by organizations within the following institutional frameworks)

<table>
<thead>
<tr>
<th>Institution</th>
<th>Stages</th>
<th>Reported</th>
</tr>
</thead>
<tbody>
<tr>
<td>National</td>
<td>3</td>
<td>5%</td>
</tr>
<tr>
<td>State</td>
<td>8</td>
<td>12%</td>
</tr>
<tr>
<td>County</td>
<td>17</td>
<td>26%</td>
</tr>
<tr>
<td>Municipal</td>
<td>30</td>
<td>46%</td>
</tr>
<tr>
<td>Private</td>
<td>7</td>
<td>11%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>65</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

(Total Participant Organizations = 40)

TABLE 7.
Type of System Development in the Region

<table>
<thead>
<tr>
<th>1) Planning</th>
<th>31%</th>
</tr>
</thead>
<tbody>
<tr>
<td>2) Design</td>
<td>15%</td>
</tr>
<tr>
<td>3) Acquisition</td>
<td>7%</td>
</tr>
<tr>
<td>4) Implementation</td>
<td>8%</td>
</tr>
<tr>
<td>5) Operation</td>
<td>29%</td>
</tr>
<tr>
<td>6) Enhancement</td>
<td>10%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

(Total developmental phases included = 65)

TABLE 8.
Basic Units of Information Collection
(Number and percentage of organizations using each unit)

<table>
<thead>
<tr>
<th>Parcels</th>
<th>15</th>
<th>31%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Address</td>
<td>6</td>
<td>13%</td>
</tr>
<tr>
<td>Street Segments</td>
<td>5</td>
<td>10%</td>
</tr>
<tr>
<td>Quarter Sections</td>
<td>6</td>
<td>13%</td>
</tr>
<tr>
<td>&quot;Arbitrary&quot; Grid</td>
<td>7</td>
<td>14%</td>
</tr>
<tr>
<td>Other</td>
<td>9</td>
<td>19%</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td><strong>48</strong></td>
<td><strong>100%</strong></td>
</tr>
</tbody>
</table>

standards and guidelines for digital mapping. The situation in the United States is somewhat paradoxical in that:

...the U.S. is near the bottom of the world list for developing policies and guidelines for large-scale mapping and land records maintenance...while at the same time, the U.S. leads the world in the development of the technologies which might
reasonably be employed to address the problem. (Clapp et al. 1985, p. 3).

Conclusions

The most important conclusion of this study is that there is a large and growing, yet unstructured, interest in sharing geographical information. To accomplish this, there is a recognized need for improved geodetic control in the Puget Sound area. This was documented by a high response ratio to the survey; responses indicate a high level of interest in data sharing.

Yet no single organization is willing to undertake the role of systems integrator.

A solution to contemporary land information sharing problems is the development of a LISN. A LISN approach is decentralized in nature, relying on cooperative arrangements to function. Successful cooperative arrangements usually require information-exchange methodologies where all parties benefit, and no one party is assigned an undue amount of responsibility, without remuneration.

The region has a long way to go before implementing a LISN based on organizationally independent layers. Although coordinated approaches exist and are expanding at the state and municipal level, on the very beginnings of a coordinated approach can be found three (King, Snohomish, and Pierce) of the region's four counties (Thurston being the fourth). Cooperation between public and private sector organizations appears to be quite limited, although interest in public/private ventures is at least being discussed.
Recommendations for Implementation.

This project was conducted to identify the spectrum of problems to be faced and opportunities that are possible if a LISN is implemented in the Puget Sound region. The following recommendations are offered:

No single organization need be created as the “host agency” for coordinating information exchange. Of the agencies involved in this survey, limited budgets are the biggest impediment to creation of a host agency. However, an existing organization must undertake the responsibility for facilitating information exchange.

The identification of such a “focal point” for transmitting land information is essential for the Puget Sound region. Such an organization could also recommend state legislation to insure compatibility. Existing organizations that foster cooperation, such as NWCA-M, Washington State Geographic Information Council and Northwest Land Information Systems Group (NWLIS) may have the potential to take on parts of the role. There is a need for:

- A forum for Land Information Integration ideas to be presented before a cross-section of representatives of the land information community (NWCA-M and WAGI Council).
- A clearinghouse of existing regional digital data along with source, and intended application information (NWLIS). However, the focus of NWLIS is more on state and federal cooperation, and they have not focused on large-scale and local information coordination.

Existing cooperative arrangements should be enhanced. Inter-agency committees consisting of public and private sector land information users could focus on developing a “pilot project” illustrating expanded cooperative arrangements. These committees could originate in a professional society.

A cooperative effort should be forged between the National Geodetic Survey (NGS), Washington state Department of Natural Resources (DNR) and the Washington Department of Transportation (DOT) to take the lead in densifying the National Geodetic Reference System. The National Geodetic Survey has a responsibility to assume this task but does not have sufficient funds to do the job alone. The DNR, with a predominantly rural focus, and the DOT, with a more urban focus, in conjunction with the NGS, county and municipal public works departments, and the utilities should all become partners in this effort to improve the geodetic control network.

There is a need to increase the dissemination of information about national standards and guidelines now that they exist. SDTS, GIMS, and Federal Geodetic Control Committee guidelines must be made more understandable and be distributed to regional users. Users need to become aware of the existence of these standards and then be able to apply the appropriate pressure on vendors that it will take to implement standards and guidelines by means of improved translators and the opening of proprietary formats.

A variety of financing alternatives need to be explored in order to fund LISN development. The use of general funds for aspects of projects that are public goods should be promoted, while user fees should be used to recover costs that can be priced and for which there is a willingness to pay.

There is a need to develop strategies to obtain political support for information integration ideas. Some possible approaches are:

- Promote the need for a more “coordinated” approach to local government as a means to more efficiently deal with problems transcending political boundaries, such as land development, pollution, transportation, crime, and population growth.
- Promote the need for assistance to public officials in making decisions by providing current and comprehensive land information.
- Promote the need for information integration to increase efficiency and effectiveness of day-to-day operations.

Highest priority linkages to be established are probably:

- Tax and parcel information,
- Land use and impact analysis information, and
- Infrastructure information.
References


A Conceptual Model of Measurement-Based Multipurpose Cadastral Systems

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Andrew Frank is the New England section ACSM professor in land information studies and an associate professor in surveying engineering at the University of Maine. He received his Ph.D. from the Swiss Federal Institute of Technology (ETH), Zurich, Switzerland and a Dipl. Ing. from the same institute. His research interests include treatment of geometry in computer systems, and the human interface for GIS systems.

Abstract: A measurement-based multipurpose cadastral system uses measurements as the basic carrier of metric information. This concept is realized by allowing the processing of the measurements to be suspended until metric information is needed. Least squares adjustment is the tool used to process the measurements and a direct manipulation user interface provides appropriate interaction with the system. A measurement database furnishes convenient management of measurements and related data. The advantages of a measurement-based system include incremental implementation, ease of updating, improvement of accuracy over time, correct integration of different data layers, and preservation of background information.

A multipurpose cadastral system is a framework that supports comprehensive land-related information such as land use, vegetation, buildings, mineral resources, flood hazards, utilities, income, and population at the parcel level. It uses a cadastre as the basic building block. A cadastre is a
complete and up-to-date official register or inventory of land parcels in any jurisdiction containing information about the parcels regarding their locations and extensions, and other pertinent data such as ownerships, rights, uses, and valuations (Dale and McLaughlin 1988; NRC 1983).

Parcel corners are first used to define the geometry of the parcels. Later, they are used together with other points which have unique spatial positions to link and correctly register land-related data such as soil type, vegetation, topography, hydrology, and utility data. All these different types of data which make up a multipurpose cadastral system are usually seen as distinct layers superimposed on a cadastral layer (Dale and McLaughlin 1988; NRC 1980). This kind of multipurpose cadastral is based on a set of previously established, and sufficiently complete and accurate geodetic control points.

A study by the United States National Research Council (NRC 1980) indicated that there is a critical need for a better multipurpose cadastral system at each level of government to improve land-conveyance procedures, furnish a basis for equitable taxation, and provide much-needed information for resource management and environmental planning. To assist local level governments in developing multipurpose cadastral systems, the National Research Council later proposed the following implementation steps of a multipurpose cadastral system (NRC 1983):

1) establishment of a network of geodetic control points,
2) preparation of the base maps,
3) preparation of the cadastral overlay,
4) maintenance of the parcel-registers and data file; and
5) maintenance of the link between the cadastral and other land-related data.

This amounts to a coordinate-based approach and a system implemented following such procedures is called a coordinate-based cadastral system. The basic idea of coordinate-based systems is illustrated in Figure 1.

Several problems are associated with the above method of implementation because of the segmented nature of the process. First, the sequence of operations as proposed requires a large investment of resources at the beginning and a long wait before benefits are realized from the system. This makes a multipurpose cadastral system a proposition difficult to sell in the political arena. A number of attempts to implement a multipurpose cadastral system have met financial difficulties during this initial period (Bauer 1982; Wentworth 1989). Second, a multipurpose cadastral based on an accurate survey at the beginning naturally decays over time.
FIGURE 2.
A survey measurement management system as a supporter of a coordinate-based multipurpose cadastral system.

since maintenance of this accurate geometric base which is in the form of coordinates is difficult. As a matter of fact, coordinates are not maintainable; obsolete coordinate values are discarded and replaced with new values. Countries with long experiences in such systems plan a 'renovation' effort periodically (Kolbl 1987).

This paper attempts to describe a model of a multipurpose cadastral system where the implementation unites all the processes recommended by the National Research Council above in a uniform manner, using measurements as the basic data. However, a discussion of implementation details such as the required data structures is omitted to limit this paper to a reasonable length. It is also important that multipurpose cadastral systems literature separates the concepts involved in a computer program from the mechanics of their implementations.

The next section presents related work. It is followed by a discussion of the concepts and inherent problems of coordinate-based cadastral systems. A discussion about networks of control points as they apply to land surveying is then presented. The concepts and advantages of measurement-based cadastral systems are presented next, followed by a discussion of the architecture of such systems: the measurement database, the geometry module, and the user interface. Conclusions are given in the last section.

Related Work

The National Geodetic Survey (NGS) has completed the readjustment of the National Geodetic Reference System (NGRS) to the North American Datum of 1983 (NAD 83) (Schwarz 1989). Some geographic regions, however, are found to have a weak relative accuracy despite an overall improved NGRS for the nation. Ethridge (1989) described the use of a measurement database to upgrade the coordinates of the NGRS in regions where the relative accuracy is inadequate.

Jacobi (1988) discussed how discrepancies of coordinate values, after a revision or update of a digital map, can be eliminated if the original photogrammetric measurements of map points and geodetic measurements of control points are stored. In such an arrangement, new measurements are combined with old measurements and are simultaneously adjusted to obtain a unique set of coordinate values of map points whenever a map needs to be updated. This is in contrast with the normal practice of discarding the measurements after the coordinates of the associated points have been determined, which makes updating difficult (Figure 1).

Hintz et al. (1988), Hintz and Onsrud (1990) and Elfick (1989) described systems that manage surveying measurements. The primary aim of such systems is to effectively manage the huge amount of cadastral measurements inherent in any cadastral system. The described systems store cadastral measurements and periodically provide an updated set of parcel corner coordinate values by adjusting all related measurements. Storing raw cadastral measurements instead of coordinates, which are derived quantities, resulted in systems that are flexible, sensitive to changes, and that have the potential to be legally sup-
portive (Moreno and Onsrud 1990; NSF 1985).

Although Ethridge's work was concerned with the NGRS upgrade, Jacobi's work was concerned with digital photogrammetric map revisions, and the works of Hintz and Elfick primarily support cadastral systems, they all have several characteristics in common: (1) measurements are second-class objects, (2) systems are basically measurement management systems to support coordinate-based systems, and (3) computed coordinate values are transmitted to the supported systems. These characteristics are shown in Figure 2.

Kjerne and Dueker (1988) argued that present approaches to cadastral system implementations do not capture the spatial relationships between cadastral objects as determined by surveyors. Only object locations in terms of coordinates are known while the knowledge of why the objects are there has been lost. They suggested that by modeling cadastral data using an object-oriented paradigm (Atkinson et al. 1989), cadastral systems are able to: (1) trace the chain of operations that leads to a particular object being at a particular place, and (2) update an object's location without having to undergo the coordinate reconstruction processes again. An object-oriented structure also allows flexibility in the order of entry of data in a cadastral system and thus permits revision and updating more easily. Figure 3 shows this object-oriented concept where, for example, parcel X and boundary line J know if point P has changed its position.

![Figure 3](image)

The work reported in this paper extends the works of Ethridge, Jacobi, Hintz, and Elfick, and integrates the work of Kjerne and Dueker. In doing so, the gap that separates the measurement management systems and the systems they support is removed; a measurement-based multipurpose cadastral system integrates a surveying measurement management system and a multipurpose cadastral system (Figure 4). However, it is not just an integration. In such a set-up (1) measurements are first-class objects; (2) measurements are the basic carrier of metric information; and (3) the measurement-management system plays a dominant role. Efficient management of measurements and related data requires a measurement database. A coordinate database facilitates operations where the use of coordinates is more appropriate. An appropriate user interface must also be integrated.

**Coordinate-Based Systems**

Geometric queries to a multipurpose cadastral system can be divided into topological and metric queries. Topological queries are concerned with the information that is invariant under topological transformations. Metric queries are those based on the notion of a distance. The question whether or not a house is inside a parcel is a topological question, while a question about the length of a boundary line is a metric one. Figure 5 illustrates the two types of queries.

The principal concept of a coordinate-based system is that the stored coordinate values are the primary sources of data providing answers to metric queries and possibly to topological queries as well. For example, if we query a coordinate-based system about the frontage of a parcel, the information is obtained by calculating the length of the
boundary line from the coordinate values of the end points.

An implementation of a coordinate-based multipurpose cadastral system starts with the establishment of a stable geodetic control network and the preparation of the base map. Later, measurements between parcel corners and other object points are adjusted to fit the control network. The adjusted coordinate values of parcel corners and other objects of interest are stored in the database. The original measurements are utilized in the restoration of a lost boundary mark or in the subdivision of a land parcel. Unfortunately, the principle of guarding the old measurements is endangered by the advent of computerized cadastral systems. Today’s multipurpose cadastral systems are built solely on coordinates with no linkages to measurements.

In many cases, parcel corners and other objects are digitized from old maps and plans because of speed and economy. The digitized coordinate values are then transformed to conform with the underlying coordinate system of the geodetic control network. In such situations, the actual measurements do not exist in the construction of the system and can never be consulted if the need should arise.

Coordinate-based multipurpose cadastral systems have several problems. The problems range from the time of initial conception and financing of the system to the actual implementation and maintenance. This multitude of problems has been described by several authors (Bauer 1982; Dale and McLoughlin 1988; Friedley 1989; Hebblethwaite 1989; Masters 1988; Scott 1987) and can be grouped into two general categories: implementation and maintenance.

**Implementation**

Creation of a good coverage of control points requires much effort and capital investment. These are the early obstacles to the implementation of a
coordinate-based multipurpose cadastral system. Although satellite positioning techniques such as the Global Positioning System (GPS) have made this task more manageable, its cost is still beyond the limit that could easily be afforded by most local governments such as municipal and county administrations. Besides the cost of setting up the control points, the cost of converting cadastral and other related data into digital format to be stored in the database has to be considered, and experiences have shown that this cost is quite substantial (Parent, Jaffe, and Finkle 1989; Thompson 1988).

Since a lot of expenses accrue at the time of system initiation, a coordinate-based system implementation demands a heavy investment at the beginning. There is also a long lead time from the moment of investment to the time the system can be used due to the sequential implementation procedure. Elected officials, with public demand to minimize taxes and expenditures, find it hard to make a large investment where the benefits may not be perceptible to the public for quite a few years. Because of the high front-end costs and small immediate return, elected officials (usually with short terms of office) tend to concentrate on other short-term issues and problems (Dueker 1987).

**Maintenance**

The maintenance issues mostly revolve around updating the coordinate database and base map. The problems can be organized into four categories: (1) the integration of new measurements with existing coordinate values; (2) the integration of high-quality new measurements with low-quality coordinate values; (3) the continuously changing coordinate values of parcel corners; and (4) the evolving accuracy requirements of base maps.

**Integration of new measurements with coordinate values:** Integrating new measurements with stored coordinate values that were either computed from earlier measurements or digitized from other sources is an involved and expensive process. The correct method would be to obtain the earlier measurements and recalculate the coordinate values of all points after new measurements have been integrated. This method of updating a coordinate database is seldom used because of considerable efforts to recover the earlier measurements, if they are still available at all. The other option is to use a sequential adjustment technique. This method, however, requires the variances and covariances of the points from prior adjustments. Although storing the variances of point coordinate values may be justifiable, storing a huge amount of covariances is a forbidding task. To store the covariances of 10,000 points could require the storage of up to \((2 \times 10,000)^2\) values.

**Integration of high-quality new measurements with low-quality coordinate values.** Existing coordinate values in a system tend to be of lower quality than new measurements. The coordinate values are obtained either by digitizing from various maps and plans or computed.
from old measurements, which were acquired using less precise instruments and sometimes dubious procedures. Integrating new measurements acquired using today's high-technology instruments into existing coordinate sets poses a difficult problem. Most of the methods utilized do not take into consideration the quality of the existing coordinate values and the new measurements. As a result, there is a danger that precision is lost because new measurements are downgraded by fitting them into existing coordinate values. Discarding existing coordinates, on the other hand, may result in a loss of information.

**Shifting effect of the cadastral layer:** Layers of information in a multipurpose cadastral system are usually integrated through property corners. However, coordinate values of property corners in the cadastral layer are subject to constant updating due to, for example, new sub-division surveys, uncovered errors and blunders, and re-adjustment of the underlying geodetic reference framework (Hebblethwaite 1989). Since a coordinate-based system stores only coordinate values and discards the measurements that link the objects on the various layers, it loses the medium to propagate the changes of coordinate values in the cadastral layer to the other layers. As a result, it appears that the cadastral layer has moved when different layers of information are overlayed.

The adoption of a new datum (NAD 83) is an example of a process which causes the shifting effects (Bossler 1987). The problem arises after the new datum has been incorporated into the cadastral layer, for example, by readjusting measurements that are specific to this layer using the redefined control point coordinate values. While the parcel boundary points tied to geodetic control have been readjusted to the new datum, points in all other layers are still referenced to the old datum. The apparent shift of the cadastral layer with respect to the other layers when the overlay is done makes the information produced by such a system inconsistent (Figure 6).

**Accuracy of base maps:** The accuracy with which base maps are prepared depends on the use and value of the land. As the use of land changes over time, the quality of base maps may become insufficient making a re-survey to improve the accuracy necessary. Since it is generally impossible to accurately predict where development will occur, the recommended procedure is to measure the whole area according to a higher standard and prepare the base maps for higher accuracy than actually warranted. This practice of preparing base maps for possible future growth and needs that are still uncertain can be a waste of resources.

**Control Points**

The majority of the problems inherent in present implementations of multipurpose cadastral systems is associated with the notions of networks of control points and hierarchical adjustments. Rethinking these notions opens up another view of position determinations and thus a new way of implementing a multipurpose cadastral system.

A network of control points is a set of points which may or may not be realized on the ground and whose coordinate values have been determined from a survey. The coordinate values of the control points are used as the basis for other dependent surveys. The surveys from which the control point coordinate values are obtained, known as control surveys, are usually of higher precision than the dependent surveys (NGS 1986).

The concept of control surveys and subsequent surveys is due to the classical methods of land surveying, primarily the hierarchical network adjustment perspective (Bomford 1975). Before the widespread use of computers, it was impossible to establish coordinate values of a set of points for an area of significant extension based on a single network adjustment. Surveyors lacked computational tools that enabled a large number of equations to be solved simultaneity. Even the methods employed in adjusting small networks attempted to reduce the number of equations to be solved by, for example, adopting the condition equation model (Bomford 1975).

The solution to the problem was to break up the task into smaller tasks using the principle of hierarchical network design. Consequently, this gave rise to different qualities of network points (characterized by the order of networks) with different levels of precision, and a hierarchy of adjustments where
justments to determine the coordinates of lower-quality points.

With the availability of digital computers and the speed of computing today, a greater number of equations can be solved at any single time. A larger number of measurements can be adjusted simultaneously, and thus, for a lot of cases, fictitiously subdividing a network into a hierarchy is unnecessary.

Network points in dependent surveys should not be labelled as control points. The quality of network points should be determined purely from the precision of the coordinate values after the network measurements have been simultaneously adjusted; high-quality points are points with more precise coordinate values, i.e., smaller variances. To have high-quality points, precise measurements in sufficient density are needed as opposed to fallaciously dividing the points into different qualities dictated by the adjustment capability.

Measurement-based multipurpose cadastral systems will adhere to this approach. There is no reason to retain the old philosophy in an age where computing power is readily available. If partitioning of points is necessary, it should be done spatially (by regions), not hierarchically. Many advantages are expected from adopting this idea.

**Concepts Of Measurement-Based Systems**

The fundamental concept of measurement-based multipurpose...
pose cadastral systems is that measurements are the carriers of metric information (Buyong and Frank 1989). Consequently, updating a database of a measurement-based system with new measurement information only requires the addition of the measurements to the database. Users can directly communicate their original information to the system. Re-computation of coordinates is not imperative and can be deferred until needed by queries. The disseminated metric information is always up-to-date because the latest measurement can be integrated into the processing.

Implementation of a measurement-based system requires measurements to be stored in the database (Buyong and Frank 1989; Elfrick 1989; Ethridge 1989; Frank and Studemann 1984; Hintz and Onsrud 1990; Jacobi 1988; Kjerne and Dueker 1988; Weitzman 1989) such that they become accessible for future use. These measurements include measurements between higher-quality points (in coordinate-based systems, such measurements are known as control point measurements), parcel boundary measurements, and measurements of other objects of interest.

Although measurements are the primary source of metric information, coordinate values are used where it is more appropriate. Graphical representation, spatial database access, and other tasks that do not need accurate and up-to-date information are examples where coordinates are useful. To satisfy the needs of these tasks, coordinate values are stored (Alonso et al. 1988). Thus, instead of re-computing the coordinate values each time a graphical representation of parcels is requested, the stored values are retrieved.

Periodic global processing of the measurements in the system is necessary to fulfill the need to have a reliable and consistent copy of coordinate values. This can be realized in several different ways. Two of the ways are: (1) to make the system process the measurements at certain pre-set time intervals; for example, at night when most computers are essentially idle, or (2) after a certain number of measurement changes have occurred.

Advantages Of Measurement-Based Systems

A measurement-based multipurpose cadastral system has several practical advantages over a coordinate-based implementation. The advantages lie primarily in the ease of updating, incremental implementation, systems as by-product of standard activities, improvement of accuracy over time, correct integration of different layers, preservation of background information as well as in several economic benefits.

Updating: The existence and the value of each measurement in a measurement-based system are independent of other measurements. This makes system updating easy. Integration of new measurements is done simply by adding the measure-
ments into the database. Old and inaccurate measurements can coexist with better values or be deleted from the database without difficulty. The ease of updating also allows an organization to keep the data in a measurement-based system always current. Since answers to metric queries are processed only at the time they are needed, the latest available data can be incorporated. Thus, the information a measurement-based system provides is always up-to-date. It is anticipated that this advantage will become more significant as the functionality of a multipurpose cadastral system becomes more complex and the demand for accurate and up-to-date information increases.

Incremental implementation: The implementation of a measurement-based system can start with a small area of immediate concern such that a system with the necessary functionality can be set up rapidly. As time goes on and when money and manpower become available, neighboring areas can be incorporated by adding relevant measurements into the database. Islands that are initially developed independently can also be linked together.

System as a by-product of standard activities: Measurement-based systems do not demand special up-front data collection tasks. Existing measurements, however deficient, will form the basis of multipurpose cadastral systems and are supplemented by new
measurements as they become available. The new measurements may come from standard daily operations of surveyors, like subdivision, rectification, and retracement surveys.

**Improveent of accuracy:** A measurement-based system can be set up with limited quality measurements. As expected, the accuracy of such a system is poor. However, the accuracy of the system improves as the system matures and more measurements are added. The improvement of accuracy can occur by special efforts, like the addition of GPS measurements, or from daily operations of surveyors. With the availability of more precise instruments to surveyors, cadastral measurements from standard activities certainly contribute to the improvement of the accuracy of the system. No extra overhead is required to support accuracy improvement since all procedures remain the same but are supported by a higher degree of automation and integration.

**Integration of layers:** In a measurement-based system, the measurements that determine the coordinate values of points in non-cadastral layers relative to property corners are kept in the system. Thus, the changes in the coordinate values of property corners in a cadastral layer, due to whatever reasons, are automatically propagated to other layers through these measurements. This is a special case of the integrated geometry concept (Frank and Kuhn 1986).

The adoption of a new geodetic datum for the cadastral layer in multipurpose cadastral systems, e.g., the current adoption of the NAD 83 datum to replace the NAD 27 datum, will produce no discrepancies in measurement-based systems. This is because coordinate values of points in all layers of information are computed from relevant measurements as they are needed. This ensures correct relative positions between points in the cadastral layer and points in other layers when the two layers are superimposed.

**Preservation of background information:** A measurement-based system retains the original measurements and their quality information (variances). Preserving the original data as opposed to the massaged data provides evidence for any information the system offers; users can determine the basis of answers to queries. The quality information about measurements in a system permits relative weights to be placed on them. It is foreseen that the availability of measurement variances will become one of the most important advantages as users become aware of the need to keep track of the quality of metric information (Chrisman 1984; Goodchild and Gopal 1989; Robinson and Frank 1985). A system with such capability affords a major step toward the goal of a legally supportive multipurpose cadastral system (Moreno and Onsrud 1990; NSF 1985).

**Economic benefits:** Among the economic benefits resulting from the technical advantages discussed above are the low start-up capital and the short lead-time from the moment of investment until a system can be used. First, the high cost of setting up a good coverage by a control network is avoided because its prior completion is unnecessary. A measurement-based system also avoids the up-front cost of converting data from the entire project area into digital format. The ability to implement the system in a gradual manner, starting with a small area of immediate concern, also makes large start-up capital unnecessary. Second, with a small area of initial implementation, a measurement-based system can be used as soon as it is set up. The benefits of having the system can be realized much faster, and, most probably, the system can financially support itself for expansion if some kind of user fees are imposed. Thus, the small start-up cost, quick return on investment, and ability to quickly support itself make it more likely to gain support from the funding authority.

**System Architecture**

In the last two sections, the concepts of a measurement-based multipurpose cadastral system and several advantages it offers have been presented. The most important of all are the economic advantages which are no doubt the prime criteria for successful implementations. In this section, the architecture of a measurement-based system will be described. Because measurements are the primary data in a measurement-based system, the discussions of the design architecture are focused on them.
**Measurement Database**

Measurements are abstract relationships providing metric information about a set of points. Points can either be boundary points or survey points. Boundary points define the geometry of parcels, i.e., their location and extension. The location and extension of buildings, roads, rivers, utility lines, and like features are determined from the associated survey points.

