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DISPLAY TECHNIQUES FOR DYNAMIC NETWORK DATA IN TRANSPORTATION GIS¹

Abstract: Interest in the characteristics of urban street networks is increasing at the same time new monitoring technologies are delivering detailed traffic data. These emerging streams of data may lead to the dilemma that airborne remote sensing has faced: how to select and access the data, and what meaning is hidden in them? Computer-assisted visualization techniques are needed to portray these dynamic data. Of equal importance are controls that let the user filter, symbolize, and replay the data to reveal patterns and trends over varying time spans. We discuss a prototype software system that addresses these requirements.

INTRODUCTION

Recent legislation formalizes the need to understand and improve urban traffic conditions, a task that involves both analysis and communication. Computer-assisted visualization is one approach to managing the volume and complexity of traffic data for a typical urban area. What would such a traffic visualization system look like, and how might it be constructed? In the discussion that follows, we examine the types and uses of urban traffic data, and outline a small prototype visualization system for exploring their spatial and temporal aspects. We summarize how people acquire and process spatial information, and applicable principles of cartographic design. Next we provide a ‘demo’ of our prototype, and discuss the underlying data and processing structures. Finally, we conclude with ideas for further work and some comments on the additional GIS capabilities needed.

TRAFFIC DATA

Traffic data uses

There are at least three overlapping classes of traffic data use (partly based on Hautamaki and O’Hara, 1994). *Traffic control* makes changes in the network to optimize traffic conditions; it thus demands rapid response, and tight integration with monitoring and signalization equipment. This market is well-served by several vendors. *Traffic monitoring* is less interactive than traffic control, and is used for emergency dispatch, and radio and TV advisories. *Traffic analysis and planning* divides into two sub-classes: limited and broad scope. Limited scope analysis and planning deals mostly with street geometry improvements: designing turn bays

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based on a few days of volume counts, for example. Broad scope analysis and planning extends to part or all of an urban area, considers longer time spans (months and years), and attempts to relate the observed 'behavior' of the street network (load and response) to the context of population, behavior, commerce, and infrastructure.

Broad scope analysis and planning is a holistic, strategic view of the interrelated problems of rapidly increasing population, congestion, and pollution. It recognizes that urban problems are complex and that solutions will require changes in behavior, rather than relatively simple engineering improvements. The Intermodal Surface Transportation Efficiency Act (ISTEA) and the Clean Air Act are the major regulatory 'drivers' for this approach. This legislation requires that the citizenry participate in developing the policies and plans that will improve traffic conditions.

One of the tasks in this process is to analyze data describing conditions in urban networks. Where does congestion occur? When? For how long? What are the effects on travel times? What are the effects on pollution? What solutions are suggested? These study and communication tasks, unlike traffic control and monitoring, are not well served by existing software products. The prototype that we describe is a first step toward tools that could improve exploration and dialogue on the space, time and behavior of urban networks.

Traffic data types and sources

There are many types of data that address the topics above. Perhaps the most fundamental is the street network, since this forms the spatial framework for various attributes. Attributes include: speed (MPH), volume (vehicles per minute, vehicles per hour), directional splits (left, right lanes), multiple lanes (including turn bays), occupancy (% of time there is a vehicle occupying a location), vehicle type (generally, number of axles), level of service (LOS) (an *A* to *F* subjective rating of congestion, where *A* is freeflow and *F* is standing traffic), time (date, time, day of week), and *metadata* that can be used to characterize and manage the data (sampling interval, analysis methods used, error, etc.)

Traffic data are collected by two main methods: induction loops and closed-circuit television (CCTV). Induction loops are buried in the roadway and detect vehicles by changes in a current field. The Seattle region has 2000+ loops (Hautamaki and O'Hara, 1994), while other cities have only a few. Induction loops are accurate and robust, but relatively hard to retrofit. CCTV has been combined with image processing to create systems for optically-based counts. For example, the Econolite system uses an MS Windows interface; the operator simply draws counting zones on a motion video image and the software estimates counts from the dark-light sequences that passing vehicles create. These systems are easier to install, and quickly reconfigurable to focus on lanes, turn bays, etc. CCTV is however sensitive to environmental factors: sun angle (including darkness), precipitation, dirty lenses, etc. Another popular method of counting is the use of pneumatic tubes, but these tend to be employed for short-term studies of street use and geometry.

