GIS ICON MAPS

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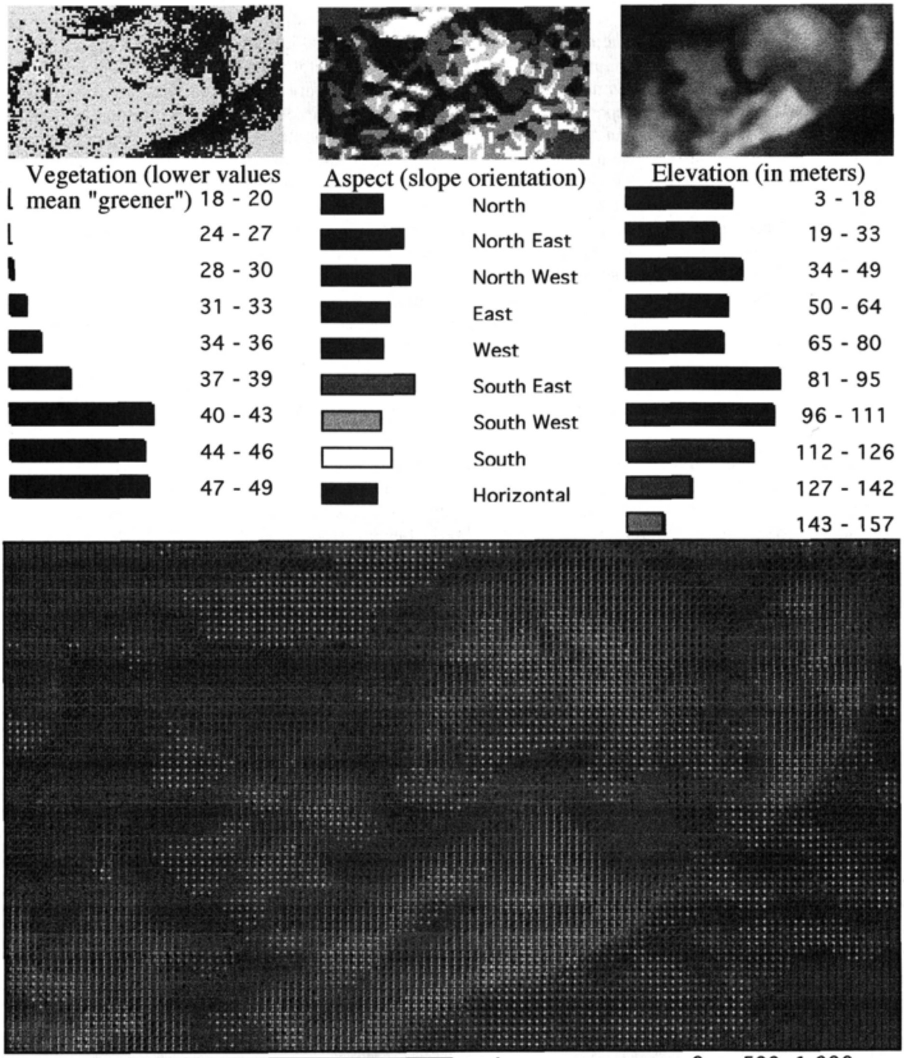
The paper presents and discusses image based GIS icon maps — a unique GIS visualization technique. A GIS icon construct allows us to map and record the interrelation of several cartographic variables at each location on a single image with minimal loss of information. GIS icon maps are designed for non-fused visualization of several variables. In these image-maps the basic assumption of each cell representing a single location is relaxed to permit multiple cells per original location. Every cell is transformed in the GIS icon map into a patterned matrix of output cells—the icon. While the underlying system's data structure remains single cell based, GIS icons can be seen as higher-level constructs that have sub-cell and super-cell properties. As a result, GIS icons are more graphically versatile than the conventional single pixel per location display. The only graphical element in a single pixel is tone or color. GIS icons support additional graphical elements including length, width, shape, angle and orientation. Examples of GIS icon maps that were created using terrain and reflectance remote sensing data are presented. This is followed by a brief discussion of the process for creating these maps. Careful design can lead to information-rich and aesthetic maps. The resultant maps reveal macro interaction patterns, while retaining in a zoomed-in micro view, full and easily visualized information for every variable at each location. The paper examines the GIS icon construct from a number of graphic and spatial science perspectives including computer graphics, spatial image processing in raster GIS, the elements of photo interpretation, issues in cartography, and E.R. Tufte's principles of graphic design in "Envisioning Information". It is concluded that GIS icon constructs can be used effectively for co-visualizing multivariate interrelation.