The stored measurements can be categorized according to their sources: (1) terrestrial measurements, (2) GPS measurements, and (3) digitized data.

**Terrestrial measurements:** Terrestrial measurements encompass horizontal angles, horizontal distances, directions, bearings, and azimuths. These are the common forms of measurement found in surveying networks. While all types of measurements provide relative positions of points, azimuth and bearing measurements give one extra piece of information: they also provide the orientation of the network with respect to the adopted reference frame.

**GPS measurements:** This category of measurement is highly accurate and available only at selected points in a project area. Due to their inherent high accuracy, GPS measurements can be used to define the reference frame and to provide a homogeneous system of coordinates between isolated areas in a multipurpose cadastral system. Their high accuracy also makes them useful for curbing error propagation from other categories of measurements.

**Digitized data:** This is probably the cheapest type of (pseudo) measurements. Digitized data can be obtained from hard-copy maps and plans. They can be used to set up a system initially and can become the predominant category of measurements at the beginning, although this is not a requirement—a measurement-based system can be built without any digitized data. Other types of measurements can later gradually be introduced into the system. It should be kept in mind that digitized data must not be left alone to provide metric information as this would just create another coordinate-based system.

Points, lines, and polygons are other major objects in the database beside measurements. Each object has particular properties called attributes that describe it. Examples of some of the prominent attributes of the objects are:

1) **Measurements**—observed values, variance, observer and date observed
2) **Points**—point number, coordinates, coordinate variances and point types
3) **Lines**—lines types
4) **Polygons**—polygon types and area

**Geometry Module**

In order for the measurement-based system to have a usable representation of the geometric properties of the real world, measurements must be processed before any metric information is disseminated. Measurement processing combines available measurements, detects blunders in the measurements, and imposes additional geometric constraints if necessary. The most suitable measurement processing method is the technique of least squares adjustment (Mikhai. 1976).

The method of least squares allows all categories of measurements, each with different accuracy, to be processed in an integrated way. Measurements can be independently weighted and the inverse of the measurement variance, expressed in some standard unit, is a natural choice for the weight. The contribution of each measurement to the coordinate values is thus determined by its variance. Since measurements with small variances will have large weights, their contribution to the adjusted coordinate values is more significant than the contribution of measurements with large variances. These are desired properties for integrating lower accuracy terrestrial, cadastral or digitized coordinate measurements with higher-accuracy GPS measurements to obtain an optimal solution. The method of least squares also permits easy integration of non-measured data, known as a priori information, in the measurement processing.

A pre-processing module is required for each measurement type due to the availability of a mixture of categories of measurements and a number of parameters on which each measurement category is dependent. With the pre-processing, each measurement type is prepared
for input into the least squares adjustment module in a uniform manner. Much of the unwanted or nuisance parameters and systematic effects are eliminated during measurement pre-processing.

Blunders of various kinds may be present in the measurements stored in a system. A system will lose its trustworthiness if the information it produces contains excessive blunders. A blunder-detection algorithm based on a sound statistical foundation can be integrated into the adjustment module. This way, blunders of significant magnitude are detectable prior to the information being given out. Procedures for post-adjustment blunder detection are discussed by Baarda (1967) and Pope (1976). These methods of blunder detection can be employed immediately after an adjustment has been carried out. A technique to detect blunders before an adjustment, introduced by Vonderohe and Hintz (1987), can be used during the measurement pre-processing stage.

Geometric constraints can be incorporated into the adjustment to improve the accuracy of information furnished. Simple examples of geometric constraints are perpendicularity, collinearity, and parallelism. These constraints are useful in areas where the quality of the available measurements is insufficient to accurately determine the desired geometry; for example, when only digitized coordinates are available, the low quality of digitized coordinate values makes additional constraints a valuable supplement.

There is no difference between a measurement and constraint from the data modeling perspective; for example, it does not make any difference whether a distance is measured 10 meters or it is constrained to be 10 meters (Kuhn 1990). Hesse, Benwell, and Williamson (1990) discussed the application of geometric constraints to digitized cadastral data in a multipurpose cadastral system.

For practical reasons, not all the measurements in a database are adjusted whenever coordinate values of some points are needed to answer queries. Only measurements around the neighborhood of the queried area that significantly influence the desired results need to be processed. This is due to the localized nature of surveying information propagation (Halmos, Kadar, and Karsay 1974). Judging from experiments carried out using simulated terrestrial data, it is only necessary to include measurements up to four measurements away around an area of interest. Inclusion of more distant measurements does not significantly improve the adjusted coordinate values of the queried area points (Buysong and Kuhn 1990).

As mentioned before, the geometry module is a tool to obtain usable metric representation from measurements. This tool, as a complete package, may be unavailable on the market. Since the theories, however, are relatively well understood, creating the package is not seen as a major task. Several good surveying network adjustment programs with blunder detection and additional constraint capabilities such as OPTUN (Grundig and Bahndorf 1984), CANDSN (Mepham and Krakiewsky 1984), and STAR*NET (Curry and Sawyer 1989) are already available on the market. A geometry module can be built around any of these programs.

**User Interface**

Direct manipulation interaction has been generally accepted to be an effective form of human-computer interaction as evidenced by its use in Macintosh computers, Microsoft Windows on IBM-PC microcomputers, and Unix operating systems. It is especially suitable for treating spatial objects because it takes advantage of the spatial properties inherent in such objects. The user interface for measurement-based multipurpose cadastral systems should adopt the direct manipulation concept.

The user interface for measurement-based systems should support objects that are meaningful to the users, i.e., the different types of measurements (such as angles, distance and directions); points (such as boundary and survey points); lines (such as boundary and survey lines); and polygonal objects (such as parcels and buildings). A set of operations to manipulate the objects must be provided; input, edit and delete operations are needed for storing, modifying and removing objects in the database, and a find operation is needed for searching objects in the database when at least one of their attribute values is known.

The most important requirement for the direct manipu-
FIGURE 7.
Graphical representations of the different types of measurements.

- Point
- Boundary line
- Digitized coordinates
- Vector
- Distance
- Azimuth
- Angle
- Directions
- Bearings

The operations of the user interface can be represented as menu items, organized in the form of pull-down menus. They are grouped according to their semantics relevant to the user's tasks. For example, operations directly relevant to the cadastral objects such as input, edit, and delete are grouped together and are separated from operations that are concerned with the display.

A display that shows all the objects in an area is not conducive to effective human-computer interaction because of the limited size of the computer screen and the existence of an upper bound of human perception of the complexity of graphical representations. Given a typical area of a multipurpose cadastre that may be in the order of several thousand square kilometers, and the availability of several different types of objects which sometimes are clustered to a few selected places, a way to reduce the complexity of a display must be provided.

The reduction in the display complexity can be achieved through effective use of multiple windows (Herot 1982; Jackson 1990). A small reference window is used to display an overview of the entire scene and a bigger main window is used to display a portion of the selected scene at a larger scale. Two legend windows permit the user to select only certain types of objects to be displayed; one legend window deals specifically with the different types of measurements while the other window deals with the rest of the objects. Figure 8 shows the different windows of the user interface with only parcels being displayed in the main window.

Interfaces to transfer measurement data from data collecting systems such as automatic field data collectors, photogrammetric triangulation systems, and GPS receivers must also be provided. Such interfaces provide convenient and...
easy input of measurements that originate from these measuring systems. Editing of these measurements can be performed in the same way after they have been stored in the system.

Conclusion

A measurement-based multipurpose cadastral system uses measurement data as the basic carrier of metric information. This concept is realized by allowing the processing of the measurements to be suspended until information is needed.

A measurement database, a geometry module, and a user interface are the three major components of the architecture of a measurement-based system. The geometry module contains measurements pre-processing, processing, and blunder detection algorithms. An efficient management of the measurements is furnished by the measurement database. A user interface that presents objects that are meaningful to users in a very simple fashion is indispensable for the system.

The advantages of a measurement-based system over a coordinate-based system are significant. An implementation does not require prior completion of a network of control points. Initially, a measurement-based system can be implemented within a small area of immediate concern and expanded at a later stage when needs and resources warrant it. Thus, it requires a low start-up capital and provides faster returns on the investment. New measurements can be integrated easily and the overall precision of a system improved over time, as more or better measurements are added. Changes in the position of parcel corners are automatically propagated to other non-cadastral layers through the stored measurements. The background information which determined the location of parcel corners and their accuracies is also retained in the system.

The evolutionary and incremental approach to building a measurement-based multipurpose cadastral system is especially attractive. Its implementation strategy is suitable for local governments such as municipalities and counties. These are the organizations that really need a multipurpose cadastral system, but lacked the funds to pursue the idea; the implementations of coordinate-based systems require substantial preparatory tasks to be completed before the system could be used.

Acknowledgements

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A Geographic Systems Approach to Fiscal Analysis

Linda K. Tomaselli

Linda Tomaselli currently is the GIS coordinator for the Metropolitan Council, a regional planning agency for the seven-county Minneapolis/St. Paul metropolitan area. She has been a city planner for more than 20 years. In 1988, she was awarded a research grant from the National Science Foundation to conduct research on the costs and benefits of a geographic information systems approach to fiscal impact analysis. Using this research for her dissertation, she earned her Ph.D. in geography from the University of Minnesota, with a supporting program in management information systems and public affairs.

Abstract: This paper describes the costs and benefits of a geographic systems approach to fiscal analysis, compared to six accepted non-geographic approaches. The research for this paper was funded by a grant from the National Science Foundation (NSF). The hypothesis of the research is that local government needs a better way to evaluate and understand the impact of its land and economic development decisions. It also needs to be able to react to changing fiscal policies of the state and federal government. The geographic systems approach meets these needs by modeling the flows of revenues and expenditures by parcel within a city. The goal of the modeling process is to produce the same results that would be produced if the city had the ideal “management information system” that was capable of recording the source of every dollar of revenue and the location of every dollar of expenditure, and then summarizing the data to make operational, tactical and strategic planning and management decisions. The geographic systems method is comparable in cost to the other methods if a city has an existing GIS database. The approach avoids some very costly mistakes, and the results are far more accurate and useful. Furthermore, the method is far less costly and takes less time to implement than the ideal “management information system.”

Local government officials need to be able to evaluate the impact of land development decisions on city finances. They also need to be able to react to the changing fiscal policies of the state or federal government. In recent years, the federal government has cut aid to states and local government. States also have cut aid to local government. Therefore, local officials need to become more aware of the impact of their own decisions, as well as the impact of decisions that are beyond their control. There are several methods that are being used to analyze fiscal impact. However, most are either too simplistic to adequately consider all the interrelated factors that affect local government finance, or they are too rigid to adapt to changing conditions. In addition, most methods ignore the spatial aspects of land development and of local service delivery. Furthermore, they do not leave the local government with a product that is useful for ongoing strategic planning and management.

The research described in this paper is based upon the premise that the currently accepted methods of determining the fiscal impact of land development are inadequate, and subject to many possible errors. The inadequacies and errors could lead to erroneous conclusions and unwise land-develop-
teristics of individual land parcels in a city. Examples of these parcel characteristics are: the land value, the value of improvements (houses, stores, and businesses), and the people living in the houses or working in the stores and businesses. The people and businesses also demand police protection and need roads to provide access to their properties.

An approach that models these revenue expenditure flows is the “Geographic Systems Approach to Fiscal Analysis.” The method uses a systems approach to tie the revenue and expenditure flows to specific parcels and land uses, using geographic information systems (GIS) technology. A system is defined by Webster’s New Collegiate Dictionary as “an interdependent group of items that form a unified whole.” The geographic systems approach models the system of local government finance to determine and understand how the system works. The method can also be used to measure the efficiency and equity of service delivery among subareas of a city. Such measures could also be determined using the same general approach at the county, region or even state levels.

This paper describes the geographic systems approach to fiscal analysis, and its costs and benefits, compared to the six currently accepted non-geographic methods. The comparisons were part of a research project conducted in the city of Anoka, Minnesota from July 1987 through September 1988. Figure 1 shows an example of the results of this approach applied to the city of Anoka.

This paper also compares the geographic systems approach to other recent local fiscal impact studies. The transferability of the method to cities in other parts of the country, and additional research needs are also described. A portion of the research described in this paper was funded by a grant from the National Science Foundation, under the Small Business Innovation Research (SBIR) Program. This research is described more extensively in a doctoral dissertation by the author of this paper (Tomaselli, 1989).

A Systems Approach

The geographic systems approach to fiscal impact analysis is designed to model the flows of revenues and expenditures within a city. The goal of the geographic systems approach is to produce the same fiscal impact results that would be produced if the city had the ideal “management information system.” This ideal system would be capable of recording the source of every dollar of revenue and the location of every dollar of expenditure, and periodically summarizing these transactions to make operational, tactical and strategic planning and management decisions. Figure 2 shows the con-
creationally summarized so as to be appropriate to the decisions being made.

The geographic systems approach views the functions of city government as being spatial in nature. These are shown conceptually in Figure 3. The center of each circle represents city government, located in city hall. Surrounding the city hall are subareas of the city; these are

the individual land parcels in the city. Revenues flow from the subareas to the city’s bank account. Expenditures are made from this account in response to the need for services. Subtracting expenditures from revenues yields the net surplus or deficit (fiscal impact) of the geographic area. The revenue and expenditure flows are the same as the transactions at the base of the MIS pyramid, shown in Figure 2. A transaction would be a police car responding to a call, or a citizen paying a parking ticket. In the geographic systems approach, a database is developed that models all of these flows for the entire community.

The geographic systems approach incorporates this spatial database into the typical management information systems (MIS) approach. This is shown conceptually in Figure 4. The geographic database becomes the base of the pyramid shown in Figure 2, because it is a model of daily transactions. Since the database is spatial, it turns the flat, two-dimensional pyramid into a cone shape. This ideal system is now capable of providing information for decision-making on where things are happening in addition to other information like “when,” and “how much.” At the top of the pyramid, strategic decisions are made, like the development and adoption of a comprehensive land use plan by the planning commission and city council. In the ideal city, these decisions are based on summaries of the detailed information that are contained in the spatial database. However, the database is also available to aid in opera-
Figure 2: A Management Information System

Management Information Systems
- Strategic Level Decisions
- Tactical Level Decisions
- Operational Level Decisions
- Data Processing (Transaction Processing)

Figure 3: Revenues flow from land parcels to the city Treasury. Expenditures flow from city hall in the form of services.

Tional and tactical decisions by the city staff.

Since it is a model of the ideal management information system, this approach provides a substitute for the more expensive and complicated ideal MIS. This approach takes a systems perspective by looking first at the whole of city finance, breaking it down into its parts, and then putting it back together. The approach is comprehensive; it covers all city revenues and expenditures, and all land uses in a city. The data developed in the approach can be used for more than just the evaluation of fiscal impact of an individual project; it can be used for overall fiscal analysis in a city.

The geographic systems approach to fiscal analysis is consistent with previous geographical research by others that described the measurement of public services using geographically distributed units of output (Chapin 1965; Massam 1975). The method uses geography to organize the data, and maps to collect, store and analyze data. The approach allows planners to evaluate the impact of their plans. This ability will help planners overcome a common criticism that they are too removed from the real world of city finance and operations. The database developed in the approach could be used for ongoing comprehensive planning, and could provide a sound basis for capital improvement programming and development impact fees. Finally, this approach is consistent with the objectives of Planning, Programming and Budgeting Systems (PPBS) and Zero-Base Budgeting (ZBB) by attempting to make government officials more accountable as to how public money is spent.

As stated previously, the geographic systems method attempts to model the transactions of revenue payments to, and expenditure disbursements from, the city's bank account. Where possible, the model is directly based on city transaction records, such as assessor's data, that show the revenue derived from property taxes. Unfortunately, information about many of the other revenue and expenditure dollar flows does not exist at this fine level of detail. In these cases, factors must be used that are surrogate measures of these flows. For example, the geographic distribution of police calls is used as an in-
indicator of police expenditures. Road frontage is a measure of road maintenance costs.

Five of the six non-geo-graphic methods view the whole of city finance as a "black box," in that there is little attempt to understand the internal workings of the city. In the geographic systems method, city finance is broken down into as many components as possible so that it can be better understood. However, since it is a model of reality, there is a level of detail for each component below which it does not go. These levels represent the "black boxes" of the geographic systems approach. The surrogate measures, such as population or police calls, are substitutes for this detail. In the other fiscal impact methods, surrogates are also used, such as population and market value, but at a citywide level of detail, rather than on a parcel or sub-area level. The use of surrogates for some revenue and expenditure flows does introduce a degree of error in the results. However, the hypothesis of this research is that the uniformly finer level of spatial detail for the surrogates used in the geographic systems approach, compared to the city-wide measures used in the other methods, reduces the degree of error.

The approach uses a digitized base map of the city to spatially locate and distribute the transactions, the surrogate measures, and the revenues and expenditure flows that they represent. Ideally, the smallest geographic unit would be an individual land parcel with a single use. Aggregations of contiguous parcels within a block that have the same use might also be used to keep the size of the database manageable. The map is also used to relate the factors to one another and to display them graphically for analysis purposes. With this method, it is possible to evaluate fiscal impact by aggregate land use categories, and also on a site-specific basis for any area in the community. Figure 5 shows the base map of geographic sub-areas used in this study. The dot represents the location of city hall, the conceptual center of revenues and expenditures.

**Previous Research**

The geographic systems approach to fiscal impact analysis was first described in a paper entitled "Computerized Planning and Development Impact Analysis for Communities in the Twin Cities Metropolitan Area," published in the 1984 URISA Proceedings. Development of the base map to conduct the geographic systems approach for the city of Anoka was described in another paper, published in the 1988 URISA Proceedings, titled "Developing a Low-cost Microcomputer GIS for Planning in a Small Community."

The "non-geographic" fiscal impact methods, to which the geographic systems method is compared, are described extensively in the book *The Fiscal Impact Handbook*, by Robert W. Burchell and David Listokin (1978). The book titled *The New Practitioner's Guide to Fiscal Impact Analysis*, by the same authors and William R. Dolphin (1985), also presents these methods in summary form, along with updated multipliers to be used with these methods. These non-geographic methods use city-wide average measures of revenues and expenditures that do not differentiate between types of residential or commercial/industrial development, which have different associated costs and revenues. The methods also use multi-
FIGURE 5.
Base map for Geographic Systems Approach as applied in the city of Anoka, Minnesota

coefficients derived from regression analysis of census data at a national level, some of which are over 17 years old. These multipliers tend to have less validity and credibility than multipliers derived from a community's own current data. These methods also have many potential sources of error or misinterpretation (Stern 1980).

For this study, the definition of "fiscal impact" provided by Burchell and Listokin, found on page 1 of the Handbook, is used:

"A projection of the direct, current, public costs and revenues associated with the residential or nonresidential growth to the local jurisdiction(s) in which this growth is taking place."

By using the word "direct," this definition includes only the impact on local revenues and expenditures. Impact of a development on surrounding property values is not a direct impact. Fiscal impact analysis also does not consider the private impacts, like special assessments, or job creation. Fiscal impact analysis deals with local costs only, and therefore the impact on county or state government is not included. Finally, fiscal impact analysis is distinguished from "cost/benefit" analysis, which may include tangible and intangible impacts on the environment or the welfare of individuals. Fiscal impact analysis does not include intangible impacts. Total fiscal impact is defined as the sum of operating, capital and school fiscal impact.

Steps In The Geographic Systems Approach

The geographic information systems approach to fiscal analysis, consists of nine steps. These steps are diagrammed in Figure 6. In the first step, the city's budget is divided into operating and capital revenue and expenditure categories. The major categories of revenues and expenditures are identified, along with the surrogate factors that are indicators of these categories. For Anoka, these factors included: land area, population, housing units, employment, assessed value, market value, property taxes and credits, police calls, fire calls, road frontage by jurisdiction, school enrollment, and electrical usage. When more than one factor is considered to be an indicator, weights are given to each. Table 1 provides examples of factors and weights.

Next, a database is developed that contains the geographic distribution of these factors by small geographic subarea, such as a land parcel, and by land use category. Geographic Information Systems (GIS) technology is used to measure spatial features such as street length and land area. It is also used to determine the spatial relationships between fea-
FIGURE 6.
Steps in the Geographic Systems Approach to Fiscal Analysis

1. Analyze Budget & Locate Key Factors
2. Calculate Factor Multipliers
3. Calculate Fiscal Multipliers
4. Existing Operating Fiscal Impact
5. Project Operating Fiscal Impact
6. Spatially Locate Existing Infrastructure
7. Locate Future Infrastructure
8. Project Future Capital Fiscal Impact
9. Project Total Fiscal Impact

TABLE 1.
Examples of Distribution Factors and Weights for Expenditures
City of Anoka, Minnesota, 1986

<table>
<thead>
<tr>
<th>Municipal Expenditures</th>
<th>Weight</th>
<th>Factor</th>
</tr>
</thead>
<tbody>
<tr>
<td>General Government</td>
<td>75%</td>
<td>Population</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>Gross Market Value</td>
</tr>
<tr>
<td>Public Safety:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Police</td>
<td>25%</td>
<td>Population</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>Gross Market Value</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>Police Calls in minutes</td>
</tr>
<tr>
<td>Fire</td>
<td>25%</td>
<td>Population</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>Gross Market Value</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>Fire Calls in minutes</td>
</tr>
<tr>
<td>Public Works:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Streets</td>
<td>15%</td>
<td>Population</td>
</tr>
<tr>
<td></td>
<td>15%</td>
<td>Employment</td>
</tr>
<tr>
<td></td>
<td>70%</td>
<td>Locally maintained road frontage</td>
</tr>
</tbody>
</table>

calls per acre, or market value per acre. In categorizing land use, acreage measurements from the GIS are used to help differentiate uses based on density.

In the third step, the city totals of the factors are used to develop the "fiscal multipliers." For example, road-maintenance expenditures are divided by the total road frontage to calculate the average cost per front foot. Table 2 shows the calculation of fiscal multipliers for the police budget. For example, if half of the police budget is devoted to responding to calls, then the weight given to police calls is 50 percent. Another 25 percent weight is given to population, and 25 percent to gross market value, reflecting the general police protection readiness and overhead that the city must have to protect people and property, regardless of the call frequency. Fifty percent of the police budget is divided by the total number of minutes spent on police calls, to derive a cost per minute. The calculations are repeated for gross market value and population. This same process is done for each of the revenue and expenditure categories.

In the fourth step of the geographic systems approach, the fiscal impacts of each existing geographic entity in the database are determined. For example, the road-maintenance costs attributable to each parcel are calculated by multiplying the front-foot cost multiplier by the measured frontage of each.

This step is a very important component of the geographic systems approach, because it helps the local officials understand the revenue and ex-
TABLE 2.
Calculation of Police Expenditure Multipliers Using the Factors and Weights

<table>
<thead>
<tr>
<th>Budget Factor</th>
<th>Factor Weight</th>
<th>Allocation of Budget</th>
<th>/</th>
<th>Total =</th>
<th>Multiplier</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calls (in minutes)</td>
<td>50%</td>
<td>723,340</td>
<td></td>
<td>198,166</td>
<td>$ 3.65</td>
</tr>
<tr>
<td>Gross Market Value</td>
<td>25%</td>
<td>361,671</td>
<td></td>
<td>$508,754*</td>
<td>$ .71**</td>
</tr>
<tr>
<td>Population</td>
<td>25%</td>
<td>361,671</td>
<td></td>
<td>$ 15,985</td>
<td>$22.62</td>
</tr>
</tbody>
</table>

Total 100% $1,446,682

*In thousands
** per thousand

penditure patterns in their own community and the complexities of local finance. The data can also be used to respond to ad hoc questions.

In the fifth step, the demographic and fiscal multipliers are used to project the impact of future development. Some of the multipliers may need to be adjusted at that time. If there are questions whether the existing demographic multipliers will be valid for future development, the multipliers may be adjusted or compared to national multipliers. For example, if the current average for street frontage for single family housing is 112 feet, but the proposed development will average 150 feet, the 150-foot multiplier should be used to project street frontage. The city's fiscal multiplier of $.58 per front foot would still be used, however. If some existing levels of service are considered inadequate, then some adjustment of the multipliers might be done at this point to reflect a future increase in service costs to be implemented citywide.

The remaining steps in the geographic systems approach deal with capital improvement impact. These steps project the increment of major capital improvement expenditures and revenues that will be generated, on a site-specific basis. In step six, layout of existing capital facilities such as roads, sewers, water lines, storm drainage, and parks are determined. In step seven, the proposed layout of additional facilities to serve the new development is determined, and the costs estimated. Additional capital costs for items such as police cars, or road-maintenance equipment are estimated based on the number of police calls or street frontage of the new development. In step eight, the future revenues to be generated to pay for the new facilities is estimated, such as special assessments against benefitted properties, or grants. The cost of the new facilities is subtracted from the available revenue to determine the amount to be paid from general city sources, such as property taxes. This would be the net fiscal impact of the new development on capital costs. The last step is to combine the operating fiscal impact measures with the capital fiscal impact measures, to determine total fiscal impact.

Results Of The Geographic Systems Approach

The fiscal impact results from the geographic systems approach are valid for the city of Anoka in 1986. The types and importance of revenue sources can vary from city to city, from state to state, and from one year to the next. The types of expenditures and level of service may also vary from city to city. Therefore, Anoka's results may be of limited value to other cities. The portion of this research that is transferable to other cities and other government levels is the geographic systems method. Most city revenues and expenditures are spatial in nature, and the systems approach used in the geographic systems method attempts to model these flows. The result is an analysis based on the unique flows for the particular community being studied. Figure 1 showed the geographic distribution of fiscal impact results for Anoka on a site-specific basis using the geographic systems approach. Table 3 and Figure 7 show these results aggregated by land use category.

Total fiscal impact is the sum of operating, capital and school fiscal impact. In Anoka in 1985, all of the commercial, industrial, service stations, and
TABLE 3.
Operating, Capital, School and Total Revenue Surplus or Deficit Per Unit and Per Acre
City of Anoka, 1986

<table>
<thead>
<tr>
<th>Code Land Use</th>
<th>Operating</th>
<th>Capital</th>
<th>School</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>/Unit /Acre</td>
<td>/Unit /Acre</td>
<td>/Unit /Acre</td>
<td>/Unit /Acre</td>
</tr>
<tr>
<td>1 Highway Business</td>
<td>$ 80</td>
<td>$ -339</td>
<td>$ 3487</td>
<td>$ 3228</td>
</tr>
<tr>
<td>2 Shopping Center</td>
<td>266</td>
<td>-420</td>
<td>4628</td>
<td>4474</td>
</tr>
<tr>
<td>2 Central Business Dist.</td>
<td>-438</td>
<td>-544</td>
<td>6958</td>
<td>5976</td>
</tr>
<tr>
<td>4 Commerical Office</td>
<td>2629</td>
<td>-771</td>
<td>9374</td>
<td>11232</td>
</tr>
<tr>
<td>5 Business Vacant</td>
<td>118</td>
<td>-52</td>
<td>673</td>
<td>739</td>
</tr>
<tr>
<td>6 Cemetery</td>
<td>-324</td>
<td>-293</td>
<td>0</td>
<td>-618</td>
</tr>
<tr>
<td>7 Church</td>
<td>-1818</td>
<td>-481</td>
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utility land uses generated an overall revenue surplus, or a positive total fiscal impact. An exception was a small deficit for industrial vacant. These surpluses were primarily due to the fact that they generated school revenue in the form of property taxes, and did not generate any additional school children or school expense. Looking at operating fiscal impact, however, service stations and the central business district generate a deficit, and highway business generated only a small surplus. This was primarily due to police calls to these areas.