Laser interferometry is a promising new technique that has been commercialized in the SmartLOOK (Santa Fe Technologies, Albuquerque NM) system. Lasers are directed at the roadway and the software analyzes the reflected returns. The system is relatively easy to install, and is less environmentally sensitive since the lasers operate beyond visible wavelengths.

The trends are obviously towards more data, more accurate data, and finer temporal and spatial resolution. Most importantly, these data will be digital and centralized, not simply old tube counter outputs stored in file cabinets.

The preceding brief summary has considered the increasing needs for holistic, long-term traffic data, some of the data types, and existing/promising methods for data collection. The remainder of this paper considers data to be a ‘black pipe’ (linear version of a ‘black box’). Data will presumably issue from this pipe in particular formats (e.g., dBase files, a relational database structure, etc.). These formats will enter the pipe from complex systems comprising data collection, cleanup and validation, aggregation, post-processing, analysis, and even simulation (for example, Xiong and Marble, 1994). How can this large quantity of data, varying in time and space, be presented in a comprehensible manner? Next we will set out the requirements for a prototype system addressing this question.

	Strengths	Weaknesses
Caliper TransCAD 2.1	Dynamic segmentation flexible symbolization	not programmable
Intergraph MGE	Dynamic segmentation Feature-based time stamping	C programmable
GDS Dynamic Graphics	Dynamic segmentation Dynamic graphics	C programmable
H-P Starbase	very fast	H-P only build-your-own dynseg C programmable
ESRI Arc/Info	Dynamic segmentation 4GL programmable	batch oriented limited support for multi-viewport, layered graphics

Figure 1: Comparison of GIS strengths and weaknesses for purposes of the DND prototype

USER AND PROJECT REQUIREMENTS

A goal of the prototype system is to help answer questions like “What kind of tool does a citizen/planner group need to study traffic patterns over time?” So the prototype itself is a means to elicit user requirements. Nonetheless, as a starting point we can generalize that a ‘generic user’ should be able to:

- Filter: select or filter in several ways: *spatially* by zooming, panning, direction of travel, choosing routes and sample zones; *temporally* by dates, times, days of week; and, by *attributes* such as ranges of volumes and/or LOS;
- Symbolize: choose how to display the variables, label the routes and sample zones, add scales and legends, etc.;
- Control time: move forward and backward, compare and contrast conditions in time periods.

Our general philosophy is to support *visual thinking* by giving the user many opportunities for interaction with the data. This approach provides opportunities for data exploration, discoveries, and spontaneous ideas that are impossible to anticipate. Later, a more ‘canned’

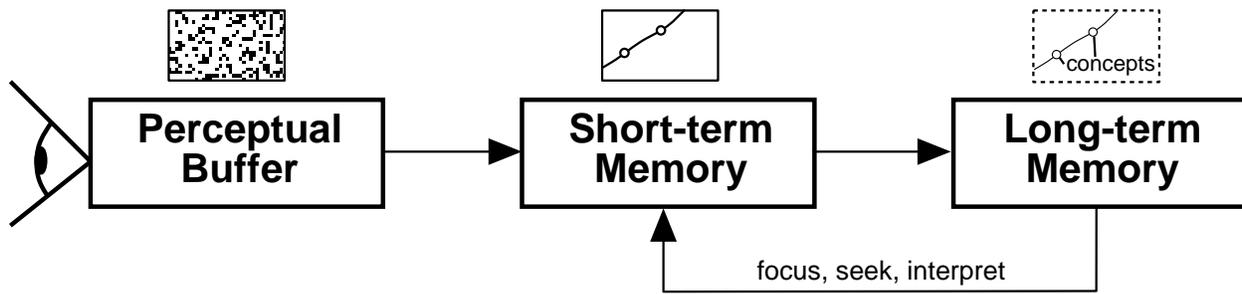


Figure 2: Simple cognitive model (based on Kosslyn, 1985)

animation can be created for *visual communication* (terms from DiBiase, et al., 1992) of conclusions to other parties such as the general public.

For a project of this scope, we chose a modest goal – display a small street network over time with two of the most interesting variables: traffic volume (load) and LOS (response). We treated data as a ‘black pipe’ that delivers temporally-registered attribute data (volume, LOS at date, time) for sampling zones along routes.