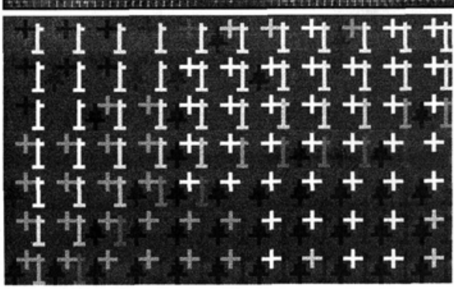
"At the heart of quantitative reasoning is a single question: Compared to what?" (Tufte, 1990).

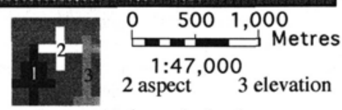
GIS ICON MAPS—A VISUALIZATION TECHNIQUE

The research question is: How can dense pixel data layers be co-visualized — with each layer's information visible? This seemingly basic question is non trivial. It addresses the ongoing challenge of visualizing multivariate data. There are a number of image overlay techniques used in digital image processing. All involve tradeoffs that result in loss of information. GIS icon maps are unique in that this loss is minimized while the visualization objective is maximized. Figure 1 shows three input layers and one output icon map.

Image based GIS icon maps were developed as a soft copy and hard copy GIS (geographic information system) visualization technique. The stimuli for their development came from a number of different sources. GIS icon maps embody principles of graphic design based on Tufte's (1990) treatise on Envisioning Information. The methodological approach is an adaptation of the work on iconographic and glyph constructs for exploratory visualization in Computer Graphics (Erbacher, Gonthier and Levkowitz, 1995) (Levkowitz, 1991) (Levkowitz and Pickett, 1990) (Pickett and Grinstein, 1988) and (Pickett, Levkowitz and Seltzer, 1990) The software tools are those of spatial image processing operations using a raster GIS (Tomlin, 1990) (Pazner, 1995). The GIS icon is a result of adopting a combined approach involving principles of visualization, a computer science glyph methodology, and image based GIS tools.







Input maps are shown with legends that have identical gray sequences to those used in the icon map. The *North Arrow* also serves to point to the location of the enlarged section (Bottom Right). Note the relations between vegetation and aspect and elevation — and the patterns and textures that are created as a result in the icon map.

Figure 1: GIS Icon Map of Vegetation, Aspect and Elevation.

GIS icon constructs allow us to map and record, both visually and digitally, the interrelation of several cartographic variables at each location on a single image with minimal loss of information. Figure 2a presents a close up view of an icon map including the underlying digital values. GIS icon maps are designed for non-fused co-visualization of several variables. By non-fused it is meant that each original data variable is present and retains a separate visual and numeric identity. In other words, we are dealing here with a type of image overlay technique — one that is distinct in a couple of ways. First, the technique is distinct in its ability to provide an answer to the research question we have posed, i.e.: how can dense pixel data layers be co-visualized — with each layer's information visible? Conventional overlay methods, which apply overlay arithmetic and logic to a single pixel location at a time, involve loss of information as a result of data fusion or superimposition. Second, unlike most other overlay methods, this technique relies on a what may be termed a reworked data resolution in order to reach its goal. GIS icon maps, presented here (Figs. 1, 2, 4) use sub-cell resolution pixel blocks to generate spatial neighborhood overlay patterns within each location. In these image-maps the basic assumption of each cell representing a single location is relaxed to permit multiple cells per original location. Every cell is transformed in the GIS icon map into a patterned matrix of output cells—the icon.

EXAMPLES OF GIS ICON MAPS

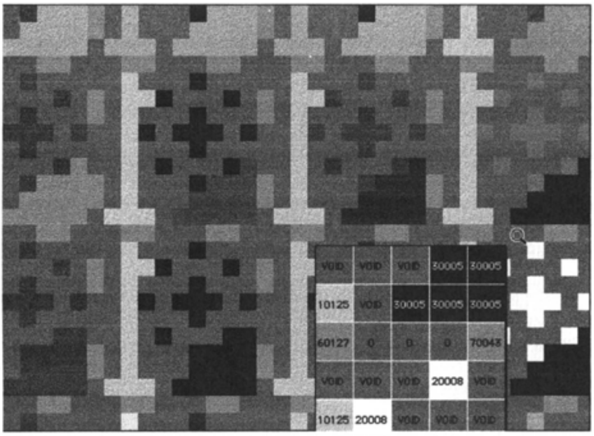
The examples shown here use remote sensing terrain and reflectance data from a SPOT satellite stereo pair. The study area, shown in Figure 3, is in the Campbell Hills, District of Mackenzie, NWT (Canada). Nine icon maps were created for terrain variables, reflectance variables, and mixed 'hybrid' icon maps that show the interrelation between terrain and reflectance variables (Table 1). The GIS icon maps were evaluated in terms of their usefulness for exploratory environmental visualization. Figures 2 and 4, for example, show an icon map of three terrain variables: Elevation (DEM) data and two of its derivatives: slope Steepness and Aspect. The DEM data was acquired from a SPOT satellite image stereo-pair. Additional terrain variables which were derived and used in other icon maps include slope Inflection and Drainage. Slope inflection is a measure of the amount of concavity or convexity of a slope location. Drainage presents a computed drainage pattern based on pouring 'digital rain' on the terrain.