All of the residential categories generated a surplus of operating revenue, but the impact of density can also be seen. The lower density single family and two-family homes generated only $44 and $50 per acre, respectively. In contrast, the higher density residential uses of quad homes, town homes, and apartments generated $608, $1095, and $1026 per acre, respectively. Mobile homes, while not as dense as the multi-family developments, generated a surplus of $1176 per acre. One reason for this surplus is a revenue redistribution law called Fiscal Disparities, that provides funding to communities in inverse relationship to their relative wealth (market value per capita). Since mobile homes are considered personal property, the real property market value per capita for mobile homes is very low. As a result, mobile homes generate a large amount of revenue from the Fiscal Disparities formula. The mobile home surplus is also due to the fact that the mobile home park owner maintains the roads in the park, and therefore no road maintenance expenditures are needed from the city.
When considering school expenditures, all residential categories except apartments and mobile homes generate a deficit. The latter two categories benefit from the Fiscal Disparities funding distribution to the school district. Furthermore, Anoka’s mobile home park has only two school children, which is far lower than expected, compared to national data. However, for comparison to the other methods, described below, a common set of demographic assumptions for each residential type were used, rather than this local data. Density is also an important factor in determining the total residential fiscal impact. Single and two-family development in Anoka generated deficits of about $900 per acre, while the more dense residential uses generated surpluses.

With the geographic systems method, it is possible to quickly determine the impact of funding changes by the state or federal government. For example, in 1988, the Minnesota Legislature changed the relative proportions of property taxes paid by different land use categories. Commercial/industrial property taxes were decreased, and the multifamily property taxes increased. Using the other non-geographic methods, it would not have been possible to measure these changes. As a result of these changes, the fiscal impact patterns that existed in 1986 in Anoka would not be valid for use in 1989. This underscores the need to have a fiscal impact method that can be adapted to changing conditions.

The Six Non-Geographic Approaches

The following descriptions of the six non-geographic approaches come primarily from the Fiscal Impact Handbook (Burchell and Listokin 1978). The six methods differ in the way that they project the future expenditures of proposed projects. They all use the same general approach to revenue projections.

1. Per Capita Multiplier Method

The per capita multiplier method is used to evaluate the fiscal impact of residential development. In this method, a share of the municipality’s operating and debt service expenses are assigned to the existing residential development in the city. This share is the proportion of residential market value to the total market value of land in the community. Included in the residential category are all uses that are not commercial/industrial. This feature could lead to misinterpretation in applying this method. The residential proportion of operating and debt service expenditures is divided by the current population to derive the per capita multiplier. The per capita multipliers are multiplied by the projected population of a proposed development to project expenditures.

2. Service Standard Method

This method is also used only for residential development. Total existing operating expenditures in the community, by major expenditure category (e. g., police, public works), are divided by the number of city employees in each category to derive average expenditures per employee. Existing debt service costs are not used. Instead, operating-to-capital expenditure ratios are multiplied times the operating costs per employee to derive the capital costs per employee. The additional employees to be hired by the city resulting from the proposed
growth are also estimated by using multipliers for different city sizes and regions of the country.

3. Comparable City Method

Also used only for residential development, this method differs from the previous methods in that it measures the marginal impact of development. The other methods assume that in the long run, average costs are the most reliable basis for projection. In a marginal method, all of the increase or decrease in costs that would result from the new development are assigned to the new development.

In this approach, the size of the community and the rate and direction of growth are key factors to be considered. This is based on two observations cited in the Fiscal Impact Handbook: 1) very large and very small communities have higher per capita costs than the average sized community, and 2) rapidly growing or declining areas also spend more per capita. Ratios are used to adjust the current per capita operating and debt service costs to reflect the future size and growth rate of the community. The adjusted per capita costs are used to project expenditures.

4. Case Study Method

The case study method is also a marginal costing approach, and may be used to evaluate both residential and nonresidential development, dealing with both operating and capital expenditures. Rather than rely simply on debt service costs as an indicator of capital improvement needs, this method consists of more in-depth evaluation of capital improvement needs on a site-specific basis. It relies on interviews of local officials and staff to determine the existing surplus or deficit in local service capacity, and the additional capacity that will have to be added to accommodate growth. For example, if the city is already deficient in its number of police officers, and it has to hire one full-time officer to correct the deficiency and meet the additional demand, the new development is charged the entire cost of the additional police officer. The geographic systems method is similar to the case study method, in that it uses local information to make the projections. The major difference is that the case study method is typically not applied in a systematic way, and may or may not consider the spatial characteristics of local service delivery.

5. Proportional Valuation Method

This is an average costing approach used to evaluate the impact of commercial/industrial development. Municipal operating expenses attributable to the new development are assumed to be proportionally related to the market value of the project compared to the total market value of the community. This relationship is not linear, however, and some refinement of this proportion is done with coefficients, to ensure that costs for relatively high value projects are not overstated, and costs for low value projects are not understated. This method groups all commercial/industrial land uses into one category and does not distinguish between types.

6. Employment Anticipation Method

The employment anticipation method is a marginal costing technique for evaluating commercial/industrial development. It relies on the relationships between employment and per capita costs that have been estimated over time through regression analysis. Coefficients have been developed for growing and declining cities of various size groups. The coefficients are multiplied by the per capita costs for different municipal service categories and debt service to derive per employee cost figures. The projected employment from the new development is then multiplied by the per employee cost to determine the expenditures that will be generated by the new development.

Comparison Of The Fiscal Impact Methods

The geographic systems and six non-geographic methods were applied to alternative development scenarios in the city of Anoka, Minnesota. The methods were compared to one another in the following ways: variation in the results, cost to apply, availability of the data, cost of mistakes, degree of local credibility, ongoing usefulness of the data, comprehensiveness, consideration of local finance
complexity, usefulness for capital projections, and other strengths and weaknesses.

The estimated cost of evaluating a mixed-use commercial/industrial and residential development using the non-geographic methods ranged from $6,000 to $11,000. The cost of the geographic systems approach used in this study was about $30,000. However, if the city had an existing GIS database, the cost would have been only about $4,300. A hidden cost of using the non-geographic methods was the potential risks in making the wrong assumptions, or overlooking a revenue redistribution law, called fiscal disparities. In one of the development scenarios, the cost of such an oversight was about $30,000 in over-estimated revenues for a single commercial/industrial development. In another residential scenario, mobile home park revenue was underestimated by $195,000. Due to the comprehensiveness of the geographic systems approach, these mistakes and oversights are avoided. The potential for these mistakes was identified as part of the analysis for Anoka. Similar mistakes were also found in fiscal impact studies by others, including a nationally-recognized fiscal impact consultant (Tomaselli 1989: 211–217).

The results of the geographic systems approach are applicable to all of the existing development types in the city, not just those for the specific proposal currently being considered. In addition to measuring the impact of commercial/industrial and residential land use, the geographic systems method is also capable of measuring the impact of tax exempt land use. With the exception of the case study method, the other non-geographic methods deal with either residential or commer-
cial/industrial development, but not both. These other methods also ignore the fiscal impact of tax exempt land use, and include it with residential land uses. Because these other methods deal with only one sector of a city’s land use rather than the whole, the practitioner must start out by making some gross assumptions about the proportion of total revenues and expenditures that are applicable to that sector. The accuracy of those initial assumptions greatly affects the results. Furthermore, there is a risk of omitting some things and double-counting others. In the geographic systems approach, everything must add up to control totals, and nothing is omitted or double-counted.

In spite of the high probability of mistakes being made in the non-geographic methods, the comparison of the geographic systems and six non-geographic approaches was made assuming no mistakes or oversights. Even with these corrections, the results varied widely from one method to another, as illustrated in Figures 8 and 9.

Two variations of the geographic systems approach were used to measure residential fiscal impact. “GIS—A” used demographic multipliers (persons per unit, students per unit) based on the city’s own data from the database. “GIS—B,” and the non-geographic residential methods used the multipliers from the book by Burdell, Listokin and Dolphin (1985). All of the methods showed a negative total fiscal impact for a proposed development of 100 units of single family development. This is consistent with the statement frequently made by planners that “single family housing does not pay its own way.” However, there was a $109,000 range in the projected deficit, from a low of about $30,000 to a high of about $139,000. The low represents the per capita method. The high is from the comparable city method that uses multipliers derived from 17-year-old 1972 U.S. Census data. Another method, the service standard, is also based on these old data. These latter two methods tend to over-predict expenditures for all residential development types.

The results of both versions of the geographic systems method lie between the high and low extremes. The geographic systems and per capita methods both use recent expenditures to make projections. However, the geographic systems method recognizes the differences in servicing residential types, based on the actual operating data from the community, such as police calls and road frontage. The per capita method, on the other hand, assumes that expenditures are the same on a per capita basis for all residential types. Since single family development is more costly to service than other types, the geographic systems approach projects a greater deficit than the per capita method. The case study method, as applied in this project, also uses actual operating experiences with different residential types, but in a less rigorously quantified or systematic way.

For the commercial/industrial development scenarios, there were also dramatic differences between the methods. In particular, the employment anticipation method projects increased municipal costs based on the number of new employees, resulting in deficits for all land use categories, except light industrial. This method, and the proportional valuation method, use multipliers and coefficients based on case studies conducted in 1977. The proportional valuation method assumes that larger projects are less costly to serve than small projects. “Prop Val—A” (Figure 10) is based on a five-acre project size, and “Prop Val—B” is based on a one-half acre project size.

The extreme differences among the methods’ results suggest that the employment anticipation method should be used with caution. To deny a proposal for a commercial office development on the basis of the employment anticipation method would mean that the city would not gain the surplus revenue that the other methods indicate. The surpluses projected by the other methods range from about $4,204 per acre using the geographic systems method, to a high of $9,731 per acre for the proportional valuation method. Employment probably does have an impact on municipal expenditures that may not be adequately measured by the geographic systems method. Therefore, additional work needs to be done on the geographic systems approach to ensure that employment impact is adequately measured.
The non-geographic methods treat capital costs in a very superficial way, generally using existing debt service costs to project future debt service. In reality, capital costs can vary from year to year. They can also vary based on the nature of the development type, and where the new development is located in the community with relationship to existing development.

The geographic systems method has the potential to measure these costs, but was beyond the scope of the project in Anoka.

Based on the wide variation in results, it is conceivable that a fiscal impact practitioner could select the method that is the most likely to produce the desired results. For example, if one were opposed to new commercial/industrial development, one would use the employment anticipation method. If one were opposed to residential development, the comparable city method might be used. Since the non-geographic methods use abstract multipliers and coefficients based on national data, it would be difficult for others to judge the validity of the results. In contrast, the geographic systems method opens up the black box of local finance to public scrutiny and discussion. By increasing the understanding of how local finance operates, it reduces the opportunity to misuse fiscal impact study results.

The above discussion compares the costs and benefits of the geographic systems approach to fiscal impact analysis as if it were being used to answer a single development question. However, the geographic systems method is intended to be used for ongoing planning, monitoring and management. The geographic systems approach could be cost-justified for a single proposal on the basis of avoiding some basic mistakes or oversights. However, the real benefit of the geographic systems approach is the ability to use the data in the database for fiscal policy analysis, day-to-day decision-making and long range comprehensive planning. For example, once the database is developed, it could be used to test very quickly the impact of proposed alternative changes to a state aid formula. It also could be used to evaluate the impact of several long-range comprehensive plan alternatives. The database also contains some essential elements needed to analyze school location, or police-call incidence.

During the time that the geographic systems study was being conducted, the city of Anoka also began a study of the data processing needs of all city departments. As a result of the study, the city decided to implement what can be described as an “integrated records processing system.” When fully implemented, this system was to have resembled the ideal management information system that the geographic systems approach is designed to model.

The hardware and software for this system was to have cost about $400,000. Training and data entry was to have been several times this amount, and it would have taken several years before the city would have collected enough data to use for fiscal impact analysis. Because of the complexity of implementing such a system, a portion of the system which included planning information, was dropped. The cost and difficulty of implementing the ideal management information system also provides a useful contrast to the relatively small cost of the geographic systems approach, which is designed to simulate such a system.

Additional Research Needs

Additional research needs to be done on the geographic systems approach to fiscal analysis. Intuitively, it seems that the method yields better projections of fiscal impact compared to the other methods. However, this conclusion needs to be demonstrated with facts. This should be done by evaluating the same community at two points in time, and determining the degree to which the geographic systems method yielded more accurate results than the other methods. This would be done by measuring the changes in land use between the two points in time, the corresponding changes in city finances, and adjusting for factors that are unrelated to land use. The use of the geographic systems method for capital improvement programming, and evaluating the performance of enterprise funds also needs to be demonstrated. In particular, the value of the geographic systems method needs to be established with regard to the use of development impact fees in rapidly growing parts of the country like Florida and California.
The transferability of the geographic systems approach to cities in other parts of the country also needs to be demonstrated through additional research. The one key data item needed to apply the geographic systems approach in other cities—computerized assessor's records—are available in about 60-80 percent of all taxing jurisdictions. The availability of an existing digitized parcel base map is less widespread, since this is a newer innovation. An alternative to an automated parcel base map could be an adaptation of the digitized 1990 U.S. Census TIGER maps, which will cover the entire country with census block boundaries. This approach was tested in Anoka, but additional research is needed.

Additional research also is needed to demonstrate that the geographic systems approach could also be used at other governmental levels, such as counties, regions, states or even nations. In these cases, the question is whether a particular land use generates a surplus or deficit, but whether sub-areas are receiving their share of services in proportion to the revenue they contribute.

Acceptance of the Approach

There are some barriers to the acceptance of the geographic systems approach. One is the cost. If a city already has a GIS that contains the information needed to model revenue and expenditure flows, the cost would be reasonable. However, if a database must first be built, adoption of the approach would mean that the city also would have to make a commitment to GIS, and have the patience to wait for the results. Elected officials are likely to want quick answers to their questions, in time for the next construction season. The other methods provide quick answers, even though the answers may not be very good. Another barrier to acceptance can be stated in the form of a question: "Do local officials really want to know the answer?" The geographic systems approach reveals some very interesting and surprising patterns of revenue and expenditure flows. A reviewer of this method has stated that the relation of the cross-subsidies between land uses and parcels could potentially be a politically explosive issue.

It has been the author's experience that the people in local government most likely to accept and adopt the geographic systems approach are city managers, finance officers, and planners. These people are genuinely interested in the results. They can see how the information can help them in their day-to-day work, and can understand why the approach takes time and resources to develop.

Summary

The geographic systems approach to fiscal impact analysis is concerned with the uniqueness of "place." No two local governments finance themselves exactly alike, since no two are alike in their geographic situation, their physical resources, historical development patterns, financing policies accepted-levels of service, and financing histories. The other non-geographic fiscal impact methods largely ignore geographical uniqueness, and attempt to search for general laws regarding the size of a city and how it finances city services.

The specific fiscal impact results from Anoka are not necessarily valid for other cities. However, the methodology of the geographic systems approach to fiscal impact is transferable to other cities or even other levels of government. The geographic systems method is a systems approach, in that it looks first at the whole to understand the overall flows of revenues and expenditures, and then breaks these flows down into their components. The method attempts to model an ideal management information system that could track all revenue and expenditure flows in government. Since nearly all city services have a spatial context, geography is used to organize, and relate the components to one another, and to display the results of the analysis. The geographic systems approach to fiscal impact analysis is comparable in cost to the other methods, if a community has an existing GIS database. The approach is more costly if a database must be built first, because it takes a substantial amount of time. However, the method avoids some very costly mistakes, and could more than offset the cost. Furthermore, the approach is intended to be an integral part of the planning process, and the data will be
useful for ongoing planning and management, beyond the initial scope of a fiscal impact analysis study.

Acknowledgements

The author would like to thank the many people who have participated and supported the development of this approach and the conduct of the study. In particular, thanks go to: Robert Kirchner, community development director, city of Anoka; Jim Barton, former local planning assistance director, Metropolitan Council; Dr. John Borchert, Regents professor of geography, University of Minnesota; and Barbara Lukermann, senior fellow, Hubert Humphrey School of Public Affairs; John Tomaselli, mentor.

References


STATEMENT OF EDITORIAL INTENT

Information, lightly or seriously treated, presented in many styles and formats, responding to your diverse interests—that is our intent.

In this section of the Journal we offer you an opportunity to share, and enjoy, information—with topics that reflect the diverse interests of our readers.

This issue of the Journal marks a transition for the Features section. John Antenucci will end his tenure as Features co-editor after this issue. With his vision and boundless energy, he has been a motivating force behind this section and the Journal. He will be missed.

Stepping in as new Features co-editor, Warren Ferguson will bring his experience in publications, printing and a broad-based knowledge in the GIS and AM/FM industries. As president of Ferguson Cartographic Technologies, Inc. and Cantex Conversion Services, Inc., his primary focus is the innovative use of digital graphics and information management to improve productivity. He is an active participant in many organizations including URISA, ACSM, CISM and ASPRS. He is also a member and founding director of AM/FM International.

John C. Antenucci (outgoing)
Gilbert H. Castle, III
Warren Ferguson (incoming)
Thoughts From the GIS Vendor Community
Charles P. Kindleberger

During the first day of the Edmonton 1990 URISA Conference, a special “executive” session was offered to political leaders and senior government managers. The intent was to introduce geographic information system considerations in a way that was understandable and relevant to higher-level government decision-makers.

Much of the session naturally focused on management issues such as cost-benefit analysis, consultant selection, training and more. However, technical considerations obviously must also be addressed by senior officials—a reality that can be particularly challenging for those with limited computing experience.

What “technical” points should be emphasized to senior managers interested in gaining a one-day understanding of GIS? To answer that question I asked for advice from URISA’s corporate members. I sent a letter, during the summer of 1990, asking the experts for their thoughts in five areas: Purchasing considerations; hardware alternatives; file-translation trends; advances in micro computers and related software and equipment; and the GIS evaluation process.

Representatives from seven firms (See acknowledgments) provided thoughtful responses to the questions. In many cases, there was consensus; often there was a difference of emphasis. In a few cases, disagreement. The responses are summarized below.

What do you think? Do you agree with the views of these URISA corporate members? Are there additional points that should have been stressed? What additional questions should have been asked? Let the *URISA Journal* editors know what technical advice you think should be brought to the attention of senior state and local government officials.

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1. Purchasing Considerations. What should be the two or three main considerations made by decision-makers as they ponder GIS hardware and software decisions?

   A) Understand Your Needs
   
   - Make sure you understand whether you need a general turnkey GIS system or a more specialized system that incorporates GIS technology to address a specific operational problem.
   - The concept of a “generic GIS” that meets all spatial data-handling needs is an over-simplification of reality; one size does not fit all requirements.
   - The importance of sophisticated topology and polygon processing is overrated. May not be worth the additional cost or complexity.

   B) Recognize Industry Standards
   
   - Conforming to communication standards is crucial.
   - Determine if the system incorporates open architecture and common industry standards like X windows.
   - Make sure that the GIS can interact directly with a recognized relational database.
   - Assess whether a given GIS is flexible enough to expand (or contract) with future requirements.

   C) Consider Data Conversion
   
   - Because some systems require extensive data manipulation, data conversion requirements should be studied during system selection.
   - Focus on how your organization will computerize its records, because those records will be around for a long time.
   - For every dollar that is spent on hardware/software, expect to spend another two or three on data.

   D) Determine Vendor Reputation
   
   - The vendor’s reputation with existing clients should be the foremost purchasing consideration.
   - Does the vendor have a good reputation as being accommodating and responsive? Will the vendor make someone responsible for your installation’s
success? Does the vendor have a user's group that you can use to voice your concerns? Has the vendor returned your calls promptly during the evaluation?

E) Think Through Your Budget

- Make sure there is a good business case for getting into GIS. Look at the cost effectiveness of GIS and decide which processes it can make possible, easier, cheaper.
- Avoid getting into a champagne-taste, beer-budget dichotomy.

How should senior government officials and political leaders think through the challenges of networking and distributed processing versus relying on the central processor?

- Our experience led us to want distributed network architecture. A properly designed network with multiple servers will withstand adversity. Micros and workstations networked to mini-file servers would seem ideal.
- I don't think the distinction between micro and workstation is particularly useful, assuming one is talking about the high end of the micro spectrum. The era of the mainframe (in the traditional sense) is over.
- The ideal hardware configuration should have some type of workstation and some type of server, regardless of what technology is used for the different levels. In fact, in some cases, the workstation and the server may be the same box.
- We believe that distributed processing continues to be the strategic direction for the 90's.
- The cost per MIP is least on workstations, but realize that the decentralized approach raises issues — the need for: tight institutional procedures for maintaining data; planned data redundancy; good library systems that keep track of update transactions; site licensing (vs seat licensing) software fees.

3. Translation. How does the advent of new file exchange and translation capability influence the traditional purchase of one hardware/software product per public organization?

- Consider a standard interchange format that will be used by all of the GIS systems used in your jurisdiction.
- We're beginning to see a little thaw in the translation considerations deadlock. With many vendors beginning to create and use more "open system" spatial database formats, and rely on relational database technology to store graphic data, traditional format problems are becoming less of an issue.
- The new open systems make translation much easier on a technical level, but we cannot assume that the operations personnel will always have the skills necessary to smooth the process. For agencies that do not intend to maintain a knowledgeable GIS staff, a common system is then preferred.

4. Next Year. What are the implications for decision-makers of the continual arrival of a new generation of micro processors (e.g., 486, 68040, and RISC) storage devices and related hardware and software improvements?

- Look into the upgrade strategies of the hardware vendors. Some vendors have very clean, easy upgrade strategies that allow the user to cost-effectively "leapfrog" into the next breakthrough phase, while others don't.
- All that GIS users have really needed is 15 or 20 MIPS on their desks to take advantage of distributed processors in order for the software to run at an acceptable speed.
- Most people are thinking RISC. These workstations are coming down to 386 and 486 prices.
- Buy only what you need today. The equipment that you postpone until tomorrow will be more powerful and/or less expensive.
- Spend your marginal dollar on data correction and conversion rather than equipment.
- Buy only what you need today. The equipment that you postpone until tomorrow will be more powerful and/or less expensive.
- Spend your marginal dollar on data correction and conversion rather than equipment.

5. Evaluation. Are there any two or three key features that you believe should receive special attention during the evaluation/benchmarking process?

- Spend more time with your potential vendor's customers than with his salesman, if you really want to know about their systems.
- How real is the vendor's R&D effort? Is the software likely to be upgraded over time?
- Has the vendor made a serious proposal in the area of training? Don't mislead yourself on the subject by selecting a "low-balled" training budget.
• Involve the people who will actually operate the system in the decision process.
• Determine those configurations that the vendor has installed that are most like your proposed system. Are they really comparable?
• Which plotters, digitizers and other peripherals can be used with the software? Do the “drivers” exist or will they be available “real soon now?”
• Ensure that the database is large enough during the demonstration, too large to be in memory.
• A proper GIS foundation starts by determining the level of accuracy that can support the entire GIS.
• Evaluate those procedures that will be most important to the specific requirements, in order, and have them demonstrated.
• Too many cities don’t test applications during the benchmark process.
• Try to see that the hardware performance is evaluated for standardized software, and, in turn, that the hardware is kept constant when evaluating the performance of software.
• Demonstrations should include fast display of “spaghetti data” without topology, and also display of polygon overlay capability.

• Ensure that raster overlay of a digital orthophoto will be possible, in registration with vectors.
• Political considerations are also important. Is your organization ready to handle the implications of a sharable system? Loss of a “data kingdom” can be very threatening and can cause otherwise rational human beings to behave in an unpredictable manner.

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LANIS: the GIS for Nature Conservation in Germany
Hans-Werner Koeppe

The Federal Research Centre for Nature Conservation and Landscape Ecology in Bonn, Germany has used a geographic information system, called LANIS (Landscape Information System) for about 10 years. LANIS is a nationwide GIS; it has become an important information instrument, primarily for nature conservation, landscape and environmental planning.

In the Federal Republic of Germany, a highly industrialized country with dense population, natural areas have become a rare resource. In the Germany of today, protecting nature and the environment ranks equal in importance with the government's economic and social policies. In 1976, the German Parliament passed the Federal Nature Conservation Act. Today the Act continues as the legal base for conservation and landscape and natural resources planning. Its objectives are to protect:

- Ecological processes
- The utilization and/or productivity of natural resources
- Plant and animal life
- The diversity, uniqueness and beauty of nature and the landscape.

To satisfy these objectives and policies, there was an obvious need for reliable data and information; thus, the birth of LANIS.

Concept and Function of LANIS

In its earliest conception, LANIS was a simple GIS with an emphasis on providing spatial information from maps using a raster-oriented system. From the start, LANIS was designed to:

- Collect, store and process spatial environmental and ecological data,
- Provide planners and decision makers with relevant data and with analytical methods and tools for data evaluation,
- Quantify spatial data in order to present more effective arguments for protecting nature and landscape, for better land-use and natural resources planning and, consequently, for integrated planning,
- Provide a user-friendly system with a variable out-of-map, lists, tables, plots, graphics and text, and
- Establish uniform databases and procedures for systematic updates.

With these objectives in mind, LANIS has developed into a comprehensive information system. It is now a broad-based data-processing tool for nature conservation, landscape management, and other related fields. It incorporates:

- A system for storing coordinates, numerical and textual data about natural resources, vegetation and wildlife, and land use factors which impact nature and landscape.
- Data related to different spatial planning levels and needs.
- Software, providing the necessary flexibility for data manipulation and evaluation.
- Products in the form of maps, plts, tables, graphics or text appropriate to user needs.

LANIS operates on a PRIME computer with a compact interactive graphic system, consisting of two digitizers, several vector and raster graphic terminals, two plotters, and several alphanumeric terminals. The principal GIS software consists of a customized graphic package (LDB-System), and ARCINFO (Environmental Systems Research Institute; Redlands, California).

Figure 1 shows the different functions supported by the LDB-System. Important modules of the package are vector-raster spatial data handling, integration of remote sensing imagery, and the graphic analytic tools. ORACLE is used for data storage. LANIS now integrates graphic files with descriptive (e.g., text) datafiles.
The Organization chart of the LDB-System (a GIS-Software)

FIGURE 1.