Our implementation strategy was to modify off-the-shelf GIS technology to avoid low-level database and graphics programming. At present, only Arc/Info offers dynamic segmentation that is accessible through a fourth-generation language (4GL) called Arc Macro Language (AML) (Figure 1). During implementation, we wanted to assess the strengths and weaknesses of the GIS technology used, with an eye towards more extensive experiments or systems. Having defined the scope of what we call the *Dynamic Network Display* (DND) prototype, we next consider the visual design needed to meet the user requirements.

VISUAL DESIGN

Overview of the cognitive system

While the term *visualization* has frequently been used to mean ‘neat new computer graphics,’ it is actually a very old skill – “an act of cognition, a human ability to develop mental representations that allow us to identify patterns and create or impose order.” (MacEachren et al., 1992). Promoting this form of thinking requires both powerful computing tools and at least a working understanding of their target. The human cognitive system (basically, those parts of the mind that acquire, store and use information) is adept at processing realistic graphics (instructional animations, cartoons, etc.) in near real-time, but it has a limited capacity to process *information graphics*, which use *symbols* to *represent* quantitative and qualitative *data*.

The human cognitive system is generally thought to comprise three stages (Figure 2). Stage 1 is a perceptual buffer where visual information is stored briefly but not interpreted. Stage 2 is short-term memory where specific features are assembled and recognized (e.g, a line with two circles on it). Stage 3, long-term memory, links symbols to stored concepts (e.g., circles in this context mean cities along a highway). Feedback occurs as long-term memory prompts short-term memory and the eye/buffer to acquire and examine more information. This brief overview suggests two problems: (1) Short-term memory is very fast but of limited capacity, so users

cannot be counted on to remember what they see for very long; (2) The connection between graphics (visual variables) and the concepts they represent (data variables) must be carefully constructed to allow rapid processing. Our solution should therefore allow interactivity (for example, moving back and forth between different graphics) and make a good match between data and the graphical symbols that convey it. The next section considers how symbols are constructed from visual variables.

Visual variables

Bertin (1983) identified seven *visual variables* available for graphical displays. These variables (Figure 3) are suited to displaying from one to three of the basic data types distinguished by cartographers. These are *nominal* (names), *ordinal* (classes), and *interval/ratio* (integers and real numbers). In the case of the DND prototype, the main data variables are volume, which is interval/ratio and LOS, which is ordinal. These would generally be shown by line size (width) and line value (shade), respectively. It is interesting to note that width was used to convey traffic volume on paper maps at least as early as 1963. A single wide line is used, presumably representing volume in both directions (example figure in Cleveland, 1976).

Time display

The data variables (volume and LOS) do, of course, vary over time. Data that vary over time can be displayed in several ways. *Animations* project a rapid sequence of frames, showing world time through the consumption of display time (Langran, 1992). Animation frames often are of such short duration that it is hard to perceive detailed information graphics; they must be either greatly simplified or the duration of each frame must increase (Weber and Buttenfield, 1993). A *'slide show'* allows users to control the pace and move back and forth through the slides to refresh their short-term memory, pick out features to observe over subsequent frames, etc.

Another method is a grid of frames, referred to by Tufte (1990) as *Small Multiples*. This method allows the user to rapidly compare frames, but consumes screen 'real estate' in proportion to the number of frames. The result is a tradeoff between number of frames shown, area shown, and frame size (Slocum, et al., 1993).

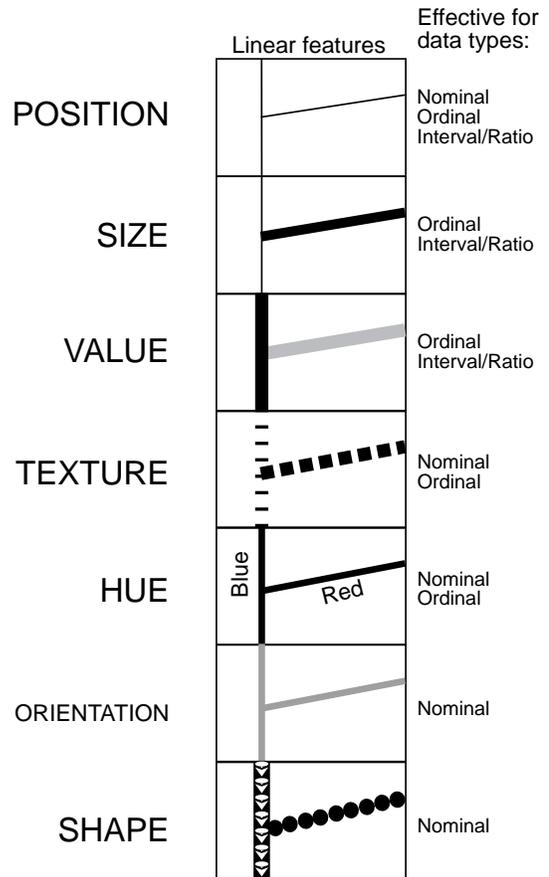


Figure 3: Visual variables (after Bertin, 1983 and DiBiase, et al., 1992)