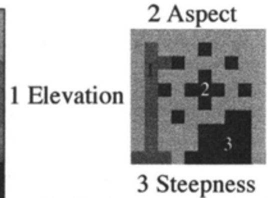
Examples of derived reflectance variables include the thematic results of remote sensing digital image classification. The reflectance variables were derived from three bands of SPOT data: Green, Red and Near Infrared. A 'V.I.S.' classification approach (Card, 1992) was used to derive the three land classes Vegetation, Impervious, Soil, and a Water class. The DEM data and the three bands of SPOT data are orthorectified, registered to a topographic map, and aligned to one another. Table 1 itemizes nine GIS icon maps by the terrain and reflectance variables used to produce them. Two of these are terrain variable maps (1, 2) one of which is shown in Fig. 4, two are reflectance variable maps (8, 9) and the five middle maps (3, 4, 5, 6, 7) are hybrids (for example see Fig. 1). Our experiments indicate that **3** is a good number of variables to use in GIS icon maps in terms of their construction, visualization and interpretation. As can be seen in Table 1, all but one of the maps are tri-variate. The hypothetical number of possible variables in GIS icon maps is *2 —> n.*

A good example of a GIS icon map is GIS Icon Map # 3 (in Table 1) which contains information on Vegetation, Elevation and Aspect (Fig. 1). This map presents meaningful information in a visually accessible manner. The interplay between the relationship of vegetation and aspect, and the relationship of vegetation and elevation (acting here as a surrogate variable for lithology) is evident in the interesting patterns and textures that appear on the icon map. The vegetation exhibits a clear preference for southerly illumination and for one of the lithologic units. A visualization of two variables exerting control over a third. The individual data layers are shown as separate maps above the icon map.

ESSENTIALS IN PRODUCING GIS ICON MAPS

We define a *GIS icon map* as a map in which every GIS pixel is transformed into a patterned matrix of output pixels—an icon. A detailed account of how GIS icon maps are produced is the focus of a previous





Elevation is represented by the 'flagpole'. Higher values are brighter and lower elevations are darker.

Aspect is represented by a 'sun'. Southerly facing slopes are brighter. North slopes are dark.

Steepness is represented by the 'stepped slope'. Steeper values are brighter.

Figure 2a: Close up view of a GIS Icon Map of elevation, steepness, and aspect. The screen shot shows the use of a numeric magnifying glass software tool to reveal the digital values (e.g.: "exactly how high?"..etc.) of each variable, including 'hidden' variables in the icon border.

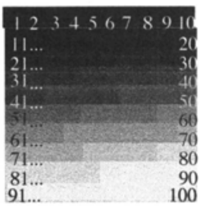


Figure 2b: Icon Addressing System.

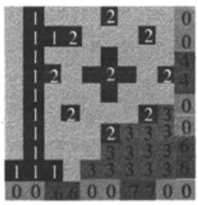


Figure 2c: The Icon Design.