EINGABE

Segment- . Linienmodus

Digitalisierung von Karten

Digitasierung von Höhenlinien

Fernerkundung

LANDSAT Satellite

DFVLR Schnittstelle

TRANS/GEO

Entzerrung und Transformation

in Gauß-Krüger-Koordinaten

AUFBEREITUNG

UND VERBESSERUNG

LDN/NETZ

Segmente zusammenführung. Fehlererkennung. Aufbau der
graphischen Datenbank

CAD - interaktive Verbesserung

graphischer Bildschirm mit Facenkreuz

DIDAK - System

inst. Photogrammetrie

Univ. Karlsruhe

räumliche Entzerrung

und rechnergestützte Klassifikation

mittels Trainingsgebiet

zuordnung zum LDB-Raster

FLÄCHEN-DATENBANK

Segmentback-Verzugs

Segmentbildung

POLYGON

RASTER-DATENBANK

Rastierung

Verwaltung

Auswertung

METHODENBANK (Flächen)
- Flächeninhalte
- Längenberechnungen
- Nachbarschaftsbezug
- Aggregierung
- Verschneidung

METHODENBANK (Raster)
- Überlagerung
- Analysenprogramme
- Sichtbarkeit, Ausbreitung, etc.
- Bewertungen

SCHRAFFUR-KARTE

ISOLINEN-KARTE

3-D-ZEICHNUNG

AUSGABE

Plotdarstellungen (Zeichentisch)

Rasterkarte Listen

Text

Dokumentation

Schnelldrucker
Data Requirement and Availability

The data requirements for nature conservation and natural resources planning can be divided into three basic categories: 1) areal or spatial data, 2) statistical data, and 3) descriptive data.

All three data types should be geographically referenced. Areal or spatial data include:

- Areas of nature and landscape protection
- Biotopes and habitat areas
- Vegetation cover and types
- Forest cover
- Soils/geology, geomorphology
- Elevation, slope and exposition
- Recreation areas
- Land-use (e.g., housing, industry, road network)
- Administrative boundaries
- Forest production units
- Landscape units
- Surface water

Most of the spatial data were mapped either through field work, aerial photo interpretation or remote sensing. Statistical data include:

- Species and population of fauna and flora
- Biotopes, habitats and protected areas
- The natural resources
- Land uses
- Agriculture
- Forest die-back

The preferred base for statistical data are the town and/or county boundary lines, as well as landscape units.

Descriptive data are urgently needed on the following subjects:

- Rare and endangered species of fauna and flora
- Site description of nature protection areas, biotopes and habitat
- Location and factual information on fauna and flora

The above data and information can be managed only through data processing and made available through an information system like LANIS. But before the data are available in the computer, extensive data collection is necessary. Data now available in LANIS are shown in Table 1. Several data sets like soil data, administrative boundary lines, forest cover or recreation areas are stored at 1:1,000,000 scale. This is rather coarse, but adequate for the needs in the federal level. The aim is to store most data at 1:200,000—like natural and landscape protection areas, biotopes or units of natural boundaries.

<table>
<thead>
<tr>
<th>Spatial data:</th>
<th>(1): 200,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nature protection areas</td>
<td>(1): 200,000</td>
</tr>
<tr>
<td>Landscape protection areas</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Nature parks</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Forest cover</td>
<td>(1): 200,000</td>
</tr>
<tr>
<td>Large forest (not dissected by roads)</td>
<td>(1): 200,000</td>
</tr>
<tr>
<td>Biotopes of European important (preliminary)</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Soils/geology</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Elevation</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Administrative boundaries</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Road and railway networks</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Forest production units</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Natural geographic units</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Precipitation, yearly average</td>
<td>(1): 1,000,000</td>
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<tr>
<td>Mean temperature</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Growing season</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Areas of outdoor-recreation</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Snow coverage</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Potential natural vegetation</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Agricultural land use</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Less favoured areas</td>
<td>(1): 1,000,000</td>
</tr>
<tr>
<td>Alphanumeric data:</td>
<td></td>
</tr>
<tr>
<td>Nature protection area description</td>
<td></td>
</tr>
<tr>
<td>Landscape planning archive</td>
<td></td>
</tr>
<tr>
<td>Statistic data:</td>
<td></td>
</tr>
<tr>
<td>Forest damage</td>
<td></td>
</tr>
<tr>
<td>Agriculture (County)</td>
<td></td>
</tr>
<tr>
<td>Land use (County)</td>
<td></td>
</tr>
</tbody>
</table>

Data Sources and Updating

Data sources vary greatly, and reflect the diversity of the stored data. The two main sources are the small-scale
overview maps and data from the federal states. Most data
digitized and stored at 1:1,000,000 are maps in the
same scale and are mainly pro-
duced by different federal agen-
cies. In some cases, (e.g., topo-
graphic features) the data were
supplied in digital form. In this
particular case the data needed
considerable processing and ad-
justment before entering into
LANIS.

The 16 states of the Fed-
eral Republic of Germany each
have different mapping pro-
grammes of varying detail. One
major programme is the map-
ing and registration of sites
with special biotopes of scales
from 1:5,000 to 1:25,000. The
biotope registers of the states
now contain about 200,000 indi-
vidual biotope descriptions with
maps from 1:5,000 to 1:25,000.
Only about 50 percent of this
enormous data collection is now
stored digitally. From this data,
the federal government needs
only the few thousand best
sites. But selecting them is quite
a difficult task. One major prob-
lem is data incompatibility
among states—the result of dif-
erent mapping methods. After
harmonizing and changing the
data to a unified standard, the
biotope data is also given to the
European Community CORINE-
biate register. (CORINE will
be described in the next issue of
URISA Journal.)

A different problem with
the state data involves the selec-
tion and automation of the
landscape-protection area data.
By law, the states protect certain
landscapes. To develop an over-
view for the Federal Republic,
the states provide maps in five
different scales (1:10,000 to
1:500,000). After digitizing, they
are brought into one large data
set with great variation in accu-
racy. The plot in Fig. 2 shows
the overview map of the land-
scape protection area at
1:1,000,000 scale.

Temporal Sensitivity

With the large amount of
spatial data stored, a systematic
procedure for updating it is
needed. Users are primarily in-
terested in the most recent data,
and data which have changed
over certain time intervals. This
requires a process for regularly
updating those data that change
most rapidly. These include
land-use classes and new nature
protection areas. It is also im-
portant to keep a time record of
the changes or additions, so that
a back trace is possible.

For certain data sets, no
updating is needed for the next
10 or 20 years. This data is con-
sidered stable, and includes ge-
ology, soils and water courses.
Should a new soil map be pub-
lished, then both maps would
be stored and the user given the
choice of using either. Constant
monitoring and updating of data
is costly, but with the increased
concern for environmental prob-
lems, monitoring has become
more necessary. Updating pro-
cedures within LANIS, however,
are not yet well developed. One
reason for this: the federal
states, in most cases, are not de-
delivering the data regularly. Na-
ture and landscape protection
areas, or the biotope sites for
example, should be registered
yearly and updated; the states,
however, do not provide this
data regularly. From the list of
spatial data in Table 1, only a
few have been updated so far.
The mapping and updating of
land uses for all of Germany is
also unresolved.

Accuracy and Data
Volume

Data gathered from dif-
erent sources present a problem
of mixed accuracies. The data
can only be as accurate as the
source material, and this can
vary greatly as previously men-
tioned. Not only are different
methods used for collecting the
data, but also different tech-
niques are applied for digitizing
and storing the data.

LANIS accounts for ac-
curacy variance by including
two scales in one database: one
in the detail scale 1:200,000,
which is subdivided into 43
data files (Figure 3) corre-
sponding to the 43 topographic base
maps at the same scale, and the
other at 1:1,000,000, which is
derived from a single base map.

The LANIS spatial data-
bases now contains about 40 at-
tributes of different spatial
structures, amounting to about
750 MBytes of storage space.
The storage space for each attri-
bute covering 250,000 square
kilometers, ranges from 100 kil-
obytes to as much as 15
MBytes. The following list illus-
trates a few examples:

- Nature park areas (1:1,000,000)
  0.5 Mbyte
- Super-highway network
  (1:1,000,000) 0.6 Mbyte
- County boundaries (1:1,000,000)
  4.0 Mbyte
- Forested areas (1:1,000,000) 10.0
  Mbyte
* Landscape protection areas (1:200,000) 15.0 Mbyte

Another example is the database of wildflower distribution in Germany; this register now requires about 200 MBytes of storage.

The demand for storage space for GIS is constantly growing. We now utilize 2 Gigabytes of storage and are in the process of doubling that in the next two years.

Applications

The really important part of a GIS is the application of the stored spatial and alphanumerical data. This means data processing, data evaluation and data display with the aim of solving many different problems. The data have to be put to use in different and creative ways to produce relevant information.

In order to provide the user with more flexibility for analysis, modelling and evaluation techniques, LANIS actually has two spatial databases: a vector database and a raster database. With the exception of linear features, all the data features shown in Table 1 are in both databases.

Aside from the negatives of duplicate data storage, there are some considerable advantages to this structure. With vector data, users have higher accuracy, the area calculation is correct and the map display is more appealing. With raster data the remote sensing data can be easily overlayed, and analytical tools for raster data are well developed.

To date, LANIS is used by planners and scientists within governmental administrations and research institutions. Within the Federal Research Centre, the spatially referenced data and information are used for governmental planning and decision-making, governmental reports on the environment, general overview maps, natural resources statistics, and monitoring landscape changes.

The same methodology has been applied to more detailed scales (1:25,000 and 1:10,000) of analysis for several environmental impact studies and ecological evaluation projects.

Conclusion

Data processing in the field of nature conservation and natural resources planning is now well accepted and beyond the experimental stage. Professional landscape planners are now setting up personal computers with computer aided drafting (CAD) and graphic and spatial analysis capabilities in their offices.

In the Federal Republic of Germany there are also several working groups involved in coordinating the data collection and setting standards for GIS software, data and information transfer and communication.

References

The development of spatial data handling has, curiously, paralleled the United States monetary system. The similarity is so complete that even the mill, a coin long out of circulation, is as outdated as the techniques that I will associate with it. It may be that study of the parallels will both clarify the past and point toward the future. It may also be that this is just coincidence. Or is it? You be the judge.

Paper Mills

In the Pre-Cambrium Age of spatial data handling (about 25 years ago), maps were prepared by putting overprinted characters on paper. Lots of paper. Where now we talk about graphic displays being medium resolution if they are 640 by 480 pixels, back then the page had a resolution of 132 by 66. To make matters worse, there were no colors, and the pixels weren't square!

The result was big maps. To show a reasonable area, at an acceptable resolution with discernable lines and patterns, took quite a few sheets of paper. A small project could cover a wall. With overlays (and any good project had lots of those) the threat to forests approached New York Times proportions.

The Minnesota Land Management Information System (MLMIS), the New York State Land Use and Natural Resources (LUNR) project, and the Canada Land Information System (CLIS) were done in this era. Whole states, nay whole countries, were gridded off, boxes of cards were punched, and more forests disappeared in an effort to inventory: trees, among other things.

The landscape architects from the Ian McHarg school of planning and analysis loved this tool. It wasn't just the geographers who were keeping International Paper in business. Think where the Harvard Laboratory for Computer Graphics and Spatial Analysis is located: in the Graduate School of Design! Howard Fisher (SYMAG) and David Sinton (GRID), and the other early Labbies were not cartographers. But they probably owned paper mill stock.

Penny Lines

The modern era of spatial data handling dawned with the advent of pen plotters. Now, instead of doing maps on line printers, a mechanical draftsman could draw lines with a pen. Line width! Color! Hershey fonts! Shade patterns! They could make a cartographer proud; these were real maps for real mappers.

Geographers started getting interested in the new-fangled technology. Instead of having to laboriously draw maps, an electronic elf would do it. All they had to do was to write the programs, digitize the data, design the map, plot it, correct a mistake, plot again, fix another mistake, . . .

Automated cartography was a step forward, but the lines had little cents. They were dumb; just data, with little information. Maybe a layer designation or a classification was attached to a line, but lines could wander across one another and lay on top of each other, as long as the map looked right.

M&S Computing (now Intergraph) and ComputerVision (now part of Prime) and a few others saw that designing circuit boards and drawing maps had enough similarities that they could tweak a few programs and voila! Provide turnkey mapping systems! But soon the time was ripe for a more worthy form of spatial data handling. And the landscape architects were still around.

Nickel Polygons

Numismatically and historically this coin follows, but
lexicographically this is a back-
formation of the next coin.
(What did he just say?) To whit:
The landscape architects had found a rich and fertile
field. They showed with their
paper mills (or, more kindly, early raster GISs) that one could
divide up a region into sets of
districts, height contours,
viewsheds—and then weight and combine the sets to do
planning and analysis. Since it
was easier to draw a line
around an area and say what is
inside than to grid a region and
say what is in each cell, they
switched to polygons.

This is the era when Jack Dangermond's Environmental

Systems Research Institute
really was nonprofit. His PIOS
program, Lane County Oregon's
system, and others hail from
this time.

Unfortunately, it is much
easier to overlay grids than to
overlay polygons. It is very
hard to digitize shared polygon
boundaries exactly the same if
you insist on doing the digitizing
separately for each polygon.
And, to top it off, real world
polygons sometimes have holes
in them (as do some coins; but I
digress).

Programmers pro-
gressed, digitizers digitized,
and computers blinked and
groaned. The result was still the
same: polygons only tell you
what is inside them, not what is
outside. They only tell you half
the story. And a nickel is half
of...? Now does the first para-
graph make cents?

DIME Segments

Then along came Marv.2
James Corbett was the father,
Marvin White was the son, and
I better stop there. When spatial
data handling got mired in nick-
els, Jim and Marv brought a
simple concept over from math-
ematics, stretched it a little to fit
the real world,3 and beat us
over the head with it (nicely, of
course) until we all said after
them: "Ten is greater than five
plus five." No, it is "dual inde-
pendent map encoding." No,
you dummies, it is:

TOPOLOGY.

Actually, some people
still cannot say the T-word, and
are proving the old adage of
John D. Rockefeller, "You can
hand out dimes, but they won’t always spend them wisely.”

There were enough converts, fortunately, to usher in the currency (no, make that “current”) era: that of “GIS.” While it used to mean “Greatly Improved Stratagem,” the geographers renamed it in their own honor; had to get back at the landscape architects for only solving the problem half way, you see.

But, more seriously, and on a higher plane: a new layer of possibilities was added to spatial data handling with the concept of topology. By only digitizing from node to node, and recording the block on either side, the building of computerized street maps was immeasurably improved from the days of address coding guides. Out with ACGs! In with GBF/DIME files!

And look what it did for digitizing areas: record a shared boundary once, and use it to build both sides. So simple. Out with sliver polygons! In with so much nomenclature Hal Moellering is probably still reeling from trying to tame the beast. Anyone for just 0-, 1- and 2-cells?

If only they would have really listened to Jim and Marv, the U.S. Census Bureau would have had a TIGER in their tank ten years ago. Another lost dime. But it could have been obverse.8

Quarter Cells

Whew! Out of the jungle, into the trees. Quad trees, range trees, Peano keys. Tessellators of the world: split up! You know how to cell an idea.

Do you know where your neighborhood attractor is? Geof Dutton will tell you on the QT(M), implying how accurate he is. Buckminster Fuller would be proud to know that one day we may view the whole world as a big geodesic dome (well, two), and locate ourselves in nested triangles rather than messing with spherical geometry. Surveyors will love it: they have been triangulating for years.

Dollar Bills

Data collection costs big bucks. Need I say more?
What is Next?

Quarters are 2.5 times a dime; do we have fractals in our future?

That's All, Pholks!

Notes
1. Not a Beatles' song title said with an Australian accent.
2. No, not a song by The Association.
3. Can you say "singularity?" I know a nice song about them. Would you like to sing it with me?
4. No, this was never made into a hit song; pity. Then again, J.D. probably didn't say it.
5. Try saying it with a German accent. Better yet, hum a few obverses.
6. "Do you know if they are ivory?" "No, but if you sing a little I'll try to play it."
7. Cue the theme music to "A Man and a Woman and a Man."
8. The real origin of the word TAPS. You can trust me on this one; would I give you a wooden nickel?

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He has been a member of URISA since 1977, and edits software news and reviews for the URISA Newsletter and Journal.

Peter H. Van Demark is an associate research analyst cartographer at the Center for Governmental Research Inc. (CGR) in Rochester NY.
An Organizational Approach to Implementing GIS

Gene V. Roe

The design target must be to create a sociotechnical system capable of serving organisational goals, not to create a technical system capable of delivering a technical service.

Ken Eason

By way of introduction, and at the risk of offending real historians, let's begin by generally tracing the trends that have taken place with respect to technology, and their relationship to society in general. For the purpose of this discussion, let's start this process in the late 1940s and early 1950s with the invention of the vacuum-tube computer. This, in many ways, signaled the birth of the "Age of Information," which we now find ourselves enveloped in.

The vacuum-tube computer was a tremendous first step, but the computer revolution really started with the invention of solid-state devices, namely the transistor and diode. These are what have laid the groundwork for today's VLSI (Very Large Scale Integration) techniques, or the "computer on a chip." Where this process will take us in 20 years, or even by the turn of the century, is virtually impossible to comprehend.

From society's point of view, during the second half of the twentieth century, the United States and many other countries began to shift from an industrial to an information-based economy. As John Naisbitt pointed out in the early 1980s:

The restructuring of America from an industrial to an information society will easily be as profound as the shift from an agricultural society to an industrial society.

The difference is that the shift from an industrial to an information society has occurred much more rapidly—20 vs. 100 years. This has left society, and most organizations, without the critical skills or game plan they need to cope with the tremendous changes occurring around them.

Somewhere during this industry-to-information shift, let's say in the 1960s, people began to look to technology as the solution to the myriad problems created by this shift. It was a natural. If we could put a man on the moon, we should certainly be able to use technology to manage information.

During this time the concept of "automation" was coming into its own. People's jobs were going to be replaced by a robot or a computer. If your job was working on an assembly line, or in a mass-production factory, to a certain extent these fears have come true. That's what the shift in society is really all about. It takes fewer people to mass-produce the required level of goods, due in large part to automation and computer technology.

Appropriate Uses of GIS Technology

GIS technology was born in the early 1970s as a tool to help manage increasingly scarce natural resources. Even today the category with the largest number of installed geographic information systems is the forest industry. Few can question the wisdom of managing vast land areas with the power of a computer-based information system—one that can visually display the results of sophisticated spatial analysis. There can be no doubt that automating the tedious, and often impossible, manual tasks required to effectively manage millions of acres of forest lands is an appropriate use of GIS technology.

Problems develop, however, when the technology is not applied wisely. Applying GIS to the management of municipal government is not the same as managing natural resources.
Automating vs. Informating

The difference as Shoshana Zuboff points out in her latest book, “In the Age of the Smart Machine: The Future of Work and Power,” is the difference between automating and “informating.” Automating may work on an assembly line process; it does not in an organization. She agrees with Naisbitt that the shift from a production-oriented society to one based on information is not just another technological breakthrough. She points out, “...we are facing a decades-long period of discontinuity, requiring organizational pioneering, discipline and adaptation.”

Her concept of informating refers to the fact that when information technology is used to automate a work process, unlike other automating technologies, it translates the process into data or information.

We are told that the key to GIS lies in automating our handling of spatial data. That implementing information technology, in the form of GIS, can be justified according to the classic model of lowering costs, reducing staff, achieving greater reliability, and simplifying work methods. But as Zuboff points out, there is a fundamental flaw in applying this “automation model” to the introduction of information technology into an organization, such as a municipal government.

Ms. Zuboff states:

...we have learned a great deal about how to design and run organizations that do a good job of automating; we know little about how to create and manage organizations to exploit the informating capability.

The Proper Focus

What is the primary goal of an “informated” organization? Zuboff says it is “...having the right information closest to the people who can use it to make a difference.” This seems obvious, but she adds that currently the informating process is being:

...driven by technology itself, rather than by some concept of effective management practice. Information is being created before any plans for its management are in place. Consequently, we often tend to think we’re being presented with too much information. We don’t think we know how to deal with all of it. But if we were organizing ourselves around this new information potential, we’d see new sources of competitive advantage, instead of information overload.

John Walker, one of the founders of AutoDesk correctly emphasized, “Technology comes from the same root as technique, it has nothing to do with machines.” In the early 1980s, computer-aided design (CAD) was predicted to significantly increase production rates. Ten
years later we are still waiting for these increases. We should not lose sight of this as our computers continue to get smaller, faster and cheaper. There is already more computer power than our organizations can effectively assimilate.

Why is this focus on the organization, rather than the technology so critical? Because to date, the track record of introducing information technology into organizations has been poor, and we risk losing a once-in-a-lifetime opportunity to do things right the first time. As someone once said, "the only problem with doing something right the first time is that nobody appreciates how difficult it was."

Ken Eason, in his important text, *Information Technology and Organizational Change*, has studied the effects of technology on organizations. He cites studies in the late 1970s and early 1980s which found that only 20 percent of the installed information systems achieved something like their expected benefits. The other 40 percent were marginally successful, and fully 40 percent were failures.

Eason attributes these results to implementation strategies with the wrong focus. His quote at the beginning of this paper highlights the critical need for placing the emphasis on the changes that the introduction of a new information technology causes in an organization. In fact, his book describes in detail an alternative strategy, which places the needs of the user organization in their proper relation to technology—ahead of it.

Nicholas Chrisman, in a short but equally thought-provoking discussion entitled, *Design of Geographic Information Systems Based on Social and Cultural Goals*, stresses the need for three critical elements to be present in order to successfully implement a GIS. These are mandate, custodian and equity.

Chrisman believes that the first step is to establish a mandate that GIS is going to be the preferred way of doing business. Next, a custodian of the system must be identified who will be responsible for its man-
agement. And thirdly, by implementing GIS, it should be possible to demonstrate that by using the system, people are treated more equitably. This approach obviously places the focus properly on the needs of the organization and its people, not on the technology.

User-Centred Design

While Chrisman lays out the goals, Eason’s text delivers the action plan for achieving them. Based on his more than 20 years of observing the results of introducing information technology into user organizations, Eason has developed an in-depth approach to designing implementation strategies which recognize the impact that an information technology can have on an organization. His is the pragmatic solution to the “informing” dilemma which Zuboff has identified.

Eason notes that “... the implementation of information technology systems is a high-risk business. Complete failure is not uncommon and marginal impact with unwanted and negative consequences is commonplace.” This being said, he introduces the concept of what he calls the “socio-technical design” of information technology systems. At the core of this approach is his “user-centred techniques.”

The general form of “user-centred design technique” (Figure 1) stresses the importance of listening and involving the stakeholders of the organization. When their needs are combined with specialists from outside the organization the design team is assembled. Then the design options and criteria can be addressed; the specialists describe the available options, and the stakeholders communicate their goals and concerns. From this, a shortlist of options is formulated and the evaluation process begins.

The complete range of socio-technical design topics which Eason has identified is shown in Figure 2. Complicated at first glance, but if you begin in the upper right-hand corner with the organizational objectives and work out from there, the logic becomes apparent.

Obviously, the interrelationship of social and technical topics is what makes the diagram complex, but this is exactly what this paper is trying to point out. The relationship between technology and organizational behavior is multi-variant and complex. Yet, it seems that the only concern of most organizations is for the technology, and how automating certain processes is going to result in significant benefits. This author’s concern is that, just as with many other information technologies, 10 years after their widespread adoption, organizations will still be waiting for the benefits to be realized.

Looking to the Future

Although the computer revolution is the engine driving the Information Age, we still are a long way from deciding what our destination is going to be. Sometimes it seems that the only goal is to design smarter machines that go ever faster in the high-tech race, but is the race from point A to point B, or are we racing around a closed-circuit track?

GIS technology is a powerful tool that can affect the future of the human race. If this is so, then we should be more aware of the impact that this technology can have on user organizations. The evidence is clear: in general, organizations are not ready for information technology. If we are to successfully implement it, changes in our approach are going to have to come about.


turning information into knowledge is the creative skill of the age, for it involves discovering ways to burrow into the abundance rather than augment it... to illuminate rather than search.

A. Smith

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Can a Computer Have a Mind?

Roger Penrose


Editor's Note: Whether mechanical devices can think—express feelings, to actually have a mind—is not a new question. But with upcoming advances in computer speed, capacity and logical design that will render today's computers primitive by comparison, it's a question that has become more urgent. And it touches upon deep philosophical issues. What does it mean to think or to feel? What is a mind? Do minds really exist? Are they simply the functioning of specific physical structures? Need those structures be biological in origin?

In pursuit of his unconventional points of view regarding these questions, Roger Penrose takes the reader on a journey through the far-ranging worlds of physics, philosophy and psychology. In so doing, he does not so much provide answers as raise issues—about thought, our understanding of 'mind,' and the fundamental laws of physics. The following excerpt from his book The Emperor's New Mind is but a part of that journey.

An area of much interest in recent years is that referred to as artificial intelligence, often shortened simply to 'AI.' The objectives of AI are to imitate by means of machines, normally electronic ones, as much of human mental activity as possible, and perhaps eventually to improve upon human abilities in these respects. There is interest in the results of AI from at least four directions. In particular there is the study of robotics, which is concerned, to a large extent, with the practical requirements of industry for mechanical devices which can perform 'intelligent' tasks—tasks of a versatility and complication which have previously demanded human intervention or control—and to perform them with a speed and reliability beyond any human capabilities, or under adverse conditions where human life could be at risk. Also of interest commercially, as well as generally, is the development of expert systems, according to which the essential knowledge of an entire profession—medical, legal, etc.—is intended to be coded into a computer package! Is it possible that the experience and expertise of human members of these professions might actually be supplanted by such packages? Or is it merely that long lists of factual information, together with comprehensive cross-referencing, are all that can be expected to be achieved? The question of whether the computers can exhibit (or simulate) genuine intelligence clearly has considerable social implications. Another area in which AI could have direct relevance is psychology. It is hoped that by trying to imitate the behaviour of a human brain (or that of some other animal) by means of an electronic device—or by failing to do so—one may learn something of importance concerning the brain's workings. Finally, there is the optimistic hope that for similar reasons AI might have something to say about deep questions of philosophy, by providing insights into the meaning of the concept of mind.

How far has AI been able to progress to date? It would be hard for me to try to summarize. There are many active groups in different parts of the world and I am familiar with details of only a little of this work. Nevertheless, it would be fair to say that, although many clever things have indeed been done, the simulation of anything that could pass for genuine intelligence is yet a long way off. To convey something of the flavour of the subject, I shall first mention some of the (still quite impressive) early achievements, and then some remarkable recent progress with chess computers.