A representation for DND

With the visual variables and time handling methods available, what is an optimal *representation* that combines the two? For DND, we chose to show location and vehicle direction through position and relative position, volume and LOS as size and value, and time as either a slide show or a grid of frames (small multiple) (Figure 4). As we will show later, the user has extensive control of this representation. For example, one can choose the relative widths for volume, step through the slide show, and set the number of frames shown in the small multiple. This representation appears to address the cognitive limitations discussed above. It allows the user to control the pace of the slide show to avoid memory overload, and the connection between data variables and visual variables is appropriate.

Data Variable	Data Type	Visual / Temporal Variable	REPRESENTATION
Location	spatial	Position	
Direction	spatial	Relative pos	
Volume	Interval/Ratio	Size	
LOS	Ordinal	Value	
Time	Time	Time	
		Frames	

Figure 4: DND Representation. The data variables are matched to appropriate visual or temporal variables to create a representation.

DND DEMONSTRATION

DND (version 2.2) consists of an Arc/Info ‘Canvas’ for display, and several surrounding control panels programmed in AML. These permanent panels provide either direct control, or they pop up additional panels. The user’s view of the prototype is shown in the following series of figures (5 through 7). These images are created by ‘capturing’ the workstation display.

Figure 5: DND showing a time ‘slice’ (number 5, time period 5:15pm) in a single frame, three routes with data, and several sampling zones. Width is proportional to volume and value (gray in this printing) conveys LOS. The VCR-like part of the Slice Display Control (lower right) steps through the slices; this is number 5 of 6.

Figure 6 shows the control panel hierarchy, with arrows indicating sequence of ‘popup’ panels. The user will typically have only one popup displayed; for illustration purposes most are shown here. When the user clicks **Spatial Selection** under the permanent *Selection Control* panel (lower left), a small panel appears (upper left). This panel allows zooming in through the **Box an**