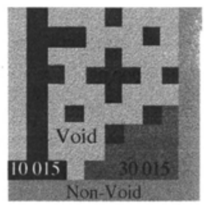


Figure 2d: Icon. loaded with data values

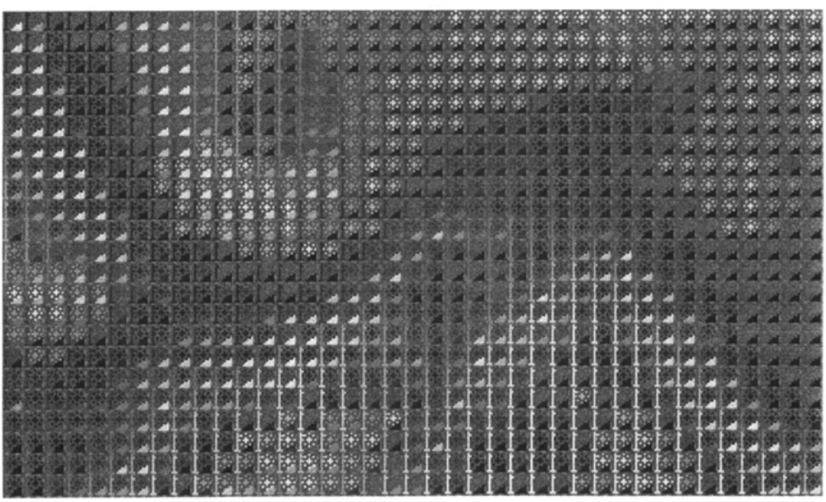


Figure 2e: Portion of a GIS Icon Map of elevation, steepness, and aspect.

article (Lafreniere, Pazner and Mateo, 1996). A very brief description of the process is provided here. GIS icon map experiments were done with Map·Factory (Limp, 1996), a raster GIS. A 10 by 10 matrix is used as a uniform project icon size in this study Icon maps with 3 variables were found to be potentially interesting, non-confounding and effective. A 10X10 icon provides sufficient space to design and place a variety of variable symbols, such as pictorial representations and alpha-numerics. A 9X9 area is used for the icon variables; one column and one row are reserved for creating a shared separating border around the icons (figs. 2c, 2d). A 10X10 icon means that the GIS icon map will contain one hundred times more image pixels than its input maps. There may be a need to reduce the size of the input prior to generating the icon map. This can be achieved by extracting a subscene, by sampling every nth row and column, or by interpolating to a coarser grid. Due to the trade-offs, several methods may be used in parallel. The input data is then rescaled to a finer cell resolution — in our case a fractional cell resolution of 0.1.

A prerequisite for creating GIS icon maps, *an icon matrix addressing system* is a relative reference system that is internal to the icon matrix and applied globally to all the icon matrices in the map (Fig. 2b). A key procedure generates the *icon matrix address map* with a cell resolution equivalent to that of the exploded map, where the cells in each 10X10 icon matrix are numbered sequentially from 1 to 100 (Fig. 2b). The value for a given cell reflects the relative position of that cell (the row and column coordinates) within the icon matrix . The purpose of the icon matrix addressing system is to enable the user to access and assign a new numeric label to a single location, or set of locations, within each address block in the address map (Fig. 2c). The procedure for creating the icon matrix addressing system is explained in detail in Lafreniere, Pazner and Mateo (1996). The addressing system is created using a logical set combination operation, with importance to order, of a cyclical row number map with a cyclical column number map, both cycling with the desired periodicity. Such row and column maps can be created using standard raster GIS operations that include distance measurement, automatic renumbering or category density slicing, and overlay subtraction.

Now that each icon matrix has a common addressing system, the variable symbol designs can be specified. The *icon design* is the result of assigning a new numeric label to a single location, or set of locations in the icon for each of the variables in the GIS icon image (Fig. 2c). Careful attention should be given to the graphic design of the variable symbol and its implementation as a set of pixels. The effectiveness and impact of the icon map will depend on the design of the variable symbols, the data, and its colorization. Once the icon design is determined the next step is to create a value template for each variable in the icon design. A *value template* consists of a map where the collection of cells that form the variable symbol have been loaded with the data values for the corresponding variable (Fig. 2d). The process for creating these maps involves three steps: creating the variable masks, processing the variable maps, and creating the value template for each variable. Unless the variables have been normalized, arithmetic adjustments need to be applied to the value templates to ensure that each variable has a unique set of values which can then be colorized. All of the cells within the icon matrix which do not represent variable values are assigned a null value. Unused border cells can be assigned a null or zero value. The final processing step is a straightforward overlaying of the value templates. The resulting map is the GIS icon map.