One of the first AI devices was W. Grey Walter's 'tortoise', made in the early 1950s, which moved around the floor under its own power until its batteries ran low, and then it would make for the nearest power socket, plug itself in and recharge its batteries. When thoroughly replenished it would detach itself from the socket and renew its adventures across the floor! Since then many
its adventures across the floor! Since then many other similar objects have been constructed. A somewhat separate line of development is exemplified by Terry Winograd's computer program, designed in 1972, which can converse sensibly about a collection of blocks, of various shapes and colours which, in simulation, it places on top of one another in different orders and arrangements. Despite such early successes, it is remarkable how difficult it has proved to be to design the control of even a simple, jointed 'robot arm', which has to manoeuvre around, avoiding crowded obstacles, where the required motions may seem obvious to a human looking on. The interpretation of visual scenes generally is also an area where the procedures of AI have so far got nowhere close to what the human brain (and, indeed, most other animals) seems effortlessly to be able to achieve.

Perhaps more in the direct line of a Turing test is the computer program of K. M. Colby, developed in the mid-1960s, which simulates a psychotherapist—so successfully that some patients find that they prefer the computer to a human therapist, and are prepared to reveal more of themselves to it than they are to its human counterparts. For an example of such an interchange between the computer 'therapist' and a patient, consider the following conversation (conducted via teletype):

**Therapist:** How can I help you?
**Patient:** I don't know
**Therapist:** Try to tell me something about it
**Patient:** No
**Therapist:** Can you elaborate
**Patient:** I am sick and tired today
**Therapist:** Do you have any idea why
**Patient:** Yes I'm old
**Therapist:** Please go on
**Patient:** I seem to have lost interest in everything
**Therapist:** Tell me more about such feelings
**Patient:** I have some idea why I feel this way too
**Therapist:** You have
**Patient:** It seems that I miss having a family
**Therapist:** What makes you feel you miss having a family
**Patient:** There is a challenge about it
**Therapist:** Why is that important to you

Though this may give an eerie impression that the computer has some understanding, in fact it has none, and is merely following some fairly simple mechanical rules. (There is also a 'converse' to this in a system where the computer simulates a human schizophrenic patient, giving all the textbook answers and symptoms, and is capable of fooling some medical students into believing that a human patient is actually supplying the answers!)

Chess playing computers probably provide the best examples of machines exhibiting what might be thought of as 'intelligent behaviour'. In fact, some machines have now (in 1989) reached an extremely respectable level of performance in relation to human players—approaching that of 'International Master' (These computers' ratings would be a little below 2300, where, for comparison, Karpov, the world champion, has a rating greater than 2700.) In particular, a computer program (for a Fidelity Excel commercial microproces-

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**The objectives of Artificial Intelligence are to imitate by means of machines, normally electronic ones, as much of human mental activity as possible.**

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Sor) by Dan and Kathe Spracklen has achieved a rating (Elo) of 2110 and has now been awarded the USCF 'Master' title. Even more impressive is 'Deep Thought', programmed largely by Hsi lung Hsu, of Carnegie Mellon University, which has a rating of about 2500 Elo, and recently achieved the remarkable feat of sharing first prize (with Grandmaster Tony Miles) in a chess tournament (in Longbeach, California, November 1988), actually defeating a Grandmaster (Bent Larsen) for the first time! Chess computers now also excel at solving chess problems, and can easily outstrip humans at this endeavour.

Chess-playing machines rely a lot on 'book knowledge' in addition to accurate calculational power. It is worth remarking that chess-playing machines fare better on the whole, relative to a comparable human player, when it is required that the moves are made very quickly; the human players perform relatively better in relation to the machines when a good measure of time is al-
An AI approach to ‘pleasure’ and ‘pain’

One of the claims of AI is that it provides a route towards some sort of understanding of mental qualities, such as happiness, pain, hunger. Let us take the example of Grey Walter’s tortoise. When its batteries run low its behaviour pattern would change, and it would then act in a way designed to replenish its store of energy. There are clear analogies between this and the way that a human being—or any other animal—would act when feeling hungry. It perhaps might not be too much of a distortion of language to say that the Grey Walter tortoise was ‘hungry’ when it acted in this way. Some mechanism within it was sensitive to the state of charge in its battery, and when this got below a certain point it switched the tortoise over to a different behaviour pattern. No doubt there is something similar operating within animals when they become hungry, except that the changes in behaviour patterns are more complicated and subtle. Rather than simply switching over from one behaviour pattern to another, there is a change in tendencies to act in certain ways, these changes becoming stronger (up to a point) as the need to replenish the energy supply increases.

Likewise, it is envisaged by AI supporters that concepts such as pain or happiness can be appropriately modelled in this way. Let us simplify things and consider just a single scale of ‘feelings’ ranging from extreme ‘pain’ (score −100) to extreme ‘pleasure’ (score +100). Imagine that we have a device—a machine of some kind, presumably electronic—that has a means of registering its own (putative) ‘pleasure-pain’ score, which I refer to as its ‘pp-score’. The device is to have certain modes of behaviour and certain inputs, either internal (like the state of its batteries) or external. The idea is that its actions are geared so as to maximize its pp-score. There could be many factors which influence the pp-score. We could certainly arrange that the charge in its battery is one of them, so that a low charge counts negatively and a high charge positively, but there could be other factors too. Perhaps our device has some solar panels on it which give it an alternative means of obtaining energy, so that its batteries need not be used when the panels are in operation. We could arrange that by moving towards the light it can increase its pp-score a little, so that in the absence of other factors this is what it would tend to do. (Actually, Grey Walter’s tortoise used to avoid the light!) It would need to have some means of performing computations so that it could work out the likely effects that different ac-

One of the claims of AI is that it provides a route towards some sort of understanding of mental qualities, such as happiness, pain, hunger.

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out! But perhaps we can implant in it a ‘desire’ for companionship with other such devices, by giving meetings with them a positive pp-score. Or we could make it ‘crave’ learning for its own sake, so that the mere storing of facts about the outside world would also score positively on its pp-scale. (More selfishly, we could arrange that performing various services for us have a positive score, as one would need to do if constructing a robot servant!) It might be argued that there is an artificiality about imposing such ‘goals’ on our device according to our whim. But this is not so very different from the way that natural selection has imposed upon us, as individuals, certain ‘goals’ which are to a large extent governed by the need to propagate our genes.

Suppose, now, that our device has been successfully constructed in accordance with all this. What right would we have to assert that it actually feels pleasure when its pp-score is positive and pain when the score is negative? The AI (or operational) point of view would be that we judge this simply from the way that the device behaves. Since it acts in a way which increases its score to as large a positive value as possible (and for as long as possible) and it correspondingly also acts to avoid negative scores, then we could reasonably define its feeling of pleasure as the degree of positivity of its score, and correspondingly define its feeling of pain to be the degree of negativity of the score. The ‘reasonableness’ of such a definition, it would be argued, comes from the fact that this is precisely the way that a human being reacts in relation to feelings of pleasure or pain. Of course, with human beings things are actually not nearly so simple as that, as we all know; sometimes we seem deliberately to court pain, or to go out of our way to avoid certain pleasures. It is clear that our actions are really guided by much more complex criteria than these. But as a very rough approximation, avoiding pain and courting pleasure is indeed the way we act.

To an operationalist this would be enough to provide justification, at a similar level of approximation, for the identification of pp-score in our device with its pain-pleasure rating. Such identifications seem also to be among the aims of AI theory.

We must ask: Is it really the case that our device would actually feel pain when its pp-score is negative and pleasure when it is positive? Indeed, could our device feel anything at all? The operationalist would, no doubt, either say ‘Obviously yes’, or dismiss such questions as meaningless. But it seems to me to be clear that there is a serious and difficult question to be considered here. In ourselves, the influences that drive us are of various kinds. Some are conscious, like pain or pleasure; but there are others of which we are not directly aware. This is clearly illustrated by the example of a person touching a hot stove. An involuntary action is set up which causes him to withdraw his hand even before he experiences any sensation of pain. It would seem to be the case that such involuntary actions are very much closer to the responses of our device to its pp-score than are the actual effects of pain or pleasure.

One often uses anthropomorphic terms in a descriptive, often jocular, way to describe the behaviour of machines: ‘My car doesn’t seem to want to start this morning’; or ‘My watch still thinks it’s running on Californian time’; or ‘My computer claims it didn’t understand that last instruction and doesn’t know what to do next.’ Of course we don’t really mean to imply that the car actually might want something, or that the watch thinks, or that the computer actually claims anything or that it understands or even knows what it is doing. Nevertheless such statements can be genuinely descriptive and helpful to our own understanding, provided that we take them merely on the spirit in which they are intended and do not regard them as literal assertions. I would take a rather similar attitude to various claims of AI that mental qualities might be present in the de-

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But as a very rough approximation, avoiding pain and courting pleasure is indeed the way we act.

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services which have been constructed—irrespective of the spirit in which they are intended! If I agree to say that Grey Walter’s tortoise can be hungry, it is in this half-jocular sense that I mean it. If I am prepared to use terms such as ‘pain’ or ‘pleasure’
for the pp-score of a device as envisaged above, it is because I find these terms helpful to my understanding of its behaviour, owing to certain analogies with my own behaviour and mental states. I do not mean to imply that these analogies are really particularly close or, indeed, that there are not other unconscious things which influence my behaviour in a much more analogous way.

I hope it is clear to the reader that in my opinion there is a great deal more to the understanding of mental qualities than can be directly obtained from AI. Nevertheless, I do believe that AI presents a serious case which must be respected and reckoned with. In saying this I do not mean to imply that very much, if anything, has yet been achieved in the simulation of actual intelligence. But one has to bear in mind that the subject is very young. Computers will get faster, have larger rapid-access stores, more logical units, and will have large numbers of operations performed in parallel. There will be improvements in logical design and in programming technique. These machines, the vehicles of the AI philosophy, will be vastly improved in their technical capabilities. Moreover, the philosophy itself is not an intrinsically absurd one. Perhaps human intelligence can indeed be very accurately simulated by electronic computers—essentially the computers of today, based on principles that are already understood, but with the much greater capacity, speed, etc., that they are bound to have in the years to come. Perhaps, even, these devices will actually be intelligent; perhaps they will think, feel, and have minds. Or perhaps they will not, and some new principle is needed, which is at present thoroughly lacking. That is what is at issue, and it is a question that cannot be dismissed lightly. I shall try to present evidence, as best I see it. Eventually I shall put forward my own suggestions.

Strong AI and Searle's Chinese room

There is a point of view, referred to as strong AI which adopts a rather extreme position on these issues. According to strong AI, not only would the devices just referred to indeed be intelligent and have minds, etc., but mental qualities of a sort can be attributed to the logical functioning of any computational device, even the very simplest mechanical ones, such as a thermostat. The idea is that mental activity is simply the carrying out of some well-defined sequence of operations, frequently referred to as an algorithm. I shall be more precise later on, as to what an algorithm actually is. For the moment, it will be adequate to define an algorithm simply as a calculational procedure of some kind. In the case of a thermostat, the algorithm is extremely simple: the device registers whether the temperature is greater or smaller than the setting, and then it arranges that the circuit be disconnected in the former case and connected in the latter. For any significant kind of mental activity of a human brain, the algorithm would have to be something vastly more complicated but, according to the strong-AI view, an algorithm nevertheless. It would differ very greatly in degree from the simple algorithm of the thermostat, but need not differ in principle. Thus, according to strong AI, the difference between the essential functioning of a human brain (including all its conscious manifestations) and that of a thermostat lies only in this much greater complication (or perhaps 'higher-order structure' or 'self-referential properties', or some other attribute that one might assign to an algorithm) in the case of a brain. Most importantly, all mental qualities—thinking, feeling, intelligence, understanding, consciousness—are to be regarded, according to this view, merely as aspects of this complicated functioning; that is to say, they are features merely of the algorithm being carried out by the brain.

The virtue of any specific algorithm would lie in its performance, namely in the accuracy of its results, its scope, its economy, and the speed with which it can be operated. An algorithm purporting to match what is presumed to be operating in a human brain would need to be a stupendous thing. But if an algorithm of this kind exists for the brain—and the supporters of strong AI would certainly claim that it does—then it could in principle be run on a computer. Indeed it could be run on any modern general purpose electronic computer, were it not for limitations of storage space and speed of operation. (The justification of this remark will come later, when we come to consider the universal Turing machine.) It is antic-
ipated that any such limitations would be overcome for the large fast computers of the not-too-distant future. In that eventuality, such an algorithm, if it could be found, would presumably pass the Turing test. The supporters of strong AI would claim that whenever the algorithm was run it would, in itself: experience feelings; have a consciousness; be a mind.

By no means everyone would be in agreement that mental states and algorithms can be identified with one another in this kind of way. In particular, the American philosopher John Searle has strongly disputed that view. He has cited examples where simplified versions of the Turing test have actually already been passed by an appropriately programmed computer, but he gives strong arguments to support the view that the relevant mental attribute of 'understanding' is, nevertheless, entirely absent. One such example is based on a computer program designed by Roger Schank. The aim of the program is to provide a simulation of the understanding of simple stories like: 'A man went into a restaurant and ordered a hamburger. When the hamburger arrived it was burned to a crisp, and the man stormed out of the

restaurant angrily, without paying the bill or leaving a tip.' For a second example: 'A man went into a restaurant and ordered a hamburger; when the hamburger came he was very pleased with it; and as he left the restaurant he gave the waitress a large tip before paying his bill.' As a test of 'understanding' of the stories, the computer is asked whether the man ate the hamburger in each case (a fact which had not been explicitly mentioned in either story). To this kind of simple story and simple question the computer can give answers which are essentially indistinguishable from the answers an English-speaking human being would give, namely, for these particular examples, 'no' in the first case and 'yes' in the second. So in this very limited sense a machine has already passed a Turing test!

The question that we must consider is whether this kind of success actually indicates any genuine understanding on the part of the computer—or, perhaps, on the part of the program itself. Searle’s argument that it does not is to invoke his concept of a 'Chinese room'. He envisages first of all, that the stories are to be told in Chinese rather than English—surely an inessential change—and that all the operations of the computer's algorithm for this particular exercise are supplied (in English) as a set of instructions for manipulating counters with Chinese symbols on them. Searle imagines himself doing all the manipulations inside a locked room. The sequences of symbols representing the stories, and then the questions, are fed into the room through some small slot. No other information whatever is allowed in from the outside. Finally, when all the manipulations are complete, the resulting sequence is fed out again through the slot. Since all these manipulations are simply carrying out the algorithm of Schank’s program, it must turn out that this final resulting sequence is simply the Chinese for 'yes' or 'no', as the case may be, giving the correct answer to the original question in Chinese about a story in Chinese. Now Searle makes it quite clear that he doesn’t understand a word of Chinese, so he would not have the faintest idea what the stories are about. Nevertheless, by correctly carrying out the series of operations which constitute Schank's algorithm (the instructions for this algorithm having been given to him in English) he would be able to do as well as a Chinese person who would indeed understand the stories. Searle’s point—and I think it is quite a powerful one—is that the mere carrying out of a successful algorithm does not in itself imply that any understanding has taken place. (The imagined) Searle, locked in his Chinese room, would not understand a single word of any of the stories!

A number of objections have been raised against Searle’s argument. I shall mention only those that I regard as being of serious significance. In the first place, there is perhaps something rather misleading in the phrase 'not understand a single word', as used above. Understanding has as much to do with patterns as with individual words. While carrying out algorithms of this kind,
one might well begin to perceive something of the patterns that the symbols make without understanding the actual meanings of many of the individual symbols. For example, the Chinese character for 'hamburger' (if, indeed, there is such a thing) could be replaced by that for some other dish, say 'chow mein', and the stories would not be significantly affected. Nevertheless, it seems to me to be reasonable to suppose that in fact very little of the stories' actual meanings (even regarding such replacements as being unimportant) would come through if one merely kept following through the details of such an algorithm.

In the second place, one must take into account the fact that the execution of even a rather simple computer program would normally be something extraordinarily lengthy and tedious if carried out by human beings manipulating symbols. (This is, after all, why we have computers to do such things for us!) If Searle were actually to perform Schank's algorithm in the way suggested, he would be likely to be involved with many days, months, or years of extremely boring work in order to answer just a single question—not an altogether plausible activity for a philosopher! However, this does not seem to me to be a serious objection since we are here concerned with matters of principle and not with practicalities. The difficulty arises more with a putative computer program which is supposed to have sufficient complication to match a human brain and thus to pass the Turing test proper. Any such program would have to be horrendously complicated. One can imagine that the operation of this program, in order to effect the reply to even some rather simple Turing-test question, might involve so many steps that there would be no possibility of any single human being carrying out the algorithm by hand within a normal human lifetime. Whether this would indeed be the case is hard to say, in the absence of such a program. But, in any case, this question of extreme complication cannot, in my opinion, simply be ignored. It is true that we are concerned with matters of principle here, but it is not inconceivable to me that there might be some 'critical' amount of complication in an algorithm which is necessary to achieve in order that the algorithm exhibit mental qualities. Perhaps this critical value is so large that no algorithm, complicated to that degree, could conceivably be carried out by hand by any human being, in the manner envisaged by Searle.

Searle himself has countered this last objection by allowing a whole team of human non-Chinese-speaking symbol manipulators to replace the previous single inhabitant ('himself') of his Chinese room. To get the numbers large enough, he even imagines replacing his room by the whole of India, its entire population (excluding those who understand Chinese!) being now engaged in symbol manipulation. Thence this would be in practice absurd, it is not in principle absurd, and the argument is essentially the same as before: the symbol manipulators do not understand the story, despite the strong-AI claim that the mere carrying out of the appropriate algorithm would elicit the mental quality of 'understanding'. However, now another objection begins to loom large. Are not these individual Indians more like the individual neurons in a person's brain than like the whole brain itself? No-one would suggest that neurons, whose firings apparently constitute the physical activity of a brain in the act of thinking, would themselves individually understand what that person is thinking, so why expect the individual Indians to understand the Chinese stories? Searle re-

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The idea is that mental activity is simply the carrying out of some well-defined sequence of operations, frequently referred to as an algorithm.

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plies to this suggestion by pointing out the apparent absurdity of India, the actual country, understanding a story that none of its individual inhabitants understands. A country, he argues, like a thermostat or an automobile, is not in the 'business of understanding', whereas an individual person is.

This argument has a good deal less force to it than the earlier one. I think that Searle's argument is at its strongest when there is just a single person carrying out the algorithm, where we restrict attention to the case of an algorithm which is sufficiently uncomplicated for a person actually
to carry it out in less than a lifetime. I do not regard his argument as rigorously establishing that there is not some kind of disembodied ‘understanding’ associated with the person’s carrying out of that algorithm, and whose presence does not impinge in any way upon his own consciousness. However, I would agree with Searle that this possibility has been rendered rather implausible, to say the least. I think that Searle’s argument has a considerable force to it, even if it is not altogether conclusive. It is rather convincing in demonstrating that algorithms with the kind of complication that Schank’s computer program possesses cannot have any genuine understanding whatsoever of the tasks that they perform; also, it suggests (but no more) that no algorithm, no matter how complicated, can ever, of itself alone, embody genuine understanding—in contradistinction to the claims of strong AI.

There are, as far as I can see, other very serious difficulties with the strong-AI point of view. According to strong AI, it is simply the algorithm that counts. It makes no difference whether that algorithm is being effected by a brain, an electronic computer, an entire country of Indians, a mechanical device of wheels and cogs, or a system of water pipes. The viewpoint is that it is simply the logical structure of the algorithm that is significant for the ‘mental state’ it is supposed to represent, the particular physical embodiment of that algorithm being entirely irrelevant. As Searle points out, this actually entails a form of ‘dualism’. Dualism is a philosophical viewpoint espoused by the highly influential seventeenth century philosopher and mathematician René Descartes, and it asserts that there are two separate kinds of substance: ‘mind-stuff’ and ordinary matter. Whether, or how, one of these kinds of substance might or might not be able to affect the other is an additional question. The point is that the mind-stuff is not supposed to be composed of matter, and is able to exist independently of it. The mind-stuff of strong AI is the logical structure of an algorithm. As I have just remarked, the particular physical embodiment of an algorithm is something totally irrelevant. The algorithm has some kind of disembodied ‘existence’ which is quite apart from any realization of that algorithm in physical terms. How seriously we must take this kind of existence is a question I shall need to return to in the next chapter. It is part of the general question of the Platonic reality of abstract mathematical objects. For the moment I shall sidestep this general issue and merely remark that the supporters of strong AI do indeed seem to be taking the reality at least of algorithms seriously, since they believe that algorithms form the ‘substance’ of their thoughts, their feelings, their understanding, their conscious perceptions. There is a remarkable irony in this fact that, as Searle has pointed out, the standpoint of strong AI seems to drive one into an extreme form of dualism, the very viewpoint with which the supporters of strong AI would least wish to be associated!

This dilemma lies behind the scenes of an argument put forward by Douglas Hofstadter—himself a major proponent of the strong-AI view—in a dialogue entitled ‘A Conversation with Einstein’s Brain’. Hofstadter envisages a book, of absurdly monstrous proportions, which is supposed to contain a complete description of the brain of Albert Einstein. Any question that one might care to put to Einstein can be answered, just as the living Einstein would have, simply by leafing through the book and carefully following all the detailed instructions it provides. Of course ‘simply’ is an utter misnomer, as Hofstadter is careful to point out. But his claim is that in principle the book is completely equivalent, in the operational sense of a Turing test, to a ridiculously slowed-down version of the actual Einstein. Thus, according to the contentions of strong AI, the book

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would think, feel, understand, be aware, just as though it were Einstein himself, but perhaps living at a monstrously slowed-down rate (so that to the book—Einstein the world outside would seem to flash by at a ridiculously speeded-up rate). Indeed, since the book is supposed to be merely a particular embodiment of the algorithm which constitutes Einstein’s ‘self’, it would actually be Einstein.
But now a new difficulty presents itself. The book might never be opened, or it might be continually pored over by innumerable students and searchers after truth. How would the book ‘know’ the difference? Perhaps the book would not need to be opened, its information being retrieved by means of X-ray tomography, or some other technological wizardry. Would Einstein’s awareness be enacted only when the book is being so examined? Would he be aware twice over if two people chose to ask the book the same question at two completely different times? Or would that entail two separate and temporarily distinct instances of the same state of Einstein’s awareness? Perhaps his awareness would be enacted only if the book is changed? After all, normally when we are aware of something, we receive information from the outside world which affects our memories, and the states of our minds are indeed slightly changed. If so, does this mean that it is (suitable) changes in algorithms (and here I am including the memory store as part of the algorithm) which are to be associated with mental events rather than (or perhaps in addition to) the activation of algorithms? Or would the book-Einstein remain completely self-aware even if it were never examined or disturbed by anyone or anything? Hofstadter touches on some of these questions, but he does not really attempt to answer or to come to terms with most of them.

What does it mean to activate an algorithm, or to embody it in physical form? Would changing an algorithm be different in any sense from merely discarding one algorithm and replacing it with another? What on earth does any of this have to do with our feelings of conscious awareness? The reader (unless himself or herself a supporter of strong AI) may be wondering why I have devoted so much space to such a patently absurd idea. In fact, I do not regard the idea as intrinsically an absurd one—mainly just wrong! There is, indeed some force in the reasoning behind strong AI which must be reckoned with, and this I shall try to explain. There is, also, in my opinion, a certain appeal in some of the ideas—if modified appropriately—as I shall also try to convey. Moreover, in my opinion, the particular contrary view expressed by Searle also contains some serious puzzles and seeming absurdities, even though, to a partial extent, I agree with him!

Searle, in his discussion, seems to be implicitly accepting that electronic computers of the present-day type, but with considerably enhanced speed of action and size of rapid-access store (and possibly parallel action) may well be able to pass the Turing test proper, in the not-too-distant future. He is prepared to accept the contention of strong AI (and of most other ‘scientific’ viewpoints) that ‘we are the instantiations of any number of computer programs’. Moreover, he succumbs to: ‘Of course the brain is a digital computer. Since everything is a digital computer, brains are too.’ Searle maintains that the distinction between the function of human brains (which can have minds) and of electronic computers (which, he has argued, cannot) both of which might be executing the same algorithm, lies solely in the material construction of each. He claims, but for reasons he is not able to explain, that the biological objects (brains) can have ‘intentionality’ and ‘semantics’, which he regards as defining characteristics of mental activity, whereas the electronic ones cannot. In itself this does not seem to me to point the way towards any helpful scientific theory of mind. What is so special about biological systems, apart perhaps from the ‘historical’ way in which they have evolved (and the fact that we happen to be such systems), which sets them apart as the objects allowed to achieve intentionality or semantics? The claim looks to me suspiciously like a dogmatic assertion, perhaps no less dogmatic, even, than those assertions of strong AI which maintain that the mere enacting of an algorithm can conjure up a state of conscious awareness!

In my opinion Searle, and a great many other people, have been led astray by the computer people. And they, in turn, have been led astray by the physicists. (It is not the physicists’ fault. Even they don’t know everything!) The belief seems to be widespread that, indeed, ‘everything is a digital computer’. It is my intention, in this book, to try to show why, and perhaps how, this need not be the case.

**Hardware and software**

In the jargon of computer science, the term *hardware* is used to denote the actual machinery
involved in a computer (printed circuits, transistors, wires, magnetic storage space, etc.), including the complete specification for the way in which everything is connected up. Correspondingly, the term software refers to the various programs which can be run on the machine. It was one of Alan Turing's remarkable discoveries that, in effect, any machine for which the hardware has achieved a certain definite degree of complication and flexibility, is equivalent to any other such machine. This equivalence is to be taken in the sense that for any two such machines A and B there would be a specific piece of software which if given to machine A would make it act precisely as one's calculations in a reasonable time. I shall be more precise in the next section about the concepts being referred to here: the machines A and B are instances of what are called universal Turing machines.

In effect, all modern general purpose computers are universal Turing machines. Thus, all general purpose computers are equivalent to one another in the above sense: the differences between them can be entirely subsumed in the software, provided that we are not concerned about differences in the resulting speed of operation and possible limitations on storage size. Indeed, modern technology has enabled computers to perform so swiftly and with such vast storage capacities that, for most 'everyday' purposes, neither of these practical considerations actually represents any serious limitation to what is normally needed, so this effective theoretical equivalence between computers can also be seen at the practical level. Technology has, it seems, transformed entirely academic discussions concerning idealized computing devices into matters which directly affect all our lives!

As far as I can make out, one of the most important factors underlying the strong-AI philosophy is this equivalence between physical computing devices. The hardware is seen as being relatively unimportant (perhaps even totally unimportant) and the software, i.e., the program, or the algorithm, is taken to be the one vital ingredient. However, it seems to me that there are also other important underlying factors, coming more from the direction of physics. I shall try to give some indication of what these factors are.