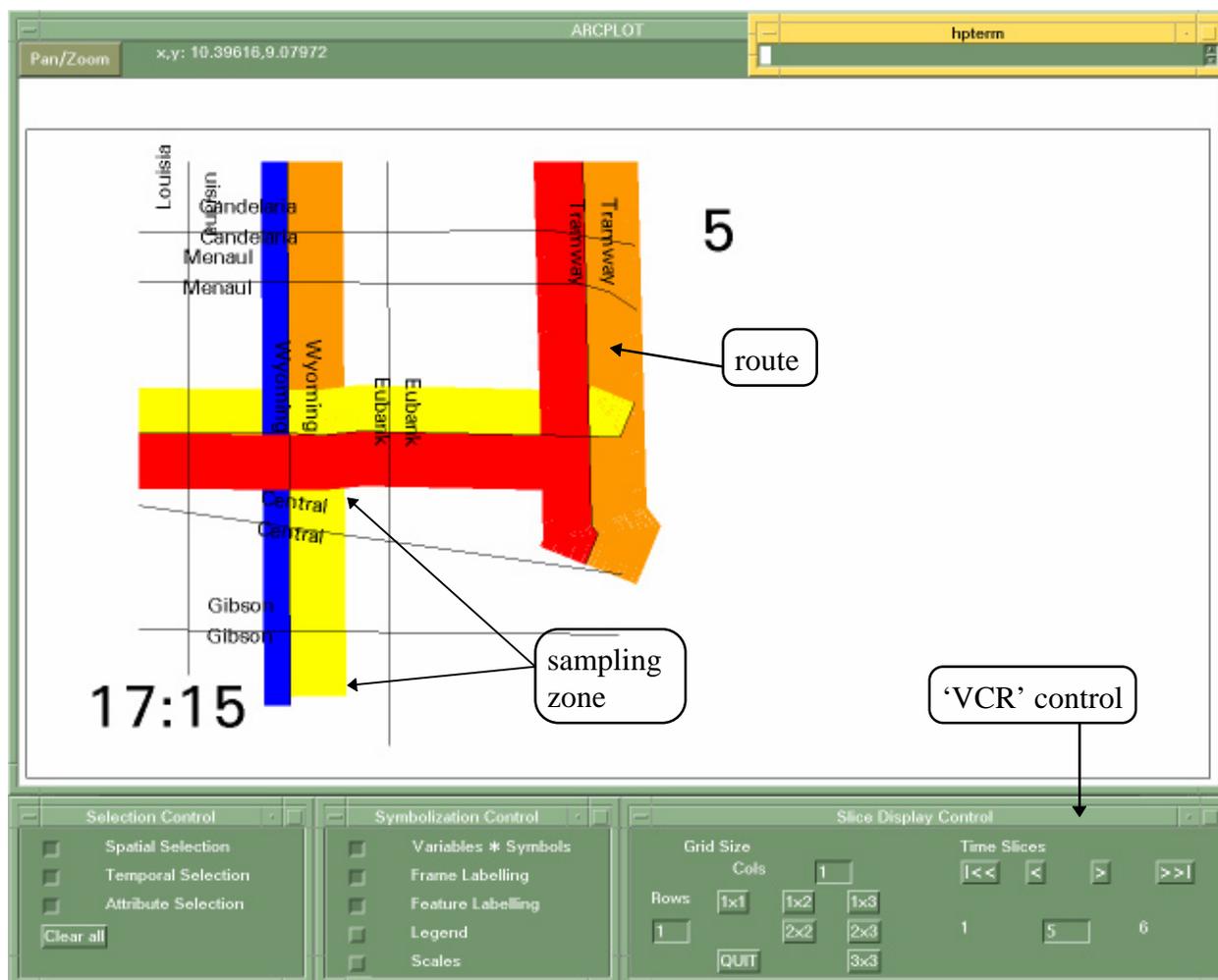


Figure 5: User view of DND with central display and control panels for selection, symbolization and slice display along bottom.

area button and zooming out to the whole coverage through the **Whole** button. Since these are frequent choices, the menu is typically left 'up' and accessible. The **Sel...** checkbox produces the *Select Features* panel with checkboxes for routes, directions, and sampling zones.

Temporal Selection brings up another panel, with widgets for choosing days and time periods. **Attribute Selection** brings up a panel with widgets that set a range of volumes and specific levels of service (LOS).

The next permanent panel is *Symbolization Control* (bottom center). The first popup is *Variables * Symbols* which at present only allows the user to scale the volume symbol (width) for the default representation (see Figure 4). The second popup is *Frame Labels* which controls the labels for the frames; as visible in Figure 5 the lower left label indicates time period (17:15 hours), and the upper right label indicates the time slice. The *Labels* popup controls labels for the routes and sample zones. The Legend and Scales options are not implemented in this version.

 **Figure 7** shows a rush hour sequence (4:15 to 5:30pm at 15 minute intervals) in a small multiple or grid of 2 by 3 panels. The user has zoomed out with the **Whole** button to show all