At this stage of the process the usefulness of the GIS icon map depends on our ability to colorize the results effectively. The map needs to be assigned tone and color sequences that have been carefully chosen for a specific visualization goal (Fig. 4). A gray-tone version is useful for getting a good first look and for generating non-color hardcopy output (Figs. 1, 2). In addition, a gray monochromatic scheme is also useful for image interpretation of the results; providing an equal and controllable good dynamic range of tones for each of the variables (Figs. 1, 2). At certain viewing scales, gray icon maps can take on a textured appearance (Fig. 1). Using color is tricky but can yield valuable visual patterns (Fig. 4). A single color sequence can be applied in many different ways to a particular variable, highlighting different information. Variables may be classed, ie. placed in value groupings, and the color sequences applied to the classes. Different color sequences assigned to the various variables will interact with each other and with the background colors (Fig. 4). It is important to note that the icon design strongly affects the visual patterning of the GIS icon image. For example, if one variable occupies a large area within the icon, this variable will tend to dominate the visualization. Therefore, icon design and colorization are critical factors

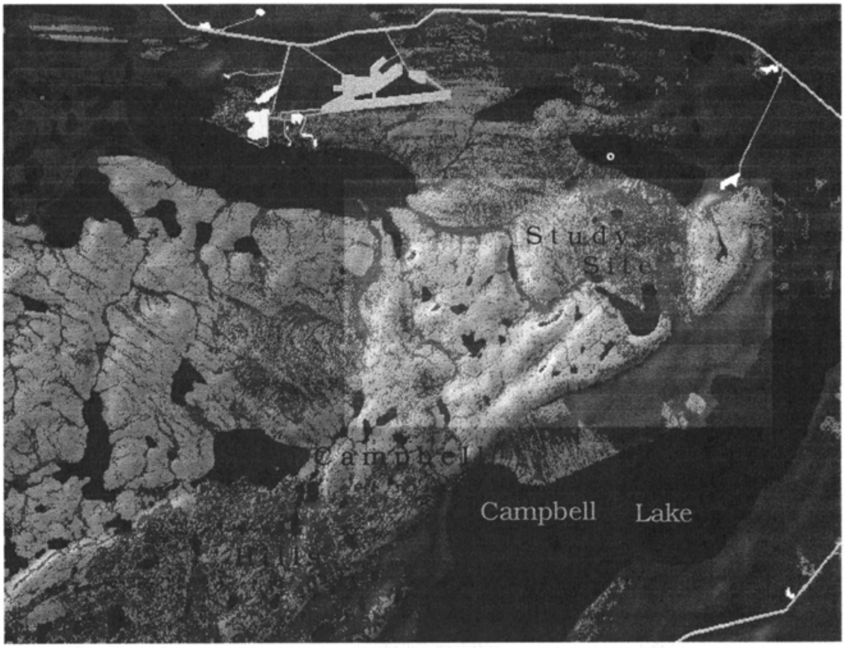


Figure 3: The Study Area in the District of Mackenzie, NWT (Canada). The study site in the Campbell Hills for which GIS icon maps were created is highlighted. The airport of Inuvik and the Dempster Highway are visible in this shaded relief, hydrology and vegetation satellite data composite.

	GIS Icon Map #	*1*	*2*	*3*	*4*	*5*	*6*	*7*	*8*	*9*
Terrain Variable*	Drainage					■	■	■		
	Inflection		■							
	Steepness	■	■		■		■			
	Orientation	■		■	■	■				
	Elevation	■	■	■						
Reflectance Variable*	Vegetation			■	■	■		■	■	
	Water						■		■	
	Impervious							■	■	
	Soil								■	
	Band 1: Green									■
	Band 2: Red									■
	Band 3: NIR									■

* Derivative variables are indented

Table 1: Nine GIS Icon Maps of terrain and reflectance variables.

in the effectiveness of GIS icon maps. Good data, variable selection, icon design and visualization can lead to good interpretations.

EVALUATING ICON IMAGES FROM GRAPHIC AND SPATIAL SCIENCE PERSPECTIVES

GIS icon maps represent a visualization technique. This section examines the GIS icon construct from a number of perspectives including computer graphics, raster GIS, photo interpretation, cartography, and graphic design. GIS icon maps were inspired by the glyph and icon approach implemented in the Exvis system developed by the computer graphics group at the University of Massachusetts at Lowell (Erbacher, Gonthier and Levkowitz, 1995) (Levkowitz, 1991) (Levkowitz and Pickett, 1990) (Pickett and Grinstein, 1988) and (Pickett, Levkowitz and Seltzer, 1990). An example and brief explanation of Exvis appears in a chapter on multivariate geographic displays (DiBiase et al., 1994) in a book on visualization in modern cartography, and in the book Visual Cues (Keller and Keller, 1993). In Exvis the icon design is based on pixelated line segments somewhat similar to a stick figure with limbs portruding at various angles. Each line segment represents a variable. The strength of the variable determines the orientation (angle) of the line segment. The macro result are 'velcro maps' or images exhibiting various surface textures. A sound (acoustic) interface helps interpret regional combinations. Due to the relatively large number of variables represented (e.g.: five, seven, etc.) and the uniform graphic design of each variable as a line segment, it is difficult to interpret local features in the image. As such, one could argue that the multivariate visualization product ends up graphically scrambling and hiding information on how the variables are co-related.

