DEVELOPMENT OF A COMMON FRAMEWORK TO EXPRESS RASTER AND VECTOR DATASETS

J. Raul Ramirez, Ph.D.
Senior Research Scientist
The Ohio State University
Center for Mapping
Columbus, Ohio, USA

ABSTRACT

The most common ways to graphically represent geographically referenced data (geographic data) in computer-compatible form are raster and vector Conventionally, raster and vector are considered to be two different and independent ways to portray geographic space. Software programs are developed to deal only with raster or vector data. Of course, there are computer applications that allow the simultaneous display of raster and vector data, but internally, different software routines deal with each data type This is inefficient and costly. At The Ohio State University Center for Mapping, we have been working on the conceptualization of a highly advanced mapping system the Total Mapping System (TMS) One aspect of the TMS is data distribution In dealing with this topic, we decided to investigate some fundamental questions about data models. Are raster and vector really different types of data? If not, is there a common framework which expresses both datasets as unique data types? Is there a need for a different type of geographic representation (besides conventional raster and vector)? This paper presents the results of this research

BACKGROUND

There are many ongoing research efforts toward the development of new alternatives to conventional mapping The Total Mapping System (TMS) concept, in development at the Center for Mapping, is one of them. The TMS will support comprehensive real-time acquisition, processing, and distribution of up-to-date geographic information. The Airborne Integrated Mapping System (AIMS) is one component of the TMS and is currently in development at the Center for Mapping

The goal of the AIMS initiative is to develop a fully computer-compatible, real-time mapping system "capable of large-scale mapping and other precise positioning applications" (Bossler, 1996). This airborne system will integrate state-of-the-art positioning and imaging technology such as. differential GPS, INS, CCD, laser, and infrared sensors As indicated by Bossler (1996), the goals of AIMS are to. (1) acquire position and orientation of an aerial platform at 5-10 centimeters and ~10 arcsec, respectively, in real-time; (2) perform essential processing of digital images such as histogram equalization and imprinting in real-time, (3) generate dense ground control coverage in real-time, and (4) post-process digital imagery to calculate feature coordinates at submeter accuracy and to automatically recognize targets

The end product of AIMS will be ground images with a large number of three-dimensional ground control points generated in real-time. This will eliminate the current need for ground surveying and post-flight photogrammetric triangulation, and could provide very precise relief representation But, AIMS needs to be complemented with other research projects in order to achieve the goals of the TMS Of course, one major problem to be solved is the automatic extraction of terrain features from the remotely sensed images.

The major obstacle for the automatic extraction of features from remotely sensed images is the limited amount of explicit information in the images A possible solution to this problem is to increase the amount of explicit information per pixel This can be achieved by combining different sensors as part of a new data acquisition system such as AIMS. Additional sensors may be thermal cameras, laser profiler and imaging laser, SAR, SLAR, interferometric SAR, and/or multi- and hyper spectral scanners (Heipke and Toth, 1995) Using Figure 1 and Set notation, this concept could be expressed as follows

A conventional pixel carries today three pieces of information two planar coordinates (I,J) defining its location on the image, and an attribute The attribute is usuall, a graphic attribute, such as color This can be written as.

$$P = \{I, J, \text{Attribute}\} \qquad (1)$$

Let us consider a different type of raster image,

$$R_N = \{P_{11}\ P_{12}\ P_{ij} \ldots\}, \quad (2)$$

where P_{ij} indicates a particular pixel. Each pixel, besides the conventional information, has information generated from the different sensors For example,

$$P_{ij} = \{I, J, \text{Attribute}, \phi, \lambda, \text{elevation}, g_{ij}\ l_{ij}\ t_{ij}\ h_{ij} \ldots\}, \quad (3)$$

as defined in Figure 1 These ideas fundamentally change our conceptualization of raster data. Under this concept, pixels carry a rich amount of positional and attribute information It is expected that pixels belonging to the same terrain feature have a subset S (of $\mathbf{P}_{ij}$) of common characteristics. With enough integrated sensors, it is possible that these characteristics are sufficient to automatically recognize the outline of each terrain feature

New mapping concepts such as the TMS of The Ohio State University Center for Mapping will radically change the field of geographic data generation. But, they will also change our ideas about data models It is clear that the current raster model will not be able to satisfy the needs of systems such as the TMS. Thus, we decided to study the problem of conventional geographic data models.