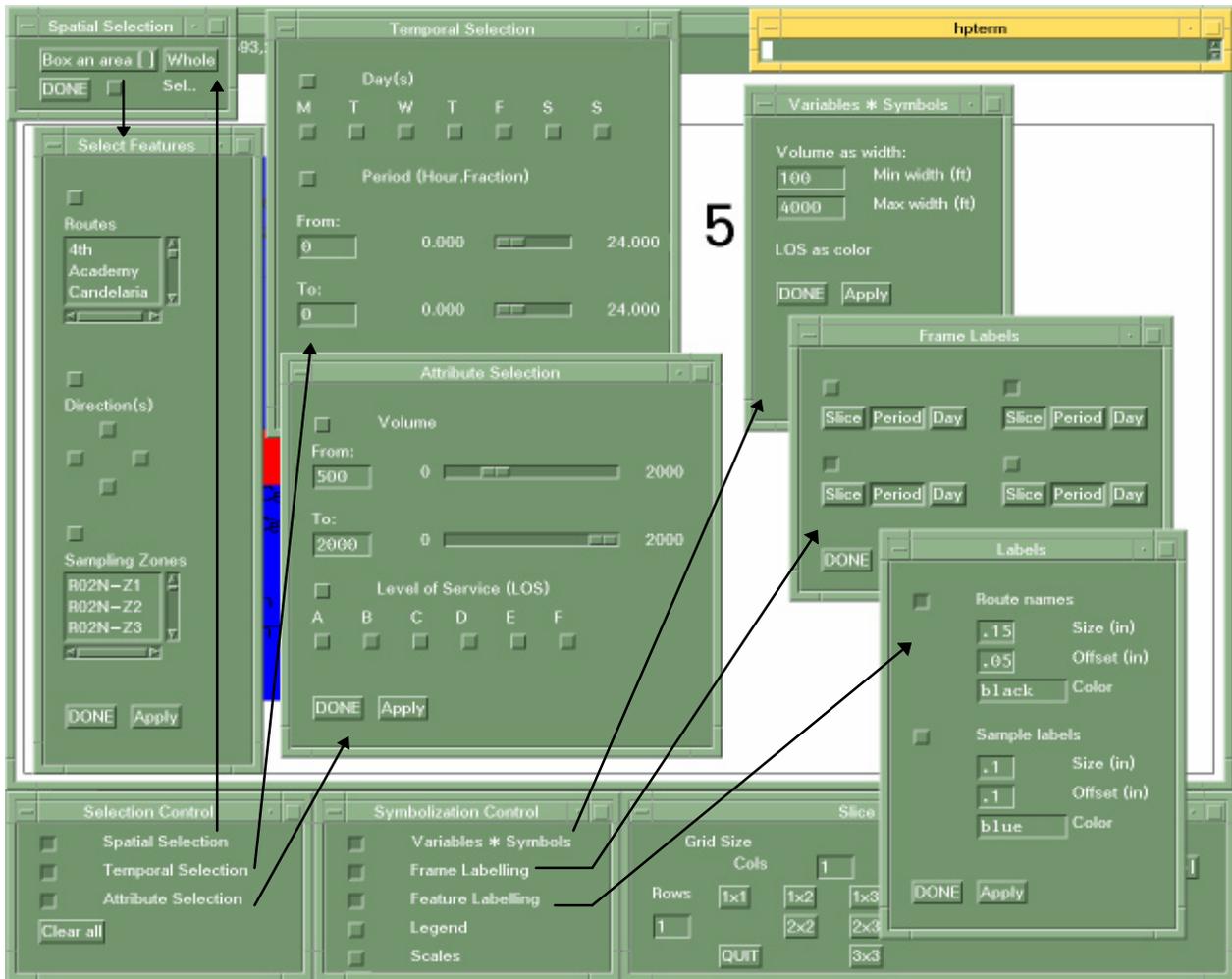


Figure 6: View of most popup control panels. Arrows indicate how popups are called up from the permanent panels (bottom). Normally, the user would not have more than one popup displayed at a time.

the simulated data for Albuquerque. (For the DND prototype, data were concocted from ‘participant observation.’) The user can set any reasonable grid size but, as discussed above, there is an inherent tradeoff in number of frames versus size.

DND IMPLEMENTATION

Data structure

DND must handle three classes of data: spatial, temporal, and attribute. **Spatial data** are, in Arc/Info terms, *arcs* (polylines), *sections* (fractions of an arc: in this case a street like Wyoming Ave), *routes* (a street with a direction: Wyoming Ave northbound), and *events*² (parts of a route: sampling zone 1 from 0 to 25000 feet along Wyoming Ave northbound). **Temporal data** are date, day of week, time, and sampling interval. **Attribute data** are volume and LOS. The three

² This use of the term *event* to indicate a linear spatial feature conflicts with everyday and temporal GIS meanings. Zone is perhaps a better term. ‘DSevent’ is used to distinguish the dynamic segmentation definition.