However, the fundamental notion of an icon design where an array of pixels is used to represent each original image location, is sound and holds considerable potential — given proper implementation. Our question was: is it possible to develop an icon image variant in a raster GIS environment? As this paper and Lafreniere et al. (1996) demonstrate, it is indeed possible to develop a raster GIS model, or procedure, that leads to the derivation of GIS icon maps. The model is implemented as a macro-like script which can be reused, altered and adapted to varying data, icon sizes, and icon element designs. A key difference from Exvis is that GIS icon design is based on fixed micro location variable templates, with color used as the graphic means to portray variability. There are advantages to this static design for the end user in terms of interpreting clearcut results based on a non-varying geometry. And it gives the map-maker control over the variable template design (Fig. 2c), allowing him/her to create fixed diverse pictorial cues (e.g. a sun template to reflect illumination, a tree template to represent vegetation, etc.). It also gives the map-maker control over physical separation and graphic differentiation between variable templates in the icon design stage.

GIS icon design has a special ability to take into account the classic elements of photointerpretation (Avery and Berlin, 1992). Visual variables such as color, length, width, orientation, shape, size, pattern and texture can be designed and implemented for optimal visualization impact (Buttenfield, 1993) (Bertin, 1983). While computer assisted image interpretation is routinely used to create derivatives for the human interpreter, it has been generally limited to affecting pixel tone/color. A good example are false color composites of remote sensing data which are single pixel column based. Both color composites and icon maps are multivariate visualization products, and tend to be well suited for use with three variables. They differ in that only icon maps offer multi-pixel, non-fused, and patterned co-visualization of the variables. A multi cell approach is needed in order to represent and manipulate higher order elements of photointerpretation than tone/color. While the underlying system's data structure remains single cell based, GIS icons can be seen as higher-level constructs that have sub-cell and super-cell properties. As a result, GIS icons are more graphically versatile than the conventional single pixel per location display. The icon map approach points to the fact that there are substantial advantages to moving from a single pixel processing mode to an aggregate pixel block (such as the icon). The image-processing and map-making analyst that prepares GIS icon maps has some control over designing elements of photointerpretation that can then be used by an image interpreter — the end user — which may or may not be the same person.

