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The U. S. Army currently relies on raster products as source data for map background displays in tactical systems. In the future, The Defense Mapping Agency would prefer to support these requirements with vector products to reduce production costs and take better advantage of their new Digital Production System. Creative and innovative solutions are needed to allow map-like symbolized displays to be generated on current generation computers, within acceptable time tolerances, using vector source data. Science Applications International Corporation (SAIC) under contract with the U.S. Army Topographic Engineering Center (TEC) has demonstrated that this can be done effectively using special indexing techniques.

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**OPTIMIZATION OF VECTOR PRODUCT FORMAT (VPF) DATA
FOR MAP BACKGROUND DISPLAY IN ARMY TACTICAL SYSTEMS**

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ABSTRACT

The U. S. Army currently relies on raster products as source data for map background displays in tactical systems. In the future, The Defense Mapping Agency would prefer to support these requirements with vector products to reduce production costs and take better advantage of their new Digital Production System. Creative and innovative solutions are needed to allow map-like symbolized displays to be generated on current generation computers, within acceptable time tolerances, using vector source data. Science Applications International Corporation (SAIC) under contract with the U.S. Army Topographic Engineering Center (TEC) has demonstrated that this can be done effectively using special indexing techniques.

INTRODUCTION

The U. S. Army currently relies on raster products as source data for map background displays in tactical systems. Most Army command and control developers utilize Arc-Digitized Raster Graphics (ADRG) produced by the Defense Mapping Agency (DMA). The full resolution 24-bit, 254 dpi ADRG is transformed by various methods to produce spatially compressed, reduced color variants. Transformation is required due to the limited storage and display capabilities of currently fielded Army Common Hardware Systems. For example, the file size of one 1:50,000 Topographic Line Map (TLM) in full resolution ADRG format approaches 75 MB. A transformed 4-bit, 127 dpi TLM requires only 5 MB of storage.

The Army is now faced with the prospect of changing its source data for map background displays from raster data to vector data. This change is driven by DMA's stated desire to cease production of raster products in the long term and move to an all-vector product line. Citing cost concerns associated with the production of raster data and the ability to leverage the increased production capabilities of the Digital Production System (DPS), DMA envisions that the majority of digital products released in the future will be in the Vector Product Format (VPF). The move to VPF data

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sets poses a host of technical challenges to Army tactical systems and battlefield weapons developers.

The map background of the future must be able to perform on a wide range of computer platforms. The Army's current thrust towards digitization of the battlefield will result in the acquisition of thousands of new systems. The common digital map background required by this diverse array of systems is intended to provide situational awareness by displaying a quickly recognizable background for pinpointing friendly force locations and threats, as well as provide the underlaying attribution required to support mission planning and intelligence analysis activities. While many of these platforms will be state-of-the-art workstations, much of the hardware will be relatively low performance. For example, the Lightweight Computer Unit (LCU), which will be widely fielded, is a 468 CPU running SCO UNIX at 25 MHZ.

Current system requirements call for displays to be completed in a matter of seconds. While existing raster products can easily meet this goal, vector products experience significantly increased display times due to the additional processing demands inherent to topologically correct vector data. Creative and innovative solutions are necessary if display times are decreased to the point of acceptability by Army users. Compounding the problem of rapid display is symbology. Displaying complex area fill patterns or cased roads can rapidly bog down a low-end Army tactical system. A proper balance must be struck between familiar map-like appearance and data which can be quickly displayed. This will inevitably require some re-education on the part of the user, however, every attempt must be made to approximate a map-like appearance whenever possible.

The following sections discuss work performed by Science Applications International Corporation (SAIC) under contract with the U. S. Army Topographic Engineering Center (TEC). Utilizing several indexing schemes on a "compacted" form of VPF data, SAIC has demonstrated the viability of vector data as source for map background displays in Army tactical systems.

INDEXING CONCEPTS

Rapid map displays, based upon vector data, are best supported with "dumb" spaghetti data structures that have display instructions integral with **point, line, and area** data records. DXF is an example of this data structure and it is so compatible with many mapping systems that it is becoming a defacto exchange standard for this low level vector information. However, to support analysis, such as inputs to geographic information systems, one needs "smart" data which is another way of saying the data needs to include comprehensive topology. Topology provides information

on the relationship of **things** to each other. For example, a **road** can be related to the **areas** on each side of it by link-ages established with topology. Smart data carries display overhead due to the built-in topology because features must be traced by following the topological relationships. This paper assumes the reader is familiar with these concepts and will address special indexing techniques to make **smart** data nearly as fast to display as **dumb** vector data.