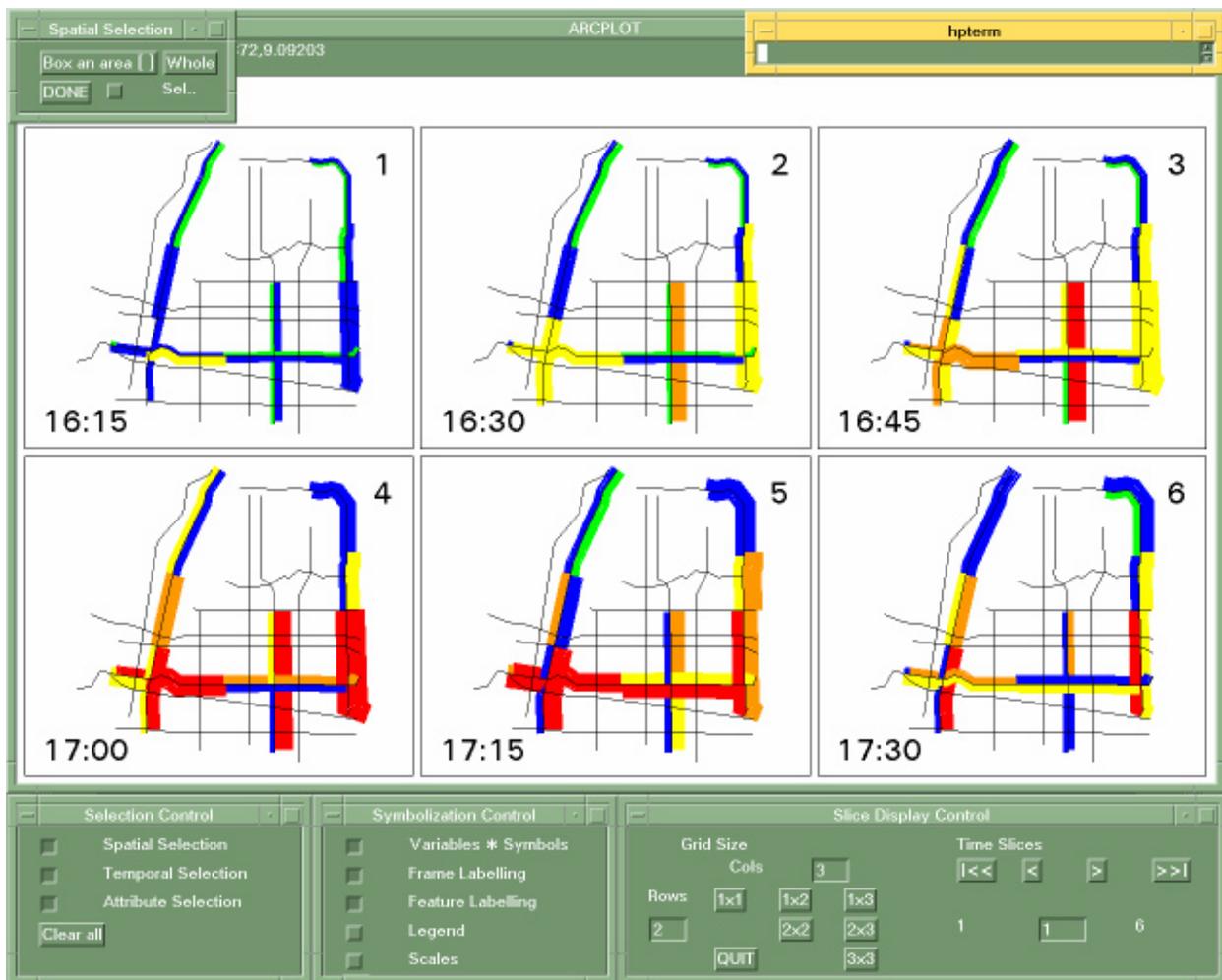


Figure 7: DND zoomed out to show all routes and sampling zones in a 2x3 frame grid or small multiple

classes of data converge in a sample, or in temporal GIS terms, an *event* (Figure 8) (Langran, 1992; Peuquet, 1994).

Processing sequence

DND software modules have two basic functions: user interface management (handling the panel hierarchy and widget calls) or display. Display involves a great deal of database access to convert the data structure (above) into a display structure that is ready to appear on the screen. The main sequence is:

- (1) selection of area, period, symbol scaling (line width), number of frames by user
- (2) create a set of time slices by examining the period, and determining the minimum and maximum volumes
- (3) plan the grid of frames, deriving scale and dimensions for the available space
- (4) display frames
 - (a) generate symbols and a lookup table (LUT) for each slice

- (b) display slice in panel using EVENTLINES, which consults the LUT to determine the symbol number for each sample zone (providing line color and width) and the line offset
- (c) while drawing, capture as a plot file for subsequent displays

Arc/Info graphics are not renowned for speed, but for DND the database access (particularly the multiple one-to-many relations, and writing of LUTs) accounts for most of the redraw time. Use of PLOT files helps greatly, but since they are not proper metafiles they must be regenerated under many conditions (e.g., PLOTs do not scale up properly when frames are enlarged).