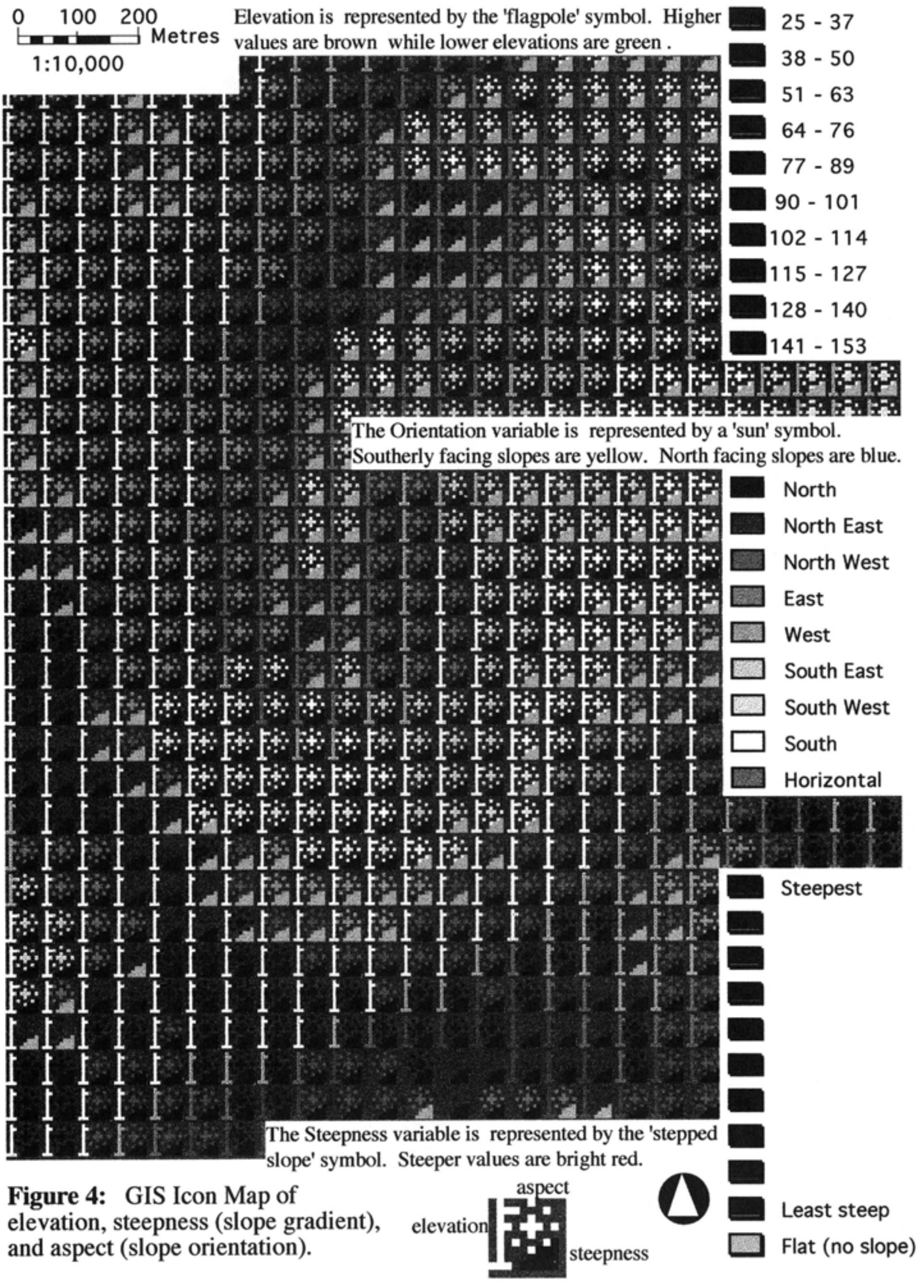


Figure 4: GIS Icon Map of elevation, steepness (slope gradient), and aspect (slope orientation).

GIS icon maps work best in color and, when viewed electronically, lend themselves to dynamic data exploration of multivariate interrelation. Macro views reveal general trends and patterns, while micro views stimulate local interpretations and hypotheses.

GIS icon maps represent an interesting cross between a modern pixel-based image and a traditional map composed of cartographic symbols. This has several implications on their use. Analyzing an icon map may require a type of hybrid map reading and image interpretation skill — which may take some getting used to. On the other hand, the potential exists to reap the advantages of interpreting image data while reading easily recognizable cartographic symbols. In reading icon maps such as Figs. 1 and 2e, the emphasis is on comparing between the 3-4 variables that are depicted on each map. This is an exercise in interpreting isolated-and-joined elements that is different from the interpretation of normal imagery (Fig. 3). The interpretation of icon maps involves explicit comparison of the inter-relation of the mapped variables.

Principles of graphic design based on Tufte's (1990) treatise on Envisioning Information were deliberately incorporated into the design of GIS icon maps. Tufte discusses issues in *layering and separation* in his book. Icon maps are inherently layered and can be read knowing that none of the layered information is neither covered nor fused (Fig. 1). GIS icon maps are also a good example of what Tufte terms *micro-macro readings.* Consequently these graphic representations can be read at a continuum of scales from fine micro detail, through meso, to macro levels of detail (Figs 1, 2). Another well known design that Tufte advocates using is *small multiples* (e.g.: the input maps at the top of Fig. 1). As this study shows (Table 1), it makes sense to design a family of icon maps, each depicting a subset of 3-4 variables. A graphic layout of a number of such maps would be a good example of a small multiples graphic design. GIS icon maps provide non-fused co-visualization within the eyespan. The visually continuous and uninterrupted presentation of information within the eyespan runs as a recommended common design thread in Tufte's exposition of graphic practises. Many of the guidelines for the use of color provided by Tufte in his chapter on *color and information* can be readily applied to colorization of icon maps. This should come as no surprise since Tufte draws heavily on Eduard Imhof's (1982) rules for the use of color in cartography. Examples of color principles that are readily applicable to icon maps include the use of muted background colors, the use of colors found in nature, the sparing use of very strong colors and contrast, and the need to apply damage control measures to mitigate negative effects of interacting color elements. A color example is shown in Figure 4.