DMA's Vector Smart Map (VMAP) program is soon to be producing vector data with full topological relationships, suitable for input to Geographical Information Systems (GIS). The VMAP data conforms rigorously to a VPF MIL-STD to insure interoperability within the DOD community. Our work has explored indexing concepts that will work with DMA's standard data structure, as well as other data structures. These concepts are designed to optimize display response and compression to work better within limited hard disk space on computer platforms used with the U. S. Army's Common Hardware Software (CHS) program.

There are two general classes of indices; **spatial** and **thematic**. The discussion that follows treats these two classes and outlines those currently defined within the DMA Standard as well as special ones we have created to support the Army's requirements for speed and display standardization.

Spatial Indices

Spatial indices keep track of records that have a high likelihood of existing within some defined spatial region. Usually, the estimate of existence is based upon the Minimum Bounding Rectangle (MBR) intersecting with the MBR of a prescribed spatial region. It is not critical that this estimate is precise, as long as every spatial record is accounted for somewhere in the spatial index and the application software properly spans the index structure.

Spatial indices support "What's That" queries and can also be used to delimit spatial records that exist within some display window of interest. The work done in this project includes a **magnification zoom** option that is particularly well supported by spatial indices. In general, the smaller the spatial region of interest, the more rapid the response can be achieved by using some good spatial index. This is why the "What's That" query is usually supported by a spatial index. Normally, this query seeks the closest feature to some designated point on the screen, which is obviously the smallest region of interest definable.

DMA's VMAP has a very good spatial index which has been compared to a simple grid index scheme that SAIC has used for several years in their work with vector data. The VMAP

spatial index divides the overall spatial extent, normally called a **tile**, in a binary sequence, leaving record identifiers in the undivided region whenever they cross the new dividing line. This process continues until some predefined limit for division is reached, or no further assignment of records can be made. Figure 1 illustrates how this process works. When doing a "What's that" query, the point of interest defines a nested set of cells, all of which must be examined for candidates for being closest to the point of interest unless the query is restricted to point features. When delimiting records for display within a window of interest, the nested set of cells is enlarged to include the window. This enlarged nest of cells identifies the set of records that might have elements in the plot window. All records identified are unique, since this spatial index does not contain duplicate record ids in any of its cells. Each record is first tested against its MBR for potential elimination and the survivors are then displayed.