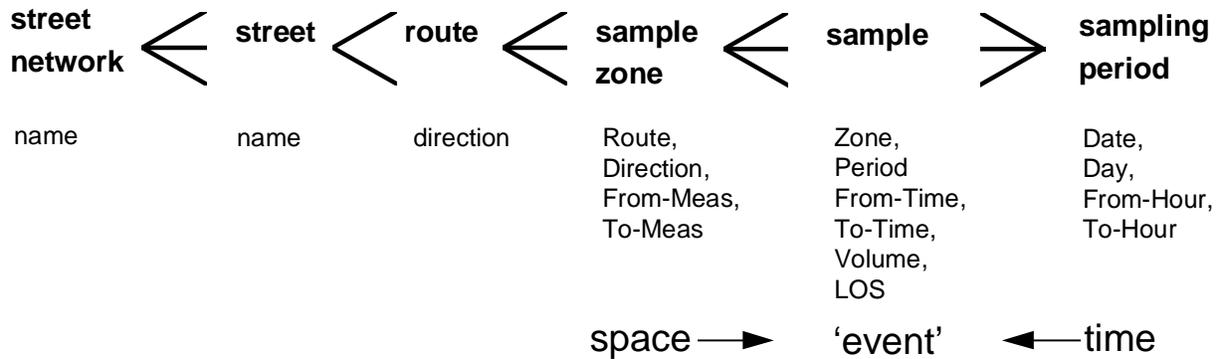


Figure 8: DND data structure

CONCLUDING REMARKS

Further work

There are several areas where DND could be enhanced, evaluated, and extended. More **symbolizations** would be useful. For example, some users might want to symbolize volume and LOS by line color and texture, respectively. The system should support such customization. **Summary graphics**, such as bar and line charts, would show the data in complementary forms (Monmonier, 1992); an earlier prototype included a dynamic bar chart that changed as the user moved through the frames. There is a need for **more complex selections**, e.g. disjoint time periods and multiple sampling zones. Users should be able to **aggregate time periods** and otherwise control the slice generation. For instance, they might want to have one slice summarize all Mondays for a particular month. There is an obvious need to obtain **real data** from an urban area to allow more comprehensive testing. DND needs **user evaluation**: are the symbolization, 'slide show' and small multiple ideas valid? Finally, it would be interesting to extend the approach to other transportation flows (e.g. inter and intra-regional trade balances) at longer time intervals (see, for example, Becker, et al., 1990).

GIS limitations

The authors have several comments on Arc/Info, but they also apply more-or-less to other GIS products examined before and since the project. Not surprisingly, the greatest limitation encountered involved the INFO database. Arc/Info is long overdue for a fully-integrated, modern, robust, non-procedural database. INFO makes queries such as 'show all north and east bound routes with volumes over 1200 vehicles per hour on March 1994 Fridays between 4 and

5pm' almost impossible since Structured Query Language (SQL) is not supported. External databases are of no help, because only INFO can be used for spatial operations on arcs, routes, DSevents, etc. Arc/Info database cursors, while essential, are very slow for the numerous one-to-many relations, writing of LUTs, etc. A new database also needs support for temporal data types (complex date, time fields), as does AML.

GIS is going far beyond the traditional Arc/Info strength of paper map production. Application developers need relatively low-level, but structured, graphics access to control drawing sequence and other parameters. For example, EVENTLINES requires graphic parameters to come from both stored symbols ('PUT'ing line symbols for color and width) and LUTs (offset). We need a more flexible spatial data and display structure with increased accessibility, e.g. a Pascal-like structure with AML access. Symbol drawing should obviously use available graphics hardware.

Summary

We have reviewed the increasing demands for time-varying data describing urban networks, the types of uses to which they are put, and new collection technologies such as laser interferometry. We set out to develop a prototype for computer-assisted visualization that would allow users to interactively symbolize, explore and replay volume and level of service data over time. Cognitive and cartographic design suggested the nature of the symbolization used, and the types of interactivity (small multiple and slide show). The prototype was built using Arc/Info, and we explain the basic data structure and processing steps. We have concluded with a list of possible future enhancements (including alternative symbolization and user testing), and observations on useful additions to current GISs to support time-varying data and dynamic graphics.

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AVAILABILITY

The beta version of DND will be available at no charge under a test and evaluation license (for commercial users) or research license (non-commercial users) granted by Sandia Corporation as directed by the U. S. Department of Energy (DOE). Contact John Ganter for more information. Telephone: (505) 844-1304, FAX: (505) 844-0244, Internet: jganter@ttd.sandia.gov

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