What is it that gives a particular person his individual identity? Is it, to some extent, the very atoms that compose his body? Is his identity dependent upon the particular choice of electrons, protons, and other particles that compose those atoms? There are at least two reasons why this cannot be so. In the first place, there is a continual turnover in the material of any living person's body. This applies in particular to the cells in a person's brain, despite the fact that no new actual brain cells are produced after birth. The vast majority of atoms in each living cell (including each brain cell)—and, indeed, virtually the entire material of our bodies—has been replaced many times since birth.
The second reason comes from quantum physics—and by a strange irony is, strictly speaking, in contradiction with the first! According to quantum mechanics, any two electrons must necessarily be completely identical, and the same holds for any two protons and for any two particles whatever, of any one particular kind. This is not merely to say that there is no way of telling the particles apart: the statement is considerably stronger than that. If an electron in a person’s brain were to be exchanged with an electron in a brick, then the state of the system would be exactly the same state as it was before, not merely indistinguishable from it! The same holds for protons and for any other kind of particle, and for whole atoms, molecules, etc. If the entire material content of a person were to be exchanged with corresponding particles in the bricks of his house, then, in a strong sense, nothing would have happened whatsoever. What distinguishes the person from his house is the pattern of how his constituents are arranged, not the individuality of the constituents themselves.

There is perhaps an analogue of this at an everyday level, which is independent of quantum mechanics, but made particularly manifest to me as I write this, by the electronic technology which enables me to type at a word-processor. If I desire to change a word, say to transform ‘make’ into ‘made’, I may do this by simply replacing the ‘k’ by a ‘d’, or I may choose instead to type out the whole word again. If I do the latter, is the ‘m’ the same ‘m’ as was there before, or have I replaced it with an identical one? What about the ‘e’? Even if I do simply replace ‘k’ by ‘d’, rather than retype the word, there is a moment just between the disappearance of ‘k’ and appearance of ‘d’ when the gap closes and there is (or, at least, sometimes is) a wave or re-alignment down the page as the placement of every succeeding letter (including the ‘e’) is re-calculated, and then re-re-calculated as the ‘d’ is inserted. (Oh, the cheapness of mindless calculation in this modern age!) In any case, all the letters that I see before me on the screen are mere gaps in the track of an electron beam as the whole screen is scanned sixty times each second. If I take any letter whatever and replace it by an identical one, is the situation the same after the replacement, or merely indistinguishable from it? To try to adopt the second viewpoint (i.e., ‘merely indistinguishable’) as being distinct from the first (i.e., ‘the same’) seems footling. At least, it seems reasonable to call the situation the same when the letters are the same. And so it is with the quantum mechanics of identical particles. To replace one particle by an identical one is actually to have done nothing to the state at all. The situation is indeed to be regarded as the same as before.

(However, as we shall see in Chapter 6, the distinction is actually not a trivial one in a quantum-mechanical context.)

The remarks above concerning the continual turnover of atoms in a person’s body were made in the context of classical rather than quantum physics. The remarks were worded as though it might be meaningful to maintain the individuality of each atom. In fact classical physics is adequate and we do not go badly wrong, at this level of description, by regarding atoms as individual objects. Provided that the atoms are reasonably well separated from their identical counterparts as they move about, one can consistently refer to them as maintaining their individual identities since each atom can be, in effect, tracked continuously, so that one could envisage keeping a tab on each separately. From the point of view of quantum mechanics it would be a convenience of speech only to refer to the individuality of the atoms, but it is a consistent enough description at the level just considered.

Let us accept that a person’s individuality has nothing to do with any individuality that one might try to assign to his material constituents. Instead, it must have to do with the configuration, in some sense, of those constituents—let us say the configuration in space or in space-time. (More about that later.) But the supporters of strong AI go further than this. If the information content of such a configuration can be translated into another form from which the original can again be recovered then, so they would claim, the person’s

“Of course the brain is a digital computer. Since everything is a digital computer, brains are too.”
Technology has, it seems, transformed entirely academic discussions concerning idealized computing devices into matters which directly affect all our lives.

thing quite different, say into fields of magnetization in a block of iron. They appear even to claim that the person's conscious awareness would persist while the person's 'information' is in this other form. On this view, a 'person's awareness' is to be taken, in effect, as a piece of software, and his particular manifestation as a material human being is to be taken as the operation of this software by the hardware of his brain and body.

It seems that the reason for these claims is that, whatever material form the hardware takes—for example some electronic device—one could always 'ask' the software questions (in the manner of a Turing test), and assuming that the hardware performs satisfactorily in computing the replies to these questions, these replies would be identical to those that the person would make whilst in his normal state. ('How are you feeling this morning?' 'Oh, fairly well, thank you, though I have a slightly bothersome headache.' 'You don't feel, then, that there's... or... anything odd about your personal identity... or something?' 'No; why do you say that? It seems rather a strange question to be asking.' 'Then you feel yourself to be the same person that you were yesterday?' 'Of course I do!')

An idea frequently discussed in this kind of context is the teleportation machine of science fiction. It is intended as a means of 'transportation' from, say, one planet to another, but whether it actually would be such, is what the discussion is all about. Instead of being physically transported by a spaceship in the 'normal' way, the would-be traveller is scanned from head to toe, the accurate location and complete specification of every atom and every electron in his body being recorded in full detail. All this information is then beamed (at the speed of light!), by an electromagnetic signal, to the distant planet of intended destination. There, the information is collected and used as the instructions to assemble a precise duplicate of the traveller, together with all his memories, his intentions, his hopes, and his deepest feelings. At least that is what is expected; for every detail of the state of his brain has been faithfully recorded, transmitted, and reconstructed.

Assuming that the mechanism has worked, the original copy of the traveller can be 'safely' destroyed. Of course the question is: is this really a method of travelling from one place to another or is it merely the construction of a duplicate, together with the murder of the original? Would you be prepared to use this method of 'travel'—assuming that the method had been shown to be completely reliable, within its terms of reference? If teleportation is not travelling, then what is the difference in principle between it and just walking from one room into another? In the latter case, are not one's atoms of one moment simply providing the information for the locations of the atoms of the next moment? We have seen, after all, that there is no significance in preserving the identity of any particular atom. The question of the identity of any particular atom is not even meaningful.
Does not any moving pattern of atoms simply constitute a kind of wave of information propagating from one place to another? Where is the essential difference between the propagation of waves which describes our traveller ambling in a commonplace way from one room to the other and that which takes place in the teleportation device?

Suppose it is true that teleportation does actually ‘work’, in the sense that the traveller’s own ‘awareness’ is actually reawakened in the copy of himself on the distant planet (assuming that this question has genuine meaning). What would happen if the original copy of the traveller were not destroyed, as the rules of this game demand? Would his ‘awareness’ be in two places at once? (Try to imagine your response to being told the following: ‘Oh dear, so the drug we gave you before placing you in the Teleporter has worn off prematurely has it? That is a little unfortunate, but no matter. Anyway, you will be pleased to hear that the other you—er, I mean the actual you, that is—has now arrived safely on Venus, so we can, er, dispose of you here—er, I mean of the redundant copy here. It will, of course, be quite painless.’) The situation has an air of paradox about it. Is there anything in the laws of physics which could render teleportation in principle impossible? Perhaps, on the other hand, there is nothing in principle against transmitting a person, and a person’s consciousness, by such means, but that the ‘copying’ process involved would inevitably destroy the original? Might it then be that the preserving of two viable copies is what is impossible in principle? I believe that despite the outlandish nature of these considerations, there is perhaps something of significance concerning the physical nature of consciousness and individuality to be gained from them. I believe that they provide one pointer, indicating a certain essential role for quantum mechanics in the understanding of mental phenomena. But I am leaping ahead. It will be necessary to return to these matters after we have examined the structure of quantum theory in Chapter 6.

Let us see how the point of view of strong AI relates to the teleportation question. We shall suppose that somewhere between the two planets is a relay station, where the information is temporarily stored before being retransmitted to its final destination. For convenience, this information is not stored in human form, but in some magnetic or electronic device. Would the traveller’s ‘awareness’ be present in association with this device?

The supporters of strong AI would have us believe that this must be so. After all, they say, any question that we might choose to put to the traveller could in principle be answered by the device, by ‘merely’ having a simulation set up for the appropriate activity of his brain. The device would contain all the necessary information, and the rest would just be a matter of computation. Since the device would reply to questions exactly as though it were the traveller, then (Turing test!) it would be the traveller. This all comes back to the strong-AI contention that the actual hardware is not important with regard to mental phenomena. This contention seems to me to be unjustified. It is based on the presumption that the brain (or the mind) is, indeed, a digital computer. It assumes that no specific physical phenomena are being called upon, when one thinks, that might demand the particular physical (biological, chemical) structure that brains actually have.

No doubt it would be argued (from the strong-AI point of view) that the only assumption that is really being made is that the effects of any specific physical phenomena which need to be called upon can always be accurately modelled by

The strong AI view holds that, being “just” a hardware question, any physics actually being called upon in the workings of the brain can necessarily be simulated by the introduction of appropriate converting software.

digital calculations. I feel fairly sure that most physicists would argue that such an assumption is actually a very natural one to make on the basis of our present physical understandings. I shall be presenting the reasons for my own contrary view in later chapters (where I shall also need to lead up to why I believe that there is even any appreciable assumption being made). But, just for the moment, let us accept this (commonly held) view.
that all the relevant physics can always be modelled by digital calculations. Then the only real assumption (apart from questions of time and calculation space) is the ‘operational’ one that if something acts entirely like a consciously aware entity, then one must also maintain that it ‘feels’ itself to be that entity.

The strong-AI view holds that, being ‘just’ a hardware question, any physics actually being called upon in the workings of the brain can necessarily be simulated by the introduction of appropriate converting software. If we accept the operational viewpoint, then the question rests on the equivalence of universal Turing machines, and on the fact that any algorithm can, indeed, be effected by such a machine—together with the presumption that the brain acts according to some kind of algorithmic action. It is time for me to be more explicit about these intriguing and important concepts.

Roger Penrose is a professor of mathematics at the University of Oxford. He has received a number of prizes and awards, including the 1988 Wolf Prize, which he shared with Stephen Hawking for their joint contribution to our understanding of the universe.
Use vs. Abuse of GIS Data

Peter V. August

Advertisements for GIS software frequently announce that their products reach new heights in "User Friendliness" or represent "THE Smart Software Solution." The marketing sages have perhaps missed the boat; we don't need smarter tools, we need smarter users. Many of the powerful features that contribute to making GIS a standard tool for land resource management are also implements of analytical destruction when used carelessly.

Let me illustrate my point by way of example. In the pre-GIS era, how frequently would someone photographically enlarge a page from a soil survey to 1:1,200 scale so the soils data could be manually overlaid a parcel map? Not often I would guess. Why? Because the time, effort, and cost would be significant and the fuzzy photographic result would clearly be of dubious accuracy. With digital representation of soils (usually digitized from 1:15,840 maps) and parcels (frequently digitized at 1:1,200), I can superimpose the two at my computer terminal using fewer keystrokes than I used to type this line of text. The image on the screen shows crisp, thin, clean lines defining parcels and soils polygons. The image on the photo enlargement of the soil survey shows fat, blurry swaths with indistinct edges. Curiously, the photo enlargement is perhaps a truer representation of the soils data than the GIS product. The GIS map gives an illusion of spatial definition, whereas the photo enlargement has generated fuzzy boundaries for soil edges. The problem is not the technology, it is the user who succumbs to the temptation of overlaying data that should not be overlaid, or done so carefully.

The ultimate culprit in this "Catch-22" is our educational system. How many environmental scientists, ecologists, geohydrologists, planners, engineers, and biologists have taken a course in cartography or map interpretation? Few I would bet. With GIS it is easy to make innocent cartographic mistakes that can seriously compromise the accuracy of an analytical product. As GIS becomes firmly entrenched in the workplace, as it should be, we must take special care to ensure the operators of these powerful systems are using the tools appropriately. Some of the topics that GIS users must be aware of include (but are not limited to) the following:

**The Implications of Map Scale**

With hard-copy maps, the scale with which the data were derived and presented are usually marked on the legend of the map. Where do you look for this information when you receive your map on floppy disk? Do you ignore source map scale? Certainly not! At what level of scale enlargement does your GIS dataset become ridiculously inaccurate?

**Sources Of Error**

Just: because the map is derived from a computer does not purge it of error. The quality of GIS data are in many cases only as good as the original analog maps they were digitized from. When you look at a hard-copy map, are you sensitive to the horizontal accuracy of the data (e.g., are the lines in the right place), are all the features present, are they correctly identified? If it is easy to ignore these questions on a hard-copy map, then it will be extremely easy to ignore them when your map consists of a 5 MB data file. Don't blindly include a dataset in your analysis until you know how much confidence you should place in it.

**Coordinate Systems**

Do you know the difference between NAD27 and NAD83? Have you asked yourself what would be the best NAD to reference that new mapping project to? Do you know what a UTM or a State Plane Coordinate system is? Do
FIGURE 1.
On traditional hard-copy maps, the essential details of scale, age, datum, coordinate system, and accuracy are often indicated in the map margins or legend (left). Where do you find this same information when maps are received in digital form (right)? (Illustration by Candace Corbridge, University of Rhode Island).

1953
PHOTOREVISED 1975

THIS MAP COMPLIES WITH NATIONAL
MAP ACCURACY STANDARDS

SCALE 1:24000

you know what coordinate system your GIS data are referenced to? In the world of hard-copy map analysis and manual overlay, these questions may mean little to you. In the era of GIS and digital data integration, these issues are fundamental and must be carefully considered.

Matching the Analysis to the Tool

CAD is a workhorse tool for engineering, drafting, and design applications. On the surface, CAD and GIS resemble each other in that they are both computer programs that can be used to generate accurate-looking maps. The two tools are fundamentally very different. For some mapping applications, either may be used interchangeably. For other mapping projects, GIS is the preferred option. Does your application require that a map dataset contain spatial topology? Do you have complex coding that you need to retain through sequential overlay procedures? Before committing to CAD or GIS (or a consultant's contract) be certain that you are using the correct tool.

If you are not clear on any of the topics above, you might consider some training. There are books, journals, and trade magazines that will help you grasp these concepts. Many colleges and universities teach
courses that are relevant to these issues. Consulting firms frequently offer high-quality training in GIS. These are, however, short-term solutions. In the long run, our educational programs and academic curricula must provide this sensitivity to maps and map data. As digital maps and mapping become part of our everyday lives (just watch the weather man on the evening news), we must begin training tomorrow’s land managers (and GIS users) on the responsible use of spatial data and the appropriate tools for analysis.

Peter August is an associate professor of natural resources science at the University of Rhode Island. He is also the director of the Environmental Data Center, a GIS lab at the university.

"We see it as a form of copy protection."
FEATURE MAP STATEMENT

STATEMENT OF EDITORIAL INTENT

In this issue, the featured map of St Paul's Cathedral crosses the boundaries of traditional (two-dimensional) mapping. This offering, hopefully, will help potential authors think expansively about the term “map.” Alternative three-dimensional perspective maps might allow users to “see” inside buildings, or access facility data.

The Journal continues to seek especially intriguing graphics, or maps that present the final graphic results of worthwhile analysis. Only your imagination and your computer graphic capabilities set the limit.

With the St. Paul’s Cathedral map, we are continuing an ad hoc pattern of featuring an urban map in the Fall issue, and a natural resource map in Spring issues. This pattern reflects the balance among URISA member interests, so we will continue on this course. (See p. 132 for guidelines for Feature Map submission.)

William J. Craig
The Great Cathedral of St. Paul's: Modeling History with Modern Technology
Darrel Foster

St. Paul's Cathedral, located in central London, is nearly three centuries old. Founded in 1673, the structure that occupies the current site is actually the fifth church to fill that site. Its immediate predecessor was destroyed in 1666 by the Great Fire of London that destroyed two-thirds of the city. The original St. Paul's was built in 604 AD.

Present day St. Paul's Cathedral encompasses an area known as Paternoster Square. Each year more than three million people visit St. Paul's and the area surrounding the cathedral. It is one of the most historically significant areas of London. When Paternoster Square fell victim to urban blight, its owners, the Paternoster Consortium, knew it was time for action. They invited a select group of architects to submit a urban master plan for the redevelopment of Paternoster Square. These plans were to include retail space, office space and public areas. One of the guidelines was to create a distinctive architecture that provided an appropriate setting, yet did not compete with the great cathedral at St. Paul's.

Arup Associates, an internationally famous design firm, was one of the firms selected for this competition. They chose to create a three-dimensional map of the cathedral and surrounding area as one way of presenting their plan. The graphics presented here were part of the competition-winning master plan. (The site has since been sold to a new consortium, which has been working up a different proposal.)

Large scale redevelopments like this need to address complex urban issues. The accurate presentation of views from many vantage points is a powerful tool in analyzing these issues, and proved very useful in describing the intentions of the proposals. In this case, in which the site contains perhaps the most famous of London’s landmarks, public response to the proposals became one of the most important issues.

The Site Model

The 3D site map began from 2D base maps. In England, these are known as Ordnance Survey maps and are available in digital form. They are analogous to TIGER and DIME maps available in the United States.

The first task was to remove surplus detail from the 2D base maps. Then a series of closed polygons was created to represent the streets, buildings and other features that would be included in the 3D model. Heights were then added to the 2D graphics, thus creating a 3D model using cost-effective approaches. The heights of less critical buildings were estimated from photographs. For buildings closer to the site, more accurate information was supplied from stereo digitizers and field verification. To get the topology, a 3D terrain model was combined with the building and street model.

St. Paul's Cathedral

The information needed to generate a 3D model of a building is usually provided from floor plans and elevation drawings. These types of drawings were not available for St. Paul's. The data needed to develop the 3D model was gathered from a book, published in 1927 by architect Arthur Poley, called St. Paul's Cathedral: Measured, Drawn and Described.

The cathedral model was developed by modeling individual components in a solid modeling module, such as the dome, columns and clock towers; then combining these individual components using an assembly modeling module. Duplicate components such as the columns were created once and copied.
The following process was used to develop the individual components:

- The designers worked in 2D over the base drawings to develop construction lines.
- They imported the construction lines into the solid modeller to define each 3D component.
- They created the 3D components and saved them to a 3D library.
- They located a projection of the 3D component in a 2D view to determine its position and orientation in world space.
- To check progress, they viewed the site and cathedral in the Scene Viewing System.

The cornice and architrave were created by drawing a cross-section in 2D. Then a path was defined in 3D and the 2D cross-section swept along it.

The completed 3D model of the site and cathedral was assembled in the assembly modeller. Since each building or feature could be represented by a single 3D component, or an assembly of 3D components, detail to the complete model could be added in stages. Individual 3D components or assemblies could be included or excluded from the view as needed.

3D maps in GIS

Traditional GIS systems use database technology for their data repository. The different types of databases available are hierarchal, parent-child and relational. The relational database, with its flexibility and power offers the best alternative for storing textual and numerical data. Database systems typically output reports, and in some cases charts, representing an analysis of the data. To enhance the usability of the data, a more detailed graphical view is needed. Thus, the marriage of database-oriented GIS systems and graphic-based CAD systems has produced a new breed of GIS system—one that provides a powerful, interactive, easy-to-use interface into the database for inputting, retrieving, manipulating and analyzing the data. Also, it has made the information in the GIS system available to a broader base of users. This new “view” of the data maps is easier to understand than textual, numerical reports and simple charts. Maps are specialized drawings, and while they have made the GIS database available to more users, those users need training to understand and interpret these maps.

Besides improving access to the information in the GIS database, the marriage of GIS and CAD systems has introduced 3D to the GIS professional. The realism of three-dimensional views make the data useful to more people. People can relate a three-dimensional view to the real world. As more GIS users see the benefits of 3D it will become more popular. I have seen 3D used with great success when communication with the public is vital—such as in rapid transportation projects.

Why now?

The CAD environment has embraced 3D technology for years. Why is it just now being
recognized as a tool for GIS? Three major reasons: 1) CAD is now acceptable as part of a GIS, 2) the computing power required to drive 3D is now available on a desktop workstation at an affordable price, and 3) 3D algorithms are now contained in firmware providing an interactive environment. Historically, very large computers with special software were required to do 3D effectively. Today, most workstation vendors provide enough power to manipulate 3D interactively in small desktop units. Advances in data collection and data storage technologies also have contributed to the acceptance of 3D in today's GIS work place.

Costs

The initial cost of a GIS system is generally the cheapest part of the overall cost of a system. In addition to on-going costs such as maintenance and training, building a useful database is the major portion of the total system cost. The addition of 3D to the database adds minimal cost to an already expensive data-gathering and data-entry process. Selecting software that has the ability to add this 3D information over a period of time can greatly reduce start-up costs.

Uses of the Data

The real power of a 3D database lies in its ability to represent the data as a real world view. This makes the data simpler to understand. This simpler view of the data makes it more useful to a larger audience of users. Making the GIS system and its data presentable and usable for the general public is one measure of its success.

Once the information is in the database, it is available to the entire user community. Fire and police departments would have access to floor plans of buildings and information on the type of building or the materials stored there. Information would be available about storm-water, sewers and electrical service, e.g., where is it located, what is its capacity, where to shut it off, etc.

Three-dimensional graphics can be dramatic in creating thematic displays. For instance, instead of a simple 2D map displaying the overlap of income to school boundaries, 3D can incorporate the number of children per household in a third dimension. This type of presentation can be very useful for helping school boards appropriate funds for schools or re-defining school boundaries.

Trouble spots in road systems can be highlighted in 3D. Right-of-ways, traffic flow, number of accidents or where repairs are needed can all be indicated graphically. Three-dimensional graphics can help make effective presentations to the public when trying to pass bond issues. Or they can be used to aid decisions on where maintenance dollars should be used for road repairs.

The 3D map of the St. Paul's site is one example of using computer technology to present complex issues in an urban setting in a simple, straightforward way to those most affected: the public. This type of computer-generated 3D technology is becoming a major tool in helping today's GIS professional solve complex problems.

Darrel Foster is the manager of product marketing for the Graphics Design System (GDS) at McDonnell Douglas Systems Integration Company. His duties include the pricing, packaging, promotion and development of the GDS product. He has a degree in architecture from Oklahoma State University and has been involved with computer graphics for more than 13 years.

Acknowledgement

All maps and graphics were provided courtesy of Arup Associates.

References


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STATEMENT OF EDITORIAL INTENT

The reviews section of the URISA Journal provides critical reviews and information concerning publications, information sources, and software in the field of urban and regional information systems. Professionals in this field must draw from a variety of sources and materials to support their activities. Accordingly, this section includes reviews of a variety of information sources that, in general, fall into one of four broad categories:

1. **Book reviews** focus on books relating to the development, implementation, application, evaluation and management of information systems in urban and regional environments. Books written for use in academic settings, as well as those aimed at the practitioner, will be included.

2. **Publication reviews** examine a variety of publications that offer significant contributions to URISA's areas of interest. These will include conference and symposium proceedings, reports, resource papers, monographs, technical publications, resource directories, workbooks and development guides and manuals related to urban and regional information systems issues.

3. **Video reviews** provide another review category. Videotapes are becoming a popular tool for education and information dissemination, particularly in the area of geographic information systems. The URISA Journal will include reviews of new videos that could be useful information sources or tools for Journal readers.

4. **Software reviews** are intended to help readers become aware of software that could aid them in their work, and to help them choose the right software by reviewing it from a URISA professional’s viewpoint.

   As with all reviews, software reviews express the opinions of the authors. The publishers of commercial software will be given the opportunity to check review drafts for factual errors, but cannot change opinions expressed in the reviews. URISA Journal does not encourage complimentary submissions of software for review. We prefer that software publishers identify expert users of their software and then encourage them to write a review. Potential reviewers are encouraged to evaluate programs they use frequently, decide whether those programs would be of interest to Journal readers, and find out if the programs have been adequately reviewed elsewhere. Many programs useful for our professions are not reviewed, or are reviewed by journalists, rather than by members of our professions.

   The software reviews are categorized as follows:

   - **In-Depth**: Detailed reviews of substantial programs. An In-Depth Review covers areas including ease of use, performance, and support. A program summary and overall rating complete the review.
   - **Head-to-Head**: Program comparisons that take a class of programs such as thematic mapping software, introduce each package, compare their strengths and weaknesses, and discuss their use.
   - **From the Inside**: Explanations of non-commercial programs by their creators, to inform readers about program capabilities and encourage use of the programs.

   In addition to submissions of book, publication, video and software reviews, we welcome suggestions and insights pertaining to the identification, critical review, and recommendations of all information sources in the field of urban and regional information systems. (See p. 131 for guidelines for submission of review materials.)

Rebecca Somers
Peter Van Demark

URISA Journal 107
BOOK REVIEWS

An Introduction to Geographic Information Systems

Reviewed by Allan H. Schmidt

Two years ago when I first saw a draft of Chapter 7 from Bill Huxhold’s book, I was struck by the way in which geographic information systems (GIS) were described as a natural extension of traditional information system activities of an urban government rather than as a special-purpose computer application developed and administered outside of existing governmental information system activities. Clearly, initial GIS activities within an urban government are likely to be developed within one department to serve a specific requirement, but this is not the way in which GIS has or will contribute most effectively to the needs of urban government.

Huxhold emphasizes that a GIS provides a means to increase the effectiveness of existing urban information systems. Increased effectiveness results from the ability of GIS to make information available across urban government functional boundaries. This is in contrast to increased efficiency that normally results from GIS in support of a single-purpose application such as automated map preparation.

Huxhold believes that GIS developers can benefit from the experience of other information system professionals and begins his book with a chapter entitled “Information in the Organization.” He describes the evolution of urban information processing from the 1960s, and the prevalent emphasis on transaction-based systems, to the emergence in the 1970s and 1980s of database systems designed to serve multiple governmental functions and share common data among departments.

He points out, however, that development of a database system for multiple users requires knowledge of all users’ requirements, development and acceptance of data standards, and creation of adequate documentation. It also imposes a long development cycle.

The goal of an urban information system, he notes, is not only to meet the operational needs of individual departments, but to do so with standards and flexibility that allow data integration with other data serving multiple operational functions. In addition, an information system requires an ability to aggregate and summarize operational data for assimilation at management and policy-making levels.

In the second chapter entitled “GIS Defined,” he points out that maps are a natural form of output from a GIS, just as reports are from any information system. However, a unique feature of a GIS is its ability to identify relations among mapped features. He states that GIS professionals must integrate information collected by different government functional units, thereby increasing each unit’s potential effectiveness in delivering governmental services.

This chapter also includes a very good summary of the characteristics and differences among flat, hierarchical, and network files versus relational databases.

Chapter 3, “Applications of GIS,” describes a rich collection of applications for which Huxhold was responsible in the city of Milwaukee from 1976 to 1990. They include map updating, zoning, reapportionment, building inspector workload balancing, and solid waste collection routing. Public policy analysis applications include housing code violations, tax delinquency, liquor license applications, lead poisoning, and library facility planning.

The fourth chapter, “Topological Data Structures,” contains an overview of graphic point, line, and area feature data and how such features are linked to their non-graphic attribute data.
Chapter 5, "Geographic Base Files," discusses geocoding procedures with particular emphasis on the use of street addresses as a common geocode for most urban data. Specific geographic base files discussed, which allow for use of addresses, include the U.S. Census Bureau's DIME and TIGER files.