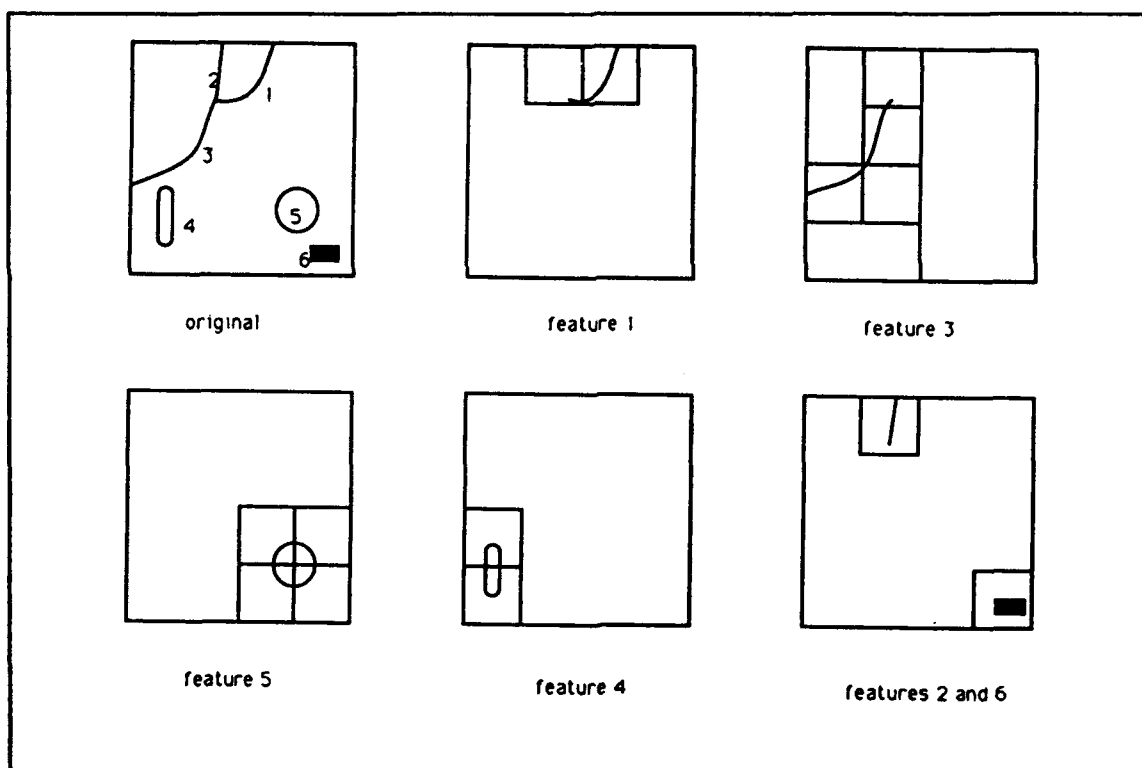


Figure 1. VPF Spatial Index Showing Cells With Feature Assignments

The Grid Index that has been used is much simpler to describe, develop, and use. Basically, the tile is divided into uniform grid cells and the MBRs of all records are examined. Any record that has an intersection of its MBR with the grid cell, becomes a member of that grid. When doing a "What's That" query, the point of interest defines a

particular grid cell and the records within that cell become the candidates for being the closest one to the point. When delimiting records for display within a window of interest, all grid cells that intersect with this window contain records that need to be further examined. The same feature may be spatially identified by more than one cell so the unique set of identified features must first be determined. Next, the actual intersection of feature MBRs and the window of interest are tested. Finally, the set of features that qualify for display are actually plotted. Figure 2 illustrates the grid index concept.

While the two spatial index schemes described above are quite different in their development and use, we found very little difference in the display response time when we tested them using VMAP prototype data sets. Both can be adapted to specific data sets by recognizing how they react to spatial characteristics. Large data sets of points could be queried faster if the spatial index is forced to high resolution delineation (i.e. more grid cells or finer division of spaces). On the other hand, data sets with large areas may work better with low resolution spatial indices.

Since we found no particular advantage in using the grid index over the defined VMAP index, we plan to use the VMAP Standard for the Army Standard Map Background work. However, there may be other applications which the grid index offers a speed advantage. Moving map displays are one such example.

Moving map displays are important for map displays in moving platforms (airplanes, ships, tanks, etc.). Raster maps are relatively easy to handle in these applications since the display can be "fringe" loaded. Fringe loading simply adds new rows (or columns) of data as the platform moves relative to the map reference. When using vector data to support moving map displays, the fringe loading idea needs to be supported with a spatial index. The grid index, noted above, is directly applicable since the row (or column) of grid cells identifies precisely the right new features that must be interrogated for generating the new fringe areas that must be displayed.