The GIS icon map is a result of implementing a computer graphics glyph method in an image based GIS environment while incorporating a set of graphic design principles. The software tools are those of spatial image processing operations using a raster GIS (Tomlin, 1990) (Pazner, 1995). The model is unique in that it approaches the map overlay problem in GIS in a non-standard way, based on changing the cell resolution and using cell aggregates to achieve a spatial neighborhood based overlay. From a modeling standpoint, the process of creating GIS icon maps can be seen as exploratory visual modeling or exploratory data visualization. Similar to exploratory data analysis, the process, not just the result, constitutes an important part of the exploration. Exploratory visual modeling is achieved by performing various modeling steps: the selection of sets of three variables, the design of the icons, processing the data derivatives, running the GIS icon map generating model, coloring the results, and visual interpretation of the results. The procedure can be done by a sole researcher or a team, and leads to familiarization with the interrelation of data variables which in turn stimulates interpretations, hypotheses, and new research questions. Augmenting rather than replacing conventional one-pixel-per-location maps, GIS icon maps can serve a unique and useful role in visualizing the interrelation of multivariate data Possible applications include visualization of natural and artificial spatially distributed variables, gradients, indices, and uncertainty. The relative simplicity and flexibility of the GIS icon map technique makes it a powerful tool for non-fused visualization of multivariate data. Interpretation of icon maps can suggest further GIS modeling in order to derive additional quantitative and visual results. With proper graphic design, GIS icon maps can be created that have substantial aesthetic appeal.

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REFERENCES

Avery T. E., and G. L. Berlin (1992). *Fundamentals of Remote Sensing and Airphoto Interpretation.* Macmillan Publishing Company, New York, Fifth Edition, 476p.

Buttenfield B. P. (1993). Scientific Visualization for Environmental Modeling: Interactive and Proactive Graphics. 11p. *Proceedings of the Second International Conference/Workshop on Integrating Geographic Information Systems and Envrionmental Modeling,* NCGIA, USA.

Bertin J. (1983). *Semiology of Graphics: Diagrams, Networks, Maps.* University of Wisconsin Press, Madison, WI. Translated by William J. Berg.

Card D. H. (1992). Characterizing Urban Morphology Using Remote Sensing and VIS Modeling. *1992 AAG Annual Meeting Abstracts Vol.* Assoc. Amer. Geographers. USA. p 33.

DiBiase D., C. Reeves, A. M. MacEachren, M. vin Wyss, J. B. Krygier, J. L. Sloan and M. C. Detweiler (1994). Multivariate Display of Geographic Data: Applications in Earth Systems Science, chapter 15 in *visualization in modern cartography,* A. L. MacEachren and D. R. F. Taylor, Eds. Elsevier Science Ltd U.K , pp. 292-293.

Erbacher R., Gonthier D., and H. Levkowitz (1995). The color icon: A new design and a parallel implementation. *SPIE,* Vol. 2410, pp. 3030-312.

Imhof E. (1982). *Cartographic Relief Presentation,* edited and translated by H. J. Steward from Imhof's Kartographische Gelandedarstellung (Berlin 1965). Berlin.

Keller P. R. and M. M. Keller (1993). *Visual Cues.* IEEE Computer Society Press and IEEE Press, USA, 229p.

Levkowitz H. Oct. (1991). Color Icons: Merging Color and Texture Perception for Integrated Visualization of Multiple Parameters. *Visualization 1991,* CA:IEEE Computer Society Press, pp. 22-25.

Levkowitz H. and R. M. Pickett (1990). Iconographic integrated displays of multiparameter spatial distributions. In B. E. Rogowitz and J. P. Allebach, eds, *SPIE '90,* Human Vision and Electronic Imaging: Models, Methods and Applications, Santa Clara, CA, Feb. 12-14, pp. 345-355.

Limp F. (1996). Map•Factory 1.02. Software review, in *GIS World,* July 1996, GIS World Inc., Ft. Collins, CO, pp. 86-87.

Pazner M (1995). Cartographic Image Procesing With GIS. *GEOMATICA,* Canadian Institute of Geomatics, Ottawa, 49 (1): 37-48.

Pickett R M and G. G. Grinstein (1988). Iconographic Displays for Visualizing Multidimensional Data. *1988 IEEE Conf. on Systems, Man,and Cybernetics,* Beijing and Shenyang, People's Republic of China.

Pickett R., H. Levkowitz and S. Seltzer May (1990). Iconographic displays of multiparameter and multimodality images. *First Conference on Visualization in Biomedical Computing,* Atlanta, GA:IEEE Computer Society Press, pp. 58-65.

Tufte E R. (1990) *Envisioning Information,* Graphics Press, New Haven, CN.

Tomlin C. D. (1990), *Geographic Information Systems and Cartographic Modeling.* Prentice Hall, New Jersey, 249p.