Chapter 6, "Land Records Information," provides an extensive discussion of cadastral and planimetric maps and the reasons why data from both types of maps when overlaid will often be inconsistent. This leads into a discussion of base map accuracy and the underlying characteristics of survey networks including local surveys, public land surveys, geodetic surveys, the North American Datum, and GPS technology.

Chapter 7, "The Model Urban GIS Project," is the most interesting chapter because it reads like a prescription for how to develop a multipurpose urban GIS prepared by someone who has had that experience. Creation of an urban GIS implies a commitment to provide continuing support for the operational needs of urban government, i.e., to become an institutional part of the local government information system. Huxhold urges the reader to become familiar with generally accepted information system methodologies that have been used for years in the information systems industry to ensure that new technology will successfully support the long-term goals of an organization.

Huxhold identifies three critical success factors for developers of an urban GIS:

• Evaluating information needs
• Gaining organizational support
• Managing the GIS project

He discusses major issues that you must address in each of these three areas.

Evaluating geographic-information needs requires developing a long-range GIS plan. Such a plan should be based upon the goals of the local government it serves. Having identified and prioritized those goals, the GIS developer then can identify the governmental functions which support those goals, describe the facilities and entities related to those functions, and determine the attributes of the facilities and entities. This activity does not take the place of, but should precede, a geographic-information needs study.

To gain organizational support for a proposed GIS, Huxhold recommends and discusses preparation of a cost-benefit study and a pilot project. Also included is a discussion of justifying the GIS project, likely objections and how to deal with them. A sobering and insightful list of 12 recommendations for information system designers by James Martin also is provided.

When discussing the management of a GIS project, Huxhold outlines the procedures involved in base map creation, the ten types of jobs required for GIS implementation and operation and how these differ among the project study phase, the implementation phase, and the operational phase. Long-term operations take on the characteristics of a traditional local-government data-processing function with the attendant need to compete for scarce government resources by cost-justifying not only initial promises but also subsequent delivery of cost-effective services.

Overall, I found this to be a very unusual book. It is not intended to be a source of esoteric spatial analytic technique but rather a description of what has worked successfully for the past 15 years in the city of Milwaukee. As such it reads like a story from the trenches. As Huxhold points out, he was doing GIS before the process was given that name. A recent employment advertisement in the URISA Newsletter by Huxhold noted that Milwaukee does not talk about GIS, they do GIS.

It is obvious that the successful introduction of a new technology such as GIS requires the presence of a local advocate who will serve as a champion and assume responsibility for the three critical success factors of evaluating information needs in relation to the goals of the locality, gaining organizational support from all levels of government, and managing the GIS project from start to finish. Many have attempted the feat; Huxhold has met the challenge and now has written a valuable book that allows him to share with us a small but invaluable part of his experience.

The book has been published by Oxford University Press as part of their series on spatial information systems edited by Messrs. P.H.T. Beckett, M. Goodchild, P.A. Burrough, and P. Switzer. It includes problems and questions at the end of each chapter but does not require use of a computer. If a
student of city planning, geography, or urban administration reads only one book related to urban geographic information systems, I would heartily recommend this one. It also deserves to be read by others interested in doing urban GIS.

Allan H. Schmidt is an independent GIS consultant working with Schmidt Associates in Concord, Massachusetts.
Mapping the GIS Way: Three Vendor Handbooks
Reviewed by Peter Van Demark

An interesting genre of book has appeared on the scene: handbooks, written and published by vendors of GIS software, to show users or potential users what can be done with their software. They are not distributed as part of the documentation but are available separately, at cost.

This review will look briefly at three members of this genre, compare and contrast their approaches, and conclude with some comments on the needs for and uses of these handbooks.

Desktop Mapping: The MapInfo® Way

This 117-page paperback book, available from the MapInfo Press ($9.95), is termed "a primer on the new technology for data visualization and analysis" and "the desktop mapping approach to data visualization."

It was edited by Dr. William Benson, with contributions from the staffs of MapInfo Corp. and Consultech Communications, and printed in November 1990.

A brief description of what desktop mapping is, and how a geographic picture of your data can revolutionize the way you work, the book has three main sections. The first has ten highly varied case studies on how people are actually using MapInfo (one is missing from the table of contents). The examples include analyzing the pattern of distributors for a Fortune 500 company, preparing maps of AIDS trouble spots for monthly meetings with outreach workers, and doing emergency response dispatch and data analysis. They even have users doing cemetery management and brain mapping!

The next main section, after defining maps and map data in MapInfo's terminology and differentiating vector and raster representations, shows what MapInfo can do: display and edit map and tabular data, do geocoding, make thematic maps, conduct geographic searches, locate objects by name, etc. The topics are a mixture of the commands in the program, like panning and zooming, and applications that can be carried out with the program, such as manage territories. Like all the sections, there are many maps and large pull-quotes to bring points home.

The discussion mixes capabilities of the older MapInfo for DOS and the extended capabilities of the graphic user interface family of newer programs that includes MapInfo for Macintosh and MapInfo for Windows. The authors distinguish the features of the old and new programs, but there is still the possibility that the reader will confuse versions and find that the one that was selected does not have certain features.

The final section describes all of the map and tabular data, for the United States, Canada and the world, available at cost from MapInfo Corp., as well as how to import your own map and tabular data. The book ends with a brief history of the company and a last pull-quote to indicate the company's goal: "Empowering people to manage information more effectively and efficiently through graphics™."

The book is written in the company's typically breezy, journalistic writing style. It is more a marketing piece than a how-to book. Your appetite is whetted, but you cannot try the program out. Many vendors, for $10 or less, will send you a demo diskette with a crippled version of the program and a manual. But the book does a very good job of telling you what desktop mapping is, how MapInfo does desktop mapping, and what desktop mapping can do for you.

Desktop Mapping for Planning and Strategic Decision-Making

This approximately 200-page, spiral-bound book was released in mid-1989 by Strategic Mapping, Inc. ($40 with two diskettes). The primary authors
are Robert Laserna, then a Ph.D. candidate, and Dr. John Landis, an assistant professor at the University of California, Berkeley, with help from the staff of Strategic Mapping. It was published before ATLAS*GIS™ was released, so it describes how to use ATLAS*GRAPHICS™, a thematic mapping package, and ATLAS*DRAW™, a geographic base file editor/analyzer. The diskettes contain example data; the reader is assumed to have copies of the programs to carry out the lessons.

The first three chapters give background information. Chapter 1 describes the basics of computer mapping, explaining how the programs store map data and relate it to tabular data. The second chapter focuses on desktop mapping, comparing that class of program with simple thematic mapping, CAD, AM/FM, and GIS programs, and discussing the capabilities and the relative benefits. Chapter 3 lays out the “desktop mapping process.” Planning a project is shown as a seven-step process, thematic mapping is explained in ATLAS*GRAPHICS terms, and some design guidelines are given.

The fourth chapter gives an overview of the ten examples, grouped into three sets: four on thematic mapping, four on geographic information analysis, and two on advanced applications. A table shows, for each example, the software, key variables, map units, presentation, map type, graphic display, analytical model, and similar applications. Some of the examples are: thematic mapping for sales area analysis for a photo developing shop that is considering expanding in the San Francisco area; analysis of target areas for test marketing of a line of frozen cajun entrees in Southern California; and notification of parcel owners within 300 feet of a proposed zoning change in Putnam City (actually parcels in downtown Rochester NY).

The remaining ten chapters detail each example. First the authors lay out the situation, the goal, and the tasks for executing the analysis. The details of the analysis are a keystroke-by keystroke explanation of what to do to perform the example. Illustrations, some in color, show what the resulting displays and maps should look like. Each example ends with an analysis of the results, limitations of this sort of analysis, and other applications of this approach.

The book fills a need for ATLAS*DRAW and ATLAS*GRAPHICS users who want more how-to suggestions than what can be covered in the program documentation. The result is very polished: clear, well-organized, and immediately useful. The 5.25”, 360KB MS-DOS diskettes include all the necessary files, including those that the reader could have created with optional tasks if they own any of three other programs: Lotus 1-2-3™, Ashton-Tate dBASE III+™ or SPSS/PC+™. With considerable translation, the reader could use the book with ATLAS*GIS; hopefully Strategic Mapping is planning a second book that shows the variety of applications of that package.

**PC Understanding GIS: The ARC/INFO® Method**

This spiral-bound book of approximately 500 pages, published in mid-1990, comes from Environmental Systems Research Institute, Inc. ($50 for the workbook, $25 for the training data diskettes in a choice of formats). David Rhind, Theresa Connolly and Birbeck College, University of London compiled portions of the book for ESRI. The book’s purpose is to “teach you the basics of geographic information systems (GIS) in the context of completing an ARC/INFO project.” By showing how to plan and carry out a typical
ARC/INFO analysis, it hopes you will be able to extend the methodology to your own projects. If done by following every step on the computer, it is estimated to be a 40-hour course. I read it in about eight hours.

The first lesson explains what a GIS is and what it can do. A brief step-by-step exercise illustrates the concept using prepared data on the training data diskettes. The second lesson describes a GIS in general and ARC/INFO in particular. Lesson 3 discusses project design, and presents the project: to locate an aquaculture laboratory in a coastal farming area with a site that is large enough, has the right soils, is brushland (not forested or farmed), is near sewer lines and is away from streams.

The remaining lessons take the phases of the project and show how they are carried out: getting spatial data into ARC/INFO, by digitizing a missing portion of one coverage; making spatial data usable, by generating the topology and editing out mistakes; getting attribute data into ARC/INFO, by using the built-in relational database patterned after dBASE III (the lessons can also be done with training data for the INFO version of PC ARC/INFO); managing the database, by tiling, projecting and edgematching maps; performing geographic analysis, by generating buffers, doing polygon overlay, and selecting areas based on tabular analysis; and presenting the results of the analysis, by designing a map and a report.

A final lesson shows how to customize ARC/INFO, by using the Simple Macro Language (SML) to write functions and access them from a menu. A short "What next?" chapter includes suggestions such as joining URISA. Five appendices include the map to be digitized, answers to written exercises and some examples of maps created with ARC/INFO, several in color. A 12-page glossary of terms and an eight-page index complete the book.

The organization and quality of writing are excellent, as are the illustrations. ESRI sets very high standards with their publications, and this one continues the standard. References are made to other sections of the workbook and to additional readings. Repetition is used often to reinforce the methods, so that you learn not only how to use ARC/INFO, but also how to ensure that projects will go smoothly and achieve the desired result.

Since ARC/INFO is so broad, not all of the capabilities in all of the modules could be covered. PC NETWORK, with address-matching, routing and allocation functions, is not even mentioned. This could give the false impression that GIS means buffering and polygon overlay. The products of the other two companies that are described in the previous books cannot even do buffering and polygon overlay, yet they have GIS functionality. But if you want to learn about those techniques using ARC/INFO, this book will teach you without having to attend a workshop.

Summary

These books are like night and day, in length, detail, approach, style—in fact, by any measure. Two come with data, one charges extra for the diskettes, two show a variety of applications. one assumes you do not have the program, two give step-by-step instructions on running the program you do have, and the list goes on.

The thing that holds them together is that they describe the GIS elephant from their side of the beast, and show how varied a field this is. The potential applications are many, and therefore there are many software attempts to address those needs in ways that users can really relate to. All three vendors have taken a stab at personal computer software for solving spatial problems, and each has been successful in targeting a market. These books play to those markets.

If you are considering spending over $500 for a version of MapInfo, it is wise to spend $10 to see if it will do what you want (though you may get the same information for free from reviews and product literature). If you already have one of the other programs but are a novice user, those books will help you to be productive in a very time and cost-effective way. Other vendors should be encouraged to look to academics to pull together handbooks of this sort, to help users just before or just after the purchase of a GIS.

Peter Van Demark is an associate research analyst cartographer at the Center for Governmental Research Inc. in Rochester NY. He has been a member of URISA since 1977, and he is Reviews co-editor of the URISA Journal.
In recent years, the development and use of GIS technology has become an important part of the mission at all levels of government, as well as the private sector. With the rapid increase in GIS awareness and use has come a parallel increase in the demand and supply of materials to assist in the education and training of professionals who will develop and support GIS.

As government officials, planners, program managers, environmental scientists, and researchers in many fields look for ways to improve the quality and timeliness of their work activities, this book of readings will find a ready audience.

Compiling a set of readings is never an easy task. Doing so for a topic like GIS that is both relatively new, and at the same time, applicable to such a wide area of applications, is doubly difficult. However, the editors have provided some useful guides that help make the compiled material as useful as possible. The preface to the book indicates that the readings are intended as a supplementary reader for use in an introductory, upper-division or graduate-level course in GIS, as well as for practicing professionals who wish to learn more about this technology. This book is an ambitious undertaking. The result is a mix of authors and materials that range from readable “feature-type” articles to highly technical articles that will likely challenge many readers.

At present, written materials on GIS tend to be scattered, as many unrelated disciplines have begun to experiment with and use this technology. Newer periodicals, such as the URISA Journal and GIS World that focus on GIS, have not yet become as widely available as older, more established journals and proceedings.

The 26 papers in the book are grouped into five major topic areas, allowing the reader to focus on or skip blocks of material as he or she sees fit. (This attention to “indexing” also will facilitate the use of Peuquet and Marble as a reference book, as many readers will want to do.) Further, each of the five sections begins with a two- to three-page introduction that attempts to integrate the papers in the section, and provides a list of additional references on the topics covered. This should be especially helpful to many readers who will be using the book without a companion textbook.

To make this book easy to use, the editors have provided guides to aid the reader in deciding what material to read, which to skip until later, and to help locate relevant materials as quickly as possible. For example, every reader should carefully read the four-page preface and introduction. These sections provide an overview of the capabilities of GIS technology, as well as a “map” of the entire book, highlighting the location of subjects and particular papers.

The ultimate usefulness of each section and its papers will depend on, among other things, the background of the reader. Those readers wanting an overview of GIS will appreciate the four articles in Part I that define GIS. An article by Tomlinson provides a crisp summary of GIS over the last 20 years and suggests a number of problem areas for which developers of GIS should be alert. The article by Dangermond provides an overview of the various GIS software components. This thorough, descriptive article provides both narrative and
graphic descriptions of various analytical and data processing functions that are typically performed in a GIS. The reader will find the graphics presented in this paper particularly helpful.

Part II, to which the editors devote over one-third of the book, contains 10 articles that describe applications of GIS technology. Of particular interest to anyone performing analyses on 1990 census data are the three papers on the DIME and TIGER databases that have been developed by the U.S. Bureau of the Census. Given the interest to date in using the TIGER files as a GIS database, the discussions by Marx and Sobel will be especially welcome. They describe how the TIGER system was built, linking U.S. Geological Survey 1:100,000 map data with census attribute data, to produce “an integrated geographic database for the entire United States.” It seems likely that this database, combined with appropriate GIS software, will indeed “form the basis for much of the urban [and rural] spatial data processing in the 1990s.”

Shorter sections of the book are devoted to:

- Building a database and the problems one is likely to encounter (four papers).
- The internal workings of a GIS, including data representation and analysis techniques (four papers).
- Materials to aid those who must design and/or evaluate GIS for use in their agency or business (four papers).

Of particular interest in the section on internal aspects of GIS is a paper by Vrana that raises and discusses the issue of temporal data—a topic that has been largely ignored in the GIS community until the very recent past. Vrana’s discussion of three prototype land information systems and the common themes and problems he identifies should be of interest to many researchers and managers who are responsible for resource management, land ownership, and land use planning activities.

URISA members will recognize one of the papers in the evaluation section, by Roitman and Epstein, on the liability for information. This paper appeared in the 1987 URISA Proceedings and it is just as timely today as when it first appeared.

The editors acknowledge that some of the material will become dated fairly quickly. This concern is real, even for some of the newer material on databases and data representation. An update in the form of a postscript or an introductory note would have improved the usefulness of some papers. For example, under the application section, the editors include a long 1979 paper on the MAGI (Maryland Automated Geographic Information) System. An update on MAGI would have been useful:

- What is the current operating status of MAGI?
- Which applications are still in operation?
- What applications have been abandoned and why?
- What are the updated cost data for the system?
- Has the software system been changed?
- If so, to what, and what conversion problems were encountered?

Not only would this information answer the questions that might arise in the reader’s mind, but would add longevity to the book and aid the reader in comprehending the rapidly changing GIS fields.

As in most such paper anthologies, readers will find that style, readability, and amount of background assumed by the authors vary widely. This is a relatively small inconvenience relative to access to a good collection of papers that will serve as a valuable reference for the relative newcomer to GIS. It also will serve well the more experienced analyst who wants to delve further into the ever-expanding field of GIS.

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SOFTWARE REVIEW

Head-to-Head: AutoCAD-Based GISs
Alan A. Lew

AutoCAD® from Autodesk Inc. is the most widely used computer-aided drawing and drafting (CAD) program in the world. It was introduced in 1984 as the first professional microcomputer-based CAD program to compete with the mainframe computer-based systems that dominated the field of professional computer drafting at the time. Frequent upgrades from Autodesk, have secured its industry lead, despite formidable competition.

As powerful as it is, AutoCAD by itself is essentially a general application drawing and drafting program. It automates the ruler, pen and ink process. While mastering advanced commands that enable complete control over the drafting environment may take time, rudimentary commands can be learned quickly and easily. These features have made AutoCAD a popular drawing front-end to many geographic information systems. Environmental Systems Research Institute (ESRI), for example, recently found that 17 percent of its 10,000 ARC/INFO® users also use AutoCAD. Drawings are drafted in AutoCAD to take advantage of its power and ease of use, then imported into ARC/INFO where attribute (tabular) data are attached and cartographic modeling facilitated. Most geographic information system (GIS) programs are able to both import and export drawings in AutoCAD's DXF (drawing interchange file) format, while many other graphics programs recognize AutoCAD slide files.

This review examines the relationship between AutoCAD and GIS. Database characteristics of AutoCAD itself are discussed first. This is followed by reviews of three GIS-related products that operate from within the AutoCAD program: GIS Manager from DCA Softdesk (formerly DCA Software) Inc.; FMS/AC™ from Facilities Mapping Systems, Inc.; and Geo/SQL™ from Generation 5 Technology, Inc. All of these programs use entirely vector-based graphic data structures. Geo/SQL and FMS/AC have topological data structures; GIS Manager uses the topology built into ARC/INFO.

AutoCAD

By most definitions, AutoCAD is not a geographic information system. It can, however, simulate a rudimentary automated mapping and facilities management system. This is accomplished by attaching AutoCAD "attributes" to "blocks." Blocks consist of any combination of point, line, polygon drawing entities. For example, a line entity representing a water pipe can have a list of attributes attached to it, which include date of installation, pipe size, material, and last repair date. If the list is not lengthy, AutoCAD by itself may prove to be a sufficient environment in which to store attribute data. Attributes can be displayed or hidden from view, and they can be edited. AutoCAD attributes can also be extracted into an ASCII file (either comma or size delimited) for more sophisticated database, spreadsheet, or report manipulation. Several third-party programs take advantage of this export capability to automate the process of moving attribute data into popular database programs, or specialized report forms (such as compiling a bill of sale).

Simple map overlay analysis, similar to the hand-drawn maps of Ian McHarg's Design with Nature (1969), can be readily accomplished in AutoCAD by placing different environmental variables on separate layers. The areal extent of each feature can be hatched using different patterns and colors. Layers can then be turned off and on (or "frozen" and "thawed") to accomplish simple geographic overlay modeling.
GIS Manager

Earlier versions of AutoCAD (through version 10) allowed accessing external LISP programs to enhance the capabilities of AutoCAD. These programs would temporarily suspend AutoCAD as they were run. With the recent release of version 11, AutoCAD now allows C-binding. This will allow external programs written in C to become an integral part of the AutoCAD operating space.

Many third-party software developers have long taken advantage of AutoCAD's open environment to add specialized features to the program's basic functions. The most common special applications are in the fields of architecture, engineering, and construction (sometimes referred to as AEC). DCA Softdesk, Inc., provides some of the more popular third-party AutoCAD programs. Among the major enhancements which DCA's software provides AutoCAD users are: surveying aids, coordinate geometry, structural and architectural design, site design, highway engineering and design, digital terrain modeling, and earthwork (cut and fill) modeling.

DCA introduced a new product in 1990 called GIS Manager. In some ways, GIS Manager functions in a similar manner to other programs which assist in connecting AutoCAD attributes to an external database management system (DBMS). However, it goes beyond that simple task by focusing specifically on GIS applications.

GIS Manager allows quick access to ESRI's PC ARC/INFO coverages from within AutoCAD. The user enters AutoCAD and loads the DCA menu (which replaces the standard AutoCAD sidebar and pull-down menus). The DCA menu allows access to all of DCA's add-on modules (listed above), as well as GIS Manager. With a couple of clicks of a mouse or tablet cursor, GIS Manager becomes active. This process temporarily shells the user out of AutoCAD and into the GIS Manager screen.

Once within the GIS Manager screen, the user first selects the mode of operation. This controls how the polygons will be displayed and whether single or multiple coverages and attributes are to be selected from the PC ARC/INFO files. The user then selects the drive and subdirectory containing the PC ARC/INFO application files. The program automatically searches the selected drive and lists all the valid ARC/INFO subdirectories. After selecting the desired subdirectory, a list of coverages appears followed by a list of coverage types (lines, polygons, or points). These last two steps are repeated if more than one coverage is desired.

GIS Manager has its own graphics display for showing the PC ARC/INFO coverages. Depending on the graphic card and monitor in use, the graphics within GIS Manager are likely to be of a lower resolution than that in AutoCAD. The GIS Manager display allows the user to zoom in and out, list attributes, and make basic distance and area measurements. However, no changes can be made to the drawing or its attributes.

The graphics on the GIS Manager screen can be easily exported to AutoCAD (by way of a transparent DXF format conversion), or to an ASCII x, y, z coordinate file. The z coordinate in the latter can reflect the values of any numeric attribute and may be used for DTM contour mapping. Attributes alone may be converted to a comma delimited ASCII file or as a dBASE III compatible file. GIS Manager allows the user to select only desired attributes for export.

To look at the coverages and attributes from within AutoCAD, the user selects the AutoCAD DXF conversion, then exits the GIS Manager screen. This pops the user back into the AutoCAD screen, performs the conversion of ARC/INFO coverages into a DXF file, and inputs the DXF file into AutoCAD. Each imported coverage is drawn on a separate AutoCAD layer. The selected attribute variables become AutoCAD attributes. They may be listed and edited through an editing window, as with any AutoCAD attribute. Displaying attributes on the drawing itself can be a problem because the attribute labels for any one object are all situated on top of each other. ARC/INFO point objects become AutoCAD points, and curved lines become chords (a series of straight lines) instead of AutoCAD arcs (lines defined by radius and length). Sophisticated cartographic modeling operations can be performed on the attribute data.
from within AutoCAD, if the user also owns DCA’s DTM or COGO programs, or other third-party software.

Because of its display capabilities, GIS Manager can also be used independently of AutoCAD for a quick perusal of PC ARC/INFO files, or to convert PC ARC/INFO information into any of the four export formats described above. DCA’s goal is to develop GIS Manager to become a seamless window between AutoCAD and PC ARC/INFO. In its present form, GIS Manager is a valuable tool for AutoCAD users who need to gain quick and easy access to the PC ARC/INFO files. However, it does not provide the same link to AutoCAD for PC ARC/INFO users. What it does provide the PC ARC/INFO user is a quick, simple, and highly intuitive vehicle for viewing PC ARC/INFO coverages. This ability alone is a great benefit to any ARC/INFO installation site.

GIS Manager can be used on a network, allowing multiple users to access the same ARC/INFO files. The manual is simple to follow and requires no special training other than basic DOS familiarity. The next release of GIS Manager (due mid 1991) is planned to add the capability of exporting AutoCAD drawing and attribute files to ARC/INFO. However, ESRI is also developing its own enhancement to interface ARC/INFO with AutoCAD. ARC/INFO v5.1 will be able to transfer files directly into and out of AutoCAD. It is uncertain how this will impact GIS Manager, although DCA is a silent partner in the development of this capability. With the enhanced ARC/INFO-AutoCAD interface, the other GIS programs evaluated here may become even more popular in enabling AutoCAD to serve as a graphic front end for ARC/INFO. In addition, DCA is evaluating the possibility of supporting similar links to other GIS databases.

FMS/AC

While GIS Manager is primarily a GIS interface for AutoCAD, Facilities Mapping System for AutoCAD (FMS/AC) comes closer to being a true GIS. When FMS/AC was introduced in 1986, it was the first GIS dedicated to operating within the AutoCAD environment. As such, it has the largest number of users of all the programs reviewed here. The program is sold in a number of different modules, each of which is purchased separately. These include: Parcel records, Street maintenance, Sanitary sewers, Water supply, Storm drainage, Street lighting/signage, Building/leasing, Natural gas, Electric utility, Land use planning (map overlay/polygon processing), and Census. Network connectivity (tracing/flow analysis) is also available.

The basic FMS/AC program contains AutoCAD templates (pull down menus) for each of the modules available. The standard AutoCAD templates are consolidated into a single pull-down menu. Each module’s template reflects a fully configured graphic database and attribute database. The graphic database comes with pre-defined layers (for parcels, streets, topographic land base, water supply, etc.), as well as pre-defined drawing symbols (for manholes, pipes, valves, meters, etc.). The components and structure of one of the graphic databases (Parcel) are shown in Table 1. The Parcel module contains one of the
TABLE 1.  
FMS/AC Parcel Graphic Database Structure.

<table>
<thead>
<tr>
<th>Graphic Component</th>
<th>Layer Assignment</th>
<th>Line Type</th>
<th>Color</th>
<th>Symbol Name</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boundaries</td>
<td>PARCEL</td>
<td>Continuous</td>
<td>Yellow</td>
<td>PAR-TAG</td>
</tr>
<tr>
<td>Right-of-Way Lines</td>
<td>ROW</td>
<td>Continuous</td>
<td>Blue</td>
<td></td>
</tr>
<tr>
<td>Parcel Identifier Tag</td>
<td>PAR-TAG</td>
<td>Continuous</td>
<td>Yellow</td>
<td>PAR-ATT</td>
</tr>
<tr>
<td>Variable Attributes</td>
<td>PARTEMP</td>
<td>Continuous</td>
<td>Red</td>
<td></td>
</tr>
<tr>
<td>Easements</td>
<td>EASEMENT</td>
<td>Dashed</td>
<td>Green</td>
<td></td>
</tr>
<tr>
<td>Temporary Parcel Edge</td>
<td>PAREdge</td>
<td>Continuous</td>
<td>Red</td>
<td></td>
</tr>
<tr>
<td>Parcel Hatching</td>
<td>PARHATCH</td>
<td>Continuous</td>
<td>Blue</td>
<td></td>
</tr>
<tr>
<td>Parcel Highlighting</td>
<td>PARMARK</td>
<td>Continuous</td>
<td>Red</td>
<td></td>
</tr>
</tbody>
</table>

smaller graphic databases and primarily uses different layer assignments to distinguish variables. The Gas utility module, by contrast, contains 29 different graphic components (valve, regulator, meter, flange, etc.) all of which are on the same layer. In this instance, each component is distinguished by using a different symbol.