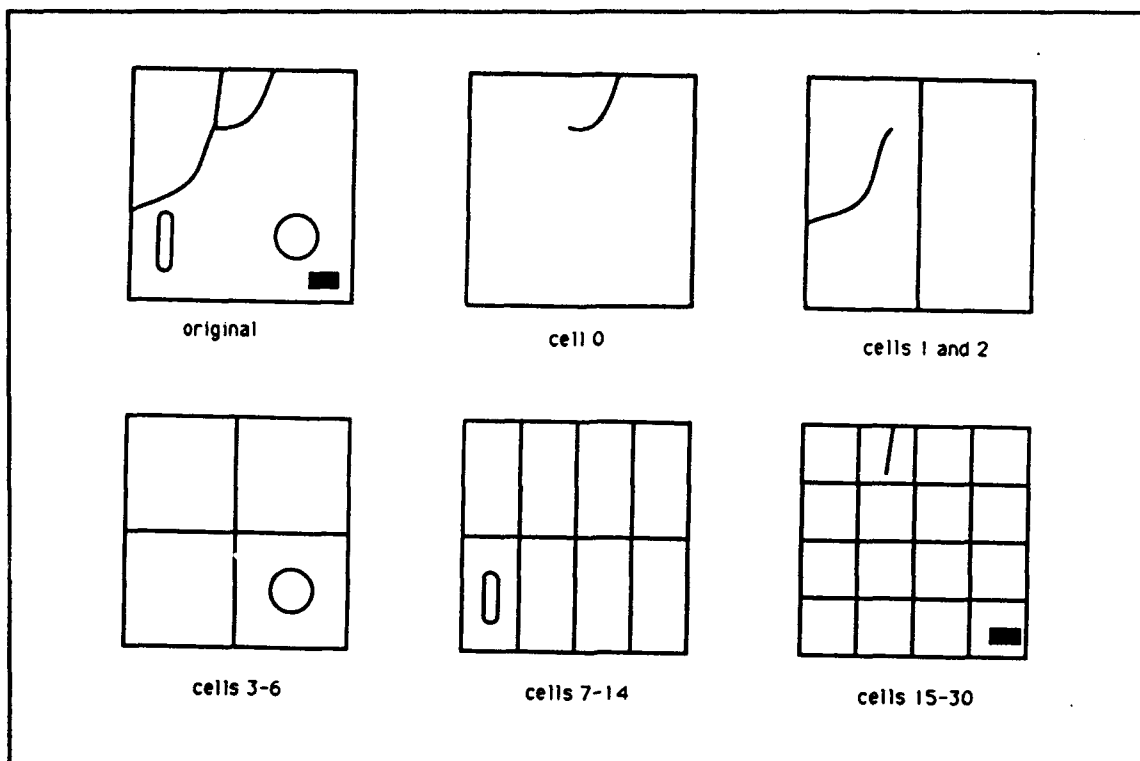


Figure 2. SAIC Spatial Index Showing Features With Grid Assignments

Thematic Indices

Thematic indices basically keep track of things you want to see in the map display and allow software to efficiently locate the proper records. In addition, there is a spatial element to thematic indices when tiles are used to divide the data into convenient subsets. In this case, things you want to see, are identified within the tile structure. Highly attributed data, typical of high resolution and/or terrain analysis data, offer a very diverse set of options for data display. For these reasons, design of thematic indices can be fairly complex and challenging. DMA's VMAP Prototypes have illustrated several options for thematic indices and the VPF MIL-STD has defined the generic structure for many others. The most general definition of a thematic index is an *Inverted List*. By sorting an Inverted List it is possible to use a *Binary Search* to find specific subsets of items in a column of information. Boolean algebra can also be applied to columns of information to identify combinations of attribute information to support specific objectives. In essence, this is what we have done to support the Army's goal of rapid display of standardized map backgrounds. We have formalized these procedures to allow most of the computer processing to be done during index preparation, thus allowing the display software to simply

use the result to get spatial records and properly display them. The paragraphs that follow amplify how this is done.

VMAP data bases consist of libraries which have layers of data called coverages. Coverages consist of feature information (feature codes and attributes) linked to spatial primitives. Usually the spatial primitives are stored in tiles which cover the spatial extent of the library. Feature information is stored in **feature tables** and each row of the feature table links the feature to its spatial primitive with a tile and spatial element id number. If a feature requires more than one spatial element to describe its spatial extent then the linkage occurs through **join tables**. Since map displays are spatially defined, the first order thematic index must be a **tile index**. So far, all VMAP prototypes have included a tile index and one would expect this to continue into the production phase since this is always required for efficient retrieval of display information.

VMAP uses the Feature and Attribute Coding Catalog (FACC) to describe features. This system consists of a 5-character feature code, using the first one or two characters to describing a basic hierarchy of information layers such as *drainage, elevation, population, transportation, etc.* The remaining characters are used to extend the hierarchy to the extent needed with these basic layers. Each feature code (FACC) may have one or more attribute codes. These attributes carry actual measured values, like length, width, area, etc. or a **coded value**. Coded values have meaning described in a specification based table. Thus, a road feature (FACC=AP030) has several attributes:

ACC...accuracy category	NAM...name
EXS...existence category	RST...surface type
LOC...location category	RTT...intended use
LTN...number of lanes	USE...usage
MED...median category	WD1...width of traveled way
WTC...weather type category	

0...unknown	1...hard/paved	2...loose/unpaved
3...loose/light		

All values are **coded** except LTN, NAM, and WD1 which are **actual values**. For example, the coded values assignable to RST are:

For RTT the assignable values are:

0...unk 13...primary 14...secondary 15...limited access

With this brief overview of VMAP constructs, we can describe our **Thematic Library Concept**. This concept defines feature identification by tile and includes symbology codes. In other words, it identifies map background features you may want to display and includes the color and style used in the display. The identified features may only require a particular FACC or they may require multiple FACCs and/or several selected attributes and coded values. Development of the Thematic Library is a deliberate tailoring of selectable feature sets and is highly dependent on data content in order to satisfy the end user.

Thematic Library entries include identification of **data library, coverage, class (Point, Line, Area, Text), symbology codes, number of features, and a pointer**. The pointer identifies the entry location in a companion file that stores the spatial element ids that belong to the feature. An example of a portion of a Thematic Library for road features is shown below.

Id	Lib	Theme	Class	color	style	num.	ptr	definition
1.	1	trans	line	0	37	20	1	EXS=5...under construction
2.	1	trans	line	2	2	107	21	RTT=15... limited access
3.	1	trans	line	1	1	432	128	RTT=13... primary route
4.	1	trans	line	3	0	1194	560	RTT=14 & RST=1 & WTC=1 secondary route, paved, all weather
5.	1	trans	line	0	13	3929	1754	RTT=14 & RST=2 & WTC=2 secondary route, paved, all weather

Similar thematic library entries are made for other coverages of VMAP as well as terrain analysis features from another DMA library called **Interim Terrain Data (ITD)**. An example of a portion of the Thematic Index Library made from ITD is:

FACC-SA050 (slope polygons) for all that follow

Id	Lib	Theme	Class	color	style	num.	ptr	definition
1.	3	slp	area	7	0	118	1	gsc=2..<=3% slope
2.	3	slp	area	8	0	626	119	gsc=3 3 to 10%
3.	3	slp	area	9	0	312	745	gsc=4 10 to 20%
4.	3	slp	area	10	0	194	1057	gsc=5 20 to 30%
5.	3	slp	area	11	0	120	1251	gsc=6 30 to 45%
6.	3	slp	area	12	0	71	1371	gsc=7 >45%

where **gsc** stands for **ground slope category**

The Library code (3) is arbitrarily assigned and must be handled by the application software in the current state of development. More sophisticated use of VMAP files could make this a table driven element.

Once the Thematic Index Libraries have been developed, it is straight forward and easy to select specific theme indices for specialized applications. In particular, we were tasked to define features for displays at various levels of zoom (relative to map scale resolution). When zoomed-out, the feature content should be reduced to give a general orientation of the area. The reduced resolution reduces clutter, and most importantly, decreases rendering time. When zoomed-in, the feature content should be the most detailed based on the tailoring used in making the Thematic Index Library. Symbolization should also be the most comprehensive, using meaningful symbols for point features and area fill patterns. Displays at or near scale, i.e. having spatial extents similar to the source graphic, should fall between the extremes described here. The symbolization, for example, can be simplified, again to reduce clutter and speed display time.

To date, we have defined nine specialized thematic indices; three levels of zoom for each of three general categories of map background. The three background categories are:

(1) General Map Background, (2) Slope-Emphasized Map Background, and (3) Surface Material-Emphasized Map Background.

RESULTS

The best way to describe results obtained so far would be to demonstrate the Standard Map Background Displays. This will, in fact be happening within the Army Community in the near future. Central to this demonstration is the application software being used and the computer platforms being used to host this software. The software has evolved over a period of three years supporting a multitude of applications using raster and vector data bases. Many indexing concepts have been used and a compressed form of DMA's vector products has proven to be particularly useful. In this section, we will discuss the software, mention a few characteristics about the compressed data structure, and highlight the performance obtained with the various indices.

The Geographic Display and Query System (GDAQS)

The Geographic Display and Query System (GDAQS) was developed on a SUN UNIX platform. It is written in the "C" language and uses MOTIF. It has been successfully ported to HP 9000 and Silicon Graphics platforms. Some of the modules were developed under a SAIC sponsored IR&D program, so they have been identified as company proprietary. In general, the code should be considered "engineering code" which works well but has not undergone rigorous design development and documentation. It is not "frozen" and tends to take on new capabilities almost daily. In addition to demonstrating the indices, the code supports many data browse features and is useful for rapidly inspecting data content. SAIC has furnished the Executable Programs to TEC for use in refining the indices that will support Standard Army Map Background Displays. Negotiations are now underway to deliver a fully documented version of the source code.