Attributes associated with the graphic components are stored in a non-graphic relational database. FMS/AC will work with any data that has been saved in an ASCII fixed-length file. Table 2 shows the structure of the non-graphic attribute database of the Parcel module. Data for these variables may be entered using an external database or spreadsheet, or may be entered from within FMS/AC which temporarily shells out of AutoCAD into the FMS/AC database manager.

A menu-driven report generator in the FMS/AC database manager enables the user to redefine and rearrange the pre-established attribute fields. For example, the parcel module is especially suited to defining polygon data. This module comes with the variable fields shown in Table 2 already defined. The user, however, may change the name and characteristics of any attribute. Instead of cadastral and assessor parcel information, the new parcel module could be used to manage totally different areal features such as forest land cover, soil types, or census tracts. Changes made through the report generator are only stored for the current application (which has its own subdirectory). Source code is also available to users familiar with Ashton Tate's dBASE (TM) programming to implement more advanced customizations, such as adding fields and linking tables.

Continuing with the example of the Parcel module, Figure 1 shows the pull-down menu template that would be accessed from within AutoCAD. Note that AutoCAD provides two different menu options: pull-down menus and sidebar menus. Most standard AutoCAD commands may also be selected from a plastic template placed over the digitizing tablet, or by typing them directly in from the keyboard. Across the top of Figure 1 are the names for nine of the FMS/AC templates which have replaced the standard AutoCAD pull-down menus. The Help menu provides several illustrated help screens. These are provided as a quick mnemonic device for users who already have some proficiency in the use of FMS/AC. A pull-down menu entitled "Basic" provides access to standard AutoCAD commands. All the other pull-down menu templates contain similar functions to those shown in Figure 1, with minor variations specific to the module with which it is associated.

The first four items in the pull-down template menu relate to building both the graphic and attribute databases. The second set of menu choices manipulate variables associated with specific graphic objects on the map. "Extract" copies the attribute data shown on the map into an external ASCII file. "Merge Variable Attributes" places attribute data onto a temporary layer (e.g., the PAR-TEMP layer of the graphic database in Table 1) for display.
TABLE 2.
FMS/AC Parcel Non-graphic Database Structure.

<table>
<thead>
<tr>
<th>Attribute</th>
<th>Length</th>
<th>Range</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>PAR-NO</td>
<td>15</td>
<td>1-15</td>
<td>Assessor Parcel Number (NNN-NN-NNN)</td>
</tr>
<tr>
<td>PAR-ADDR</td>
<td>20</td>
<td>16-35</td>
<td>Address (w/concatated street name)</td>
</tr>
<tr>
<td>PAR-S-ID</td>
<td>10</td>
<td>36-45</td>
<td>Street Segment ID</td>
</tr>
<tr>
<td>PAR-OW</td>
<td>23</td>
<td>46-68</td>
<td>Name of Property Owner</td>
</tr>
<tr>
<td>PAR-LV</td>
<td>10</td>
<td>69-78</td>
<td>Assessed Land Value</td>
</tr>
<tr>
<td>PAR-JV</td>
<td>10</td>
<td>79-88</td>
<td>Assessed Value of Improvements</td>
</tr>
<tr>
<td>PAR-PV</td>
<td>10</td>
<td>89-98</td>
<td>Assessed Value of Personal Property</td>
</tr>
<tr>
<td>PAR-RN</td>
<td>10</td>
<td>99-108</td>
<td>Recordation Number</td>
</tr>
<tr>
<td>PAR-UC</td>
<td>5</td>
<td>109-113</td>
<td>Assessor Land Use Code</td>
</tr>
<tr>
<td>PAR-UN</td>
<td>5</td>
<td>114-118</td>
<td>Total Residential Units</td>
</tr>
<tr>
<td>PAR-BY</td>
<td>5</td>
<td>119-123</td>
<td>Base Year of Parcel Assessment</td>
</tr>
<tr>
<td>PAR-AR</td>
<td>9</td>
<td>124-132</td>
<td>Parcel Area (square units)</td>
</tr>
<tr>
<td>BL:Orient</td>
<td>3</td>
<td>133-135</td>
<td>Angle for Display of Attributes next to Tag</td>
</tr>
<tr>
<td>PAR-FA</td>
<td>20</td>
<td>136-155</td>
<td>Auxiliary Factor A (user defined)</td>
</tr>
<tr>
<td>PAR-FB</td>
<td>20</td>
<td>136-155</td>
<td>Auxiliary Factor B (user defined)</td>
</tr>
<tr>
<td>PAR-FC</td>
<td>20</td>
<td>136-155</td>
<td>Auxiliary Factor C (user defined)</td>
</tr>
<tr>
<td>BL:X</td>
<td>11</td>
<td>196-206</td>
<td>Easting Coordinate (two decimals)</td>
</tr>
<tr>
<td>BL:Y</td>
<td>10</td>
<td>207-216</td>
<td>Northing Coordinate (two decimals)</td>
</tr>
<tr>
<td>PARMHANDLE</td>
<td>8</td>
<td>217-224</td>
<td>Unique ID Number assigned by AutoCAD to the Parcel Tag</td>
</tr>
</tbody>
</table>

These attributes may have been selected through either a database search or spatial search of the graphic screen. For example, the assessed property value may be displayed for all parcels with base-year assessments prior to 1980 within a two mile radius of a selected school. The temporary layer may be turned off using standard AutoCAD commands or “Clear Variable Attribute Tags” from the FMS/AC menu. Similarly, “Marked” parcels are highlighted in response to a query search. They become red by being temporarily copied on the PARMARK layer of the graphic database (see “color” in Table 2).

In addition to the nine standard pull-down menus, there is also a “Base Map” sidebar menu. This allows for entering roads, street names, tree, topo lines, hydrology, and other base map features onto separate, pre-defined AutoCAD layers.

At an additional cost, FMS/AC users can purchase the network connectivity capabilities of the Sanitary sewer, Water supply, Storm drainage, Natural gas, and Electric utility modules. This feature adds another set of commands to these pull-down menu templates to allow tracing up or down a network line, pipe, or circuit. By interactively adding a new line, and turning valves and switches on and off, the user can test a series of “what if” scenarios on linear system networks. This is an important capability for identifying problems and preventing over-capacity in public utility system lines. The database attribute records pertaining to the network trace can also be extracted for further analysis.

There is one more capability that can be purchased to make FMS/AC a more complete GIS. The Automated Polygon Processing (APP) capability allows for the overlaying of up to fourteen maps in a single step. The APP pull-down menus (referred to as the Land Use Template) is a completely separate menuing system from the FMS/AC menus described thus far. Like many geographic information systems, FMS/AC assigns attributes to each polygon that reflect the conditions present throughout the polygon's area. FMS/AC refers to the resulting maps as “factor maps.”

In APP, each factor map polygon has its own boundary line and hatchure pattern. Adjoining polygons, therefore, have coincident boundaries. Most other geographic information systems attempt to avoid
this redundancy by maintaining
a tabular database with topologi-
cal information on the relative
location of adjacent areas sepa-
rated by a single line segment.
Geo/SQL’s spatial database
(SPDB) uses this approach. This
reduces the size of the graphic
drawing, but increases the com-
putational overhead to keep
track of the topology. For poly-
gen processing, FMS/AC has
opted to retain the graphic re-
dundancy and lower the com-
putational overhead. The entire
spatial model consists of objects
in the graphic database (i.e., the
AutoCAD drawing) and attri-
bute records in the database
management system. This ap-
proach is very straightforward.
It is also particularly suited to
taking advantage of AutoCAD’s
built in hatching, shading, and
3-D capabilities.

Once the individual fac-
tor maps have been created,
APP will process them. This in-
volves creating a new factor
map on a new layer. On this
new layer, new polygons are
created for each separate area
containing a distinct combina-
tion of one or more variables. In
this manner, up to 14 factor
map overlays can be simultane-
ously intersected into a compos-
ite polygon overlay map in a
one-step process. This is a ma-
jor improvement over most
other vector GIS programs,
which can only process two lay-
ers at a time.

A non-graphic ASCII file
is also generated, which lists a
unique ID assigned to each new
polygon, the area of the poly-
gon, a list of variable values
from the different factor maps.
TABLE 3.
Comparison of Features.

<table>
<thead>
<tr>
<th>Feature</th>
<th>GIS Manager</th>
<th>FMS/AC</th>
<th>Geo/SQL</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>$795</td>
<td>$3,000-6,000</td>
<td>$3,5000-27,000</td>
</tr>
<tr>
<td>Operating Environments</td>
<td>IBM PC/XT or AT coprocessor</td>
<td>IBM PC/AT w/math Sun SPARC</td>
<td>IBM PC/AT w/math coprocessor Sun SPARC</td>
</tr>
<tr>
<td>Multiuser</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Topological Data Structure</td>
<td>No</td>
<td>dBASE, Oracle</td>
<td>R:BASE, Oracle, most ANSI SQL 89 compliant database</td>
</tr>
<tr>
<td>DBMS Interface</td>
<td>INFO</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Raw Input Data Formats</td>
<td>ARC</td>
<td>DXB, DXF, DWG, IGES</td>
<td>DXB, DXF, DWG, IGES</td>
</tr>
<tr>
<td>Input Data Formats Requiring Pre-processing Modifications</td>
<td>ARC, DEM, DIME,</td>
<td>DLG, ETAK, TIGER</td>
<td>ARC, DEM, DIME,</td>
</tr>
<tr>
<td>Export Data Formats</td>
<td>(All three program have standard AutoCAD output: DXB, DXF, DWG, and IGES)</td>
<td>(All three program have standard AutoCAD output: DXB, DXF, DWG, and IGES)</td>
<td>(All three program have standard AutoCAD output: DXB, DXF, DWG, and IGES)</td>
</tr>
<tr>
<td>Polygon Analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Simple Map Overlay</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Point or Line in Polygon</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Buffer Zones</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Boolean Analysis</td>
<td>No</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>Multivariate Polygon Intersecting</td>
<td>No</td>
<td>Yes</td>
<td>No**</td>
</tr>
<tr>
<td>Terrain Analysis</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>DTM</td>
<td>(Yes)*</td>
<td>No*</td>
<td>No*</td>
</tr>
<tr>
<td>Network modeling</td>
<td>(Yes)</td>
<td>Yes</td>
<td>(Yes)</td>
</tr>
<tr>
<td>COGO</td>
<td>(Yes)</td>
<td></td>
<td>Yes</td>
</tr>
<tr>
<td>SUMMARY</td>
<td>AutoCAD interface to ARC/INFO files Flexible, Pre-built municipal AM/FM/GIS</td>
<td>Open ended SQL-based AM/FM/GIS</td>
<td></td>
</tr>
</tbody>
</table>

1 Price does not include AutoCAD ($3,000). Only GIS Manager can be used without AutoCAD.

2 (Yes) - Software capabilities provided at extra cost to base program.

** Most third party AutoCAD COGO, terrain modeling (DTM), and contouring programs can be used with all three of these programs. Generation 5 Technology is planning an overlay intersection capability for Geo/SQL (free to users), as well as separate network modeling and digital modeling modules (extra cost) sometime in 1991.

used, and an x, y coordinate point located within the polygon boundary. These attribute data are stored in an FMS/AC database, allowing for spatial and attribute queries.

FMS/AC’s polygon processing is very rapid, enabling multiple “what if” scenarios for suitability analysis. Complex land suitability queries can be made by assigning raw scores of relative “goodness” and weighted scores reflecting relative “importance”. For example, a goodness score may be based upon the soil conditions in a polygon, while the importance weight would reflect how important soil conditions are compared to other variables. The weighted scores are easily changed to reflect different policy options for community planning and resource management.

Each resulting overlay map can then be saved as an AutoCAD slide file for quick redisplay or use in other graphics programs. Drawing file size is a major consideration when working with large and complex AutoCAD maps. A general rule is that one needs empty hard disk space that is two to three times the size of the AutoCAD drawing that is being worked
on. This is due to the number and size of temporary files used by AutoCAD. With GIS Manager, the entire area of the selected coverages, along with all the selected attributes, is converted into an AutoCAD drawing file. While the number of attributes and coverages (layers) sent to AutoCAD can be limited by the user, it is still necessary to send the entire mapped area. This can result in a large file and the need for even more disk space. FMS/AC overcomes this problem by providing a Large File Management (LFM) function. Given a mapped area drawn to its furthest extents, the LFM function will divide the map into separate, user-defined map facets. FMS/AC only calls up the map facets necessary for the area currently being accessed. The total disk space needed to work on one or two separate map facets is considerably less than it would be for the entire map. The attribute database is not changed, but is now linked to a new LFM database to associate attributes with their proper map facet.

FMS/AC has an optional coordinate geometry module, though it will also work with any other AutoCAD COGO package. In establishing the base map, however, the user must be cognizant of the graphic database layer structure as defined in FMS/AC.

A new FMS/AC module was released in early 1991. FMS/Census is designed to give access to the 1990 Census TIGER files. The module is especially designed for political redistricting, although numerous other similar applications are conceivable. FMS/Census may be run either with the FMS/AC base module or independent of it.

Facilities Mapping System, Inc., provides extensive support through dealers, as well as a direct 800 number. The FMS/AC manual provides basic information on installation, menus and commands, as well as several helpful tutorials. There are some areas in the tutorials that could benefit from greater clarification, particularly for novice AutoCAD users. However, users familiar with AutoCAD should be able to master the applications of FMS/AC without formal training.

**Geo/SQL**

FMS/AC is a highly structured, yet flexible, GIS environment, developed by a former land use planner and designed primarily for community planning and facilities management. Enhancements over the years have broadened the potential applications of the program, without substantially deviating from its original format. Geo/SQL, by contrast, shares a development history similar to AM/FM and GIS programs developed by Intergraph, Synergcom and IBM. These programs all originated as highly-specialized CAD applications and have since broadened their capabilities to include those commonly associated with GIS.

Geo/SQL originated as two complimentary AutoCAD enhancement programs: MunSURVEY and MunUTILITY. ("Mun" is short for "Municipal.") MunSURVEY added coordinate geometry and other capabilities to assist in using AutoCAD for mapping land surveys. MunUTILITY provided full-screen attribute editing to earlier versions of AutoCAD and enabled attributes to be stored in the widely used R:BASE relational database management program (RDBMS). Together, these AutoCAD enhancements became known as MunMAP. Later, MunPID (Parcel IDentifier) was added to enable linkages between AutoCAD and attribute databases that already exist separate from the drawing.

In 1989 MunUTILITY and MunPID were combined into a new product called GeoREF. GeoREF was an input/output connection to R:BASE. It also introduced a spatial database. The spatial database (SPDB) stores coordinate data, topology, and other information on points, lines, polylines (lines with shape and width), and polygons.

In 1990, the entire MunMAP package was re-worked to make the software and databases ANSI SQL (a standard database format) compliant. An almost identical SQL query language could now be used to examine both the RDBMS and SPDB. With the revision, the product was given a new name, Geo/SQL—Geographic Structured Query Language. The SPDB is not entirely SQL compliant because ANSI committees have yet to develop spatial aspects for the SQL language. Generation 5 Technology is a member of the National Institute for Standards and Technologies (NIST) committee for

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Spatial Extensions to the SQL Language, which works closely with the ANSI committee on SQL. Geo/SQL is thus both the name of the software and the name of a query language that is designed to be an extension of the ANSI SQL89 standard.

The newly revised Geo/SQL also integrates the various components in a more user-friendly manner. Geo/SQL includes all the utilities to integrate AutoCAD, the spatial database (SPDB), and the relational attribute database (RDBMS). MunSURVEY, now known as GeoCOGO, is still provided with the package to enhance the initial drawing of maps.

Unlike the FMS/AC approach, Geo/SQL does not need to save AutoCAD drawing files on disk because all the drawing entity information is maintained in the spatial database. Nor does Geo/SQL divide large drawing files into separate map facets. The spatial database is composed of intelligent objects, and is analogous to a single, seamless, continuous database. What is retrieved in a Geo/SQL query is not a drawing, but a displayed report of graphic objects. For large drawings, Geo/SQL uses an indexing system in which objects are assigned to user-defined tiles. Geo/SQL tiles are used for index searches only and enable very quick access and display of information no matter how large the data files.

Different relational databases use different terminology to refer to the same features and functions. The terminology used here generally reflects that of R:BASE and Oracle. In these databases, a “table” is composed of rows (records or cases) and columns (variables or fields). Different tables are linked to one another through at least one common column. In Geo/SQL, each RDBMS table is associated with what is called a “subject” in the spatial database. Each spatial database subject is further divided into “features class codes,” and each feature code is associated with a separate drawing layer in AutoCAD. Thus, a series of related drawing objects, each of which is on a different AutoCAD layer, can be related to a single table in the RDBMS. A total of 255 subjects, each composed of 32 feature code layers, is allowed in a Geo/SQL database, and multiple databases may be used in a single system. The number of points in a database is limited only by the file size limitations of the operating system and the complexity of the objects.

The first step in using Geo/SQL involves setting up the attribute database using R:BASE or Oracle, depending upon the version of Geo/SQL purchased. (Because R:BASE does not fully implement SQL, there are presently two versions of Geo/SQL.) The only difference in creating tables for Geo/SQL from any other application is that an empty column with the heading “OBJ#” must be included. This is where the unique AutoCAD ID number will be stored to connect the attributes to the drawn object. Concurrent with the establishment of the attribute database, the user would draw the initial base map using standard AutoCAD commands, Geo-

COGC, or some other AutoCAD drawing enhancement.

After the RDBMS table(s) have been set up, the user enters AutoCAD and loads the Geo/SQL menu. The initial pull down menus in Geo/SQL include:

**Tools:** Basic AutoCAD commands and menu customization

**GeoSQL:** Define (spatial database and GeoViews setup)
Prepare (drawing clean-up)
Tag (attach text attributes to drawing objects)
Insert (loads the RDBMS and SPDB with new attribute information)
Query (ask spatial or attribute question)

**Files:** Retrieve and save files and queries

Most of these menus lead to additional nested menus. The Geo/SQL menu is the principal operational menu. The submenu selections are listed in the same order that one would go through to build the GIS after the initial drawing has been completed. Geo/SQL automatically goes to the next logical menu item as one proceeds through the process. “Define” allows for modifications to the spatial database and the creation of GeoViews. A GeoView corresponds to a “view” in relational databases and defines the operating linkages between the RDBMS, SPDB, and screen drawing. A relational database
view is a combination of variables from one or more tables into a single table for viewing or report writing. This is the "relational" part of a relational database. True SQL databases also allow the saving of views and editing of their variables. Geo/SQL's GeoView operates in a similar manner to access attributes from any combination of one or more tables and previously defined views.

Each GeoView normally consists of the SPDB subject and its related RDBMS table. More complex GeoViews, however, are also possible. Geo-Views can be used to develop input formats for entering data from within the AutoCAD-Geo/SQL environment. Existing Geo-views can also be linked to one another for queries and reports. For example, a Storm sewer GeoView and Street maintenance GeoView could be combined to query areas where sewer problems are coincident with high levels of unanticipated road maintenance. After GeoViews have been created, the Define option "GeoGEN" adds the new GeoViews to the Geo/SQL sidebar menu for future queries.

"Prepare" provides a number of utilities to ensure that the drawing contains no logical errors. The user defines tolerance distances, and Prepare removes overshoots and extends undershoots (i.e., lines that do not connect exactly to another line or intersection of lines). Prepare will also change polylines into individual line and arc segments (primitives) and break all lines at all intersections. This is all accomplished in a single step. The integrity is then checked and potential problem areas that fell through the tolerance distances are circled to allow user correction, if desired.

The "Tag" selection in the Geo/SQL menu is used to attach the information to the appropriate drawing object (point, line/arc, or polygon). The first step is to set up the Tag contents, which generally reflect the variables in an associated RDBMS table. The user can tag existing drawing objects, or draw and tag objects at the same time. Each tag is displayed on the screen as a standard AutoCAD attribute.

New data to be entered into the RDBMS are first entered as AutoCAD attributes, then exported to the attribute database. Once the tag is set up it is saved in a tag subdirectory. Tags are retrieved by way of the pull-down or sidebar menus. The user picks the tag, then picks the first drawing object. Geo/SQL prompts the user for data for each of the attribute variables defined in the tag. In adding data as Tag attributes, the user can type in the value, set default values, set values based upon size characteristics of the drawing object, or define computed values. User defined default values speed up this data entry process. Subsequent drawing objects of the same class are then selected and the data entered. Data, such as street names, may be entered as attributes by simply picking the names off the screen drawing. The user may also Tag from a pre-existing SQL attribute table, in which case the system prompts the user to select an object on the screen. The link to the row in the SQL attribute table is automatically made.

Polygon tags are centroids situated at locations selected by the user within the polygon. The polygon must consist of line and arc primitives. At the end of the polygon tagging process, Geo/SQL automatically builds a single polygon from the lines and arcs surrounding each centroid. The user has the option of rejecting automatic polygons as they are being built and shown on the screen. The resulting polygon definitions are stored in the spatial database.

The user also has the option of adding additional columns to the RDBMS during the tagging process, adding data to any empty column, or editing existing data as it applies to the selected drawing object. The user can undertake most database operations, therefore, from within the AutoCAD-Geo/SQL environment. Table and Geo-View columns (variables) are displayed and can be picked off the sidebar menu for data entry, editing, and queries.

All the graphic and attribute data are now stored in the related attribute and spatial databases. The user can now completely delete the AutoCAD drawing. The "Query" menu allows the user to select objects and attributes from the Geo/SQL database to create new AutoCAD drawings on the screen. The query language is similar to SQL database language. A query could be typed from the keyboard or selected from the pull-down menus. For example, a query to output an ASCII text file of the owner and
address of each parcel within a 100-foot distance from a target parcel might read:
Select Polygons Parcel Select Labels columns Lname [last name] Fname [first name] Address Stname Where GSC Near Crossing Polygon (select target polygon edge) "100 feet" (pick point outside target polygon) As Textfile (type filename) <Enter> Files Execute

"GSC" in this command string stands for "Geographic Search Criteria." Although the sequence may appear cryptic, it is similar to what one uses in many database programs. Once the sequence is understood, the pull-down menus assist in remembering the steps. The ASCII file resulting from the above query can be viewed by temporarily shelling out of AutoCAD to DOS.

A similar, though shorter, sequence of commands would be used to draw the parcels on the computer screen along with the owner’s name. Additional options allow for AutoCAD color selection, line height (for 3-D display), and line width based on the value of a specified variable or group of variables. (GIS Manager and FMS/AC also allow these types of AutoCAD drawing manipulations.) After each query, the user has the option of erasing everything or leaving it on the screen to underlay subsequent queries. It is also possible to browse the RDBMS with a query command.

One of the strengths of Geo/SQL is that it can use any database value to drive the look of objects drawn on the screen. For example, the attribute value stored in the database can be used to color code a parcel according to its land use, or a centerline width could be based upon traffic volume.

Queries that are commonly used can be saved for later use (like macros). These are accessed through the "Files" pull-down menu. Geo/SQL also comes with a front-end menuing program (FREND) that can be used to package queries for end users. This would allow someone with limited computer knowledge to pick the query they want to perform from the menu and have it executed. For the novice, this may be necessary since the Geo/SQL manual provides only very basic command information.

Geo/SQL presently lacks a sophisticated polygon overlay and intersecting routine. Generation 5 Technologies plans to offer this feature as the next major upgrade to the software. Network modeling and digital terrain modeling (DTM) are also planned for release in 1991. Unlike the overlay capability, these will be offered as separate modules at additional cost.

The manual for Geo/SQL is well written and easy to follow. Although a basic tutorial is provided, professional training is recommended. Geo/SQL’s LISP files (which run most of the functions) are not protected, lending themselves to user customization. Generation 5 Technology also sells a developer’s toolkit (for $500) to allow third party enhancements of Geo/SQL. Hazardous waste management, highway maintenance, and airport facilities management are among the applications that are currently available through third-party developers.

Conclusions

Each of these programs provides a powerful tool to enhance the use of AutoCAD in GIS applications. Of the three, GIS Manager is the easiest to use. It also provides the fewest capabilities and is not a stand-alone geographic information system, even when working under AutoCAD. Its strength is that it allows one to use the powerful, yet relatively user-friendly, AutoCAD interface to view and examine "unfriendly" ARC/INFO files. Its weakness is that it does not allow spatial or attribute queries from within AutoCAD. Once in AutoCAD, GIS Manager is set up to give direct access to the popular DCA civil engineering and design tools (purchased separately). These provide a useful complement to the spatial analysis capabilities of ARC/INFO. It is important to note that all three of the programs reviewed here allow the user to access numerous other AutoCAD enhancement programs provided by third party software developers. Access to other programs usually only requires the calling up of a new menu from within AutoCAD.

FMS/AC and Geo/SQL are more or less complete geographic information systems. Because they originate from a vector-based, CAD tradition, they do not contain many of the computational capabilities that are found in even the simplest raster-based systems, such as
nearest-neighbor analysis and gravity modeling. Since most planning and public works applications do not require this type of analysis, the lack of these functions may not be critical. As all three of the products reviewed here mature, they are likely to add an ever-increasing array of analytic capabilities.

The comparison of FMS/AC and Geo/SQL demonstrates a marked difference in strategy and implementation of CAD-based GIS. FMS/AC provides a well-thought-out database and mapping structure suited to most local government land use and public works planning and management. It can save many hours of database design. At the same time, it allows for significant changes to the basic database structure, although dBase programming skills are required for more sophisticated changes. Despite this shortcoming, the application modules that come with FMS/AC are sufficient to meet the needs of most small- to-medium-size communities, as well as agencies involved in natural resources management. FMS/AC is less expensive than Geo/SQL, both in its base price and potential long-term software costs. It includes a very powerful polygon intersecting routine, as well as network flow analysis capabilities. In addition, the relatively complete, self-guided tutorial enables the user to save on training costs.

Product names can sometimes be confusing. Because of its analytic capabilities, FMS/AC is more than just a facilities mapping program, as its name may seem to imply. Geo/SQL, in its present form, is a powerful geographic database system. Its lack of sophisticated analytic tools, however, may cause some to question whether it is a true GIS. The new products planned for production in 1991 will change this situation.

One of the major strengths of Geo/SQL is its integration of the ANSI SQL database standard. Graphic and attribute data are stored in separate SQL databases external to AutoCAD. Indexing allows for very large databases to be quickly accessed. Geo/SQL can be easily customized to a variety of uses. The open environment of Geo/SQL requires more user forethought in database design than does the more structured FMS/AC approach. Geo/SQL is also more expensive than FMS/AC, both for the base cost and because additional analytic modules (including third party software) may be required. It does, however, come with a basic COGO module. Geo/SQL’s abilities to create commonly used queries and recall them through a non-technical user interface enables its use by end-users with limited knowledge of the program itself. Such a capability could greatly enhance the uses and functionality of GIS in the workplace.

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