Compressed Data Structure

Early in the development of the Vector Product Standard (circa 1990), it was noted that a compressed form of the data would be useful. This was, in fact, noted as an objective in a major DMA study aimed at moving fully into the digital products arena. Suggestions on how this could be done have been noted with interest by many, rejected by some, and will probably be reinvented by others some time in the future. SAIC is willing to share their ideas with anyone interested and would take pride in having DMA use them in future refinements to the VPF MIL-STD.

Reduced storage volume is achieved by using 2-byte integers for each coordinate element as an offset from the tile lower left corner reference. Since the VPF Standard prescribes 4-byte point for coordinates so the 2-byte offset gives a 2:1 advantage with essentially no loss in accuracy for tile sizes currently defined for VMAP products. Unpack-

ing the 2-byte data does add some processing overhead, but timing runs have shown this time penalty to be small... on the order of 1 percent of the total display time. Other data structure constructs include consolidation of files and use of 2-byte integers instead of 4-byte integers wherever possible. Overall storage volume turns out to a little less than half the original volume and the number of files about one third the original.

Response Time of Standard Index Driven Map Background Displays

There are obviously many variables associated with map background display times. The main ones are; computer platform, degree of zoom, data density, complexity of symbolization, and indexing. Our goal has been to support display times that are on the order of 3-to 5-seconds on a low end Sun SPARC (IPC) platform. We believe this platform is on a par with a 486/33 PC as far as speed performance. The most dense data set available is the Fort Hood (Killeen) area which is probably no more than moderate density when judged on a world wide scale. The control of display times is through selection of individual indices from the Index Library. The Index Library includes symbology assignments, so it is possible to repeat features in the library using different symbology assignments.

Display times are considered optimal, i.e. the best that can be done, while maintaining all of the "smart" or analytic power within the VMAP data. Simpler point symbols could be important for data with numerous complex features (windmills, mines, etc.) but for the samples at hand this has not been a major consideration.

We feel the performance achieved is quite good and hosting the software on higher performance platforms will almost eliminate concern with display times. Higher performance platforms are a natural evolution in the computer industry but the performance in hand now seems adequate to satisfy field users that want to use smart vector data for map backgrounds. The indexing concepts come very close to performance achievable with low level (dumb) vector data and the same data carries analytic power needed for GIS functions.

SUMMARY

An indexing concept has been developed that supports the needs of Army system users for rapid map background display using current generation computers. Tailored indices are defined based on DMA's Vector Smart Map contents as well as terrain analysis features contained within DMA's Interim Terrain Data products. Indices include symbology

codes which may vary in complexity as a function of degree of zoom for which the index is designed to support.

So far, three choices of map background display have been defined with supporting indices:

- 1) General Map Background...close to what a topographic line map presents
- 2) Slope and contour emphasis...slope polygons, color coded by degree of slope with selective contour lines overlaid and some map features (roads, streams, built-up areas, etc.)
- 3) Surface material and contours...surface material polygons, color coded by type of material with overlays similar to 2)

- 1) Zoomed-out (from map scale)
- 2) At or near scale
- 3) Zoomed-in

For each map background, noted above, indices define feature and symbology content for three levels of zoom:

where scale is defined as the equivalent feature spacing seen on the 1:50,000 source graphic.

Display times are on the order of 3-to 5-seconds on a low end SUN (IPC) platform. A magnification feature allows small displays (3" by 3") to be very quickly generated (1-to 2-seconds) and these allow map subsets to be viewed at larger scale. The increased scale is currently set for a factor of three magnification, and the small displays occur without disturbing the base display. These subset displays can be dragged to convenient locations on the screen and others can be generated as desired.

The overall goal of creating standard map background displays has been achieved. The indexing concepts work with DMA's products without translation, or with a compressed form of the data. The adaptive symbology assignments along

with the basic indexing concept allow vector smart data to be used in both analytic GIS environments and simpler map background applications.