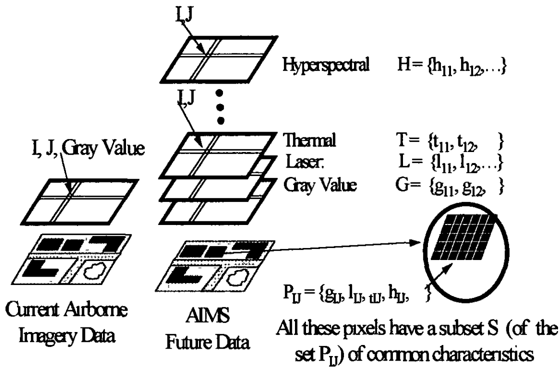


Figure 1. The TMS Acquisition Concept

THE ESSENCE OF RASTER AND VECTOR DATA MODELS

Let us define a two-dimensional geographic space to be represented in computer-compatible form Let us call this space **E.** Currently, there are two different models to express this space, the raster and the vector model The raster model is obtained by dividing the space **E** into a finite number of basic units. Each unit has a finite area and similar shape to all the others We will use the term **pixel** to designate the basic unit in the raster space The vector model is obtained by dividing **E** into an infinite number of area-less and dimension-less units We will call these basic units **geometric points.**

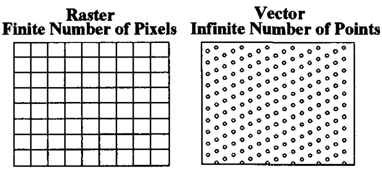


Figure 2 The Space **E** and its Basic Units

This concept can be extended to a three-dimensional space **V**, by dividing it in equal-size cubes (three-dimensional pixels) for the raster model, and three-dimensional geometric points for the vector model For simplicity the two dimensional model will be discussed here Figure 2 shows the space **E** and the basic units

Let us decrease the size of the pixels, as an example, by one-half of the original size In this case the number of pixels will increase from **n** to **4n** The result is shown in Figure 3.

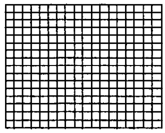


Figure 3 The Space **E** and a Smaller Raster Unit

If we repeat this process many times, in the limit, the number of pixels in the space **E** will be infinite and the raster and the vector model will be the same. Therefore,

$$\text{Limit}_{n \to \infty} (\text{Raster Model}) = \text{Vector Model} \qquad (4)$$

THE FUNDAMENTAL RELATIONSHIP

From the above result, we can argue that, in the limit, the raster and vector models are the same as shown by expression (4), and that raster and vector representation can be obtained from a single mathematical model. This global model is:

$$X = BU\,x, \quad Y = BU\,y, \qquad (5)$$

where

$$BU = \text{Distance} \quad 1, \qquad (6)$$
$$BU = \text{Basic Linear Unit}$$

$\text{Distance} = 1$ (for vector model)
$\text{Distance} > 1$ (for raster model)

x = number of basic units in a primary direction (for example the X-axis)
y = number of basic units in the other primary direction (for example the Y-axis)

In the vector domain, BU is equal to one. This is equivalent to have a dimension-less area-less geometric point as the fundamental primitive. In the raster domain BU is greater than one (we assign a finite dimension to **Distance**). In this case the fundamental primitive is the pixel of length equal to **Distance** and area equal to **Distance**^{2}

As an example, Figure 4 shows the location of an arbitrary point **A,** for the case **Distance = 10** units (pixel length) Then, from formula (5)

$$BU = 10 \times 1 = 10 \ \text{(raster)}, \quad BU = 1 \times 1 = 1 \ \text{(vector)}$$

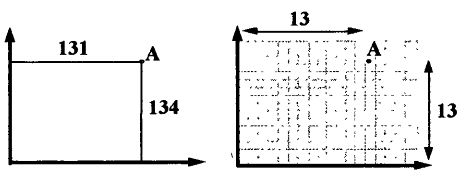


Figure 4 An Arbitrary Point In the Space **E.**

If, in expression (6), x = 13 and y = 13 for the raster representation and x = 131 and y = 134 for the vector representation of point **A**, then we have for the raster and vector spaces, respectively

$$X = 10 \quad 13 = 130, \quad Y = 10 \quad 13 = 130 \text{ (raster)}, \quad X = 1 \quad 131 = 131, \quad Y = 1 \quad 134 = 134 \text{ (vector)}$$

Expression (6) will reproduce the conventional expressions used in the raster and vector model by normalizing these equations by **BU**. In that case,

$$X = x, \quad Y = y,$$

and for Figure 4, we have.

$$X = 13, \quad Y = 13 \text{ (raster)}, \quad X = 131, \quad Y = 134 \text{ (vector)},$$

for the raster and vector cases, respectively

CARTESIAN DISTANCE, TRANSLATION, SCALING, AND ROTATION

The Cartesian distance between points **A** and **B**, shown in Figure 5, is given by,

$$d_{AB} = BU\, [\, (x_A - x_B)^2 + (y_A - y_B)^2]^{1/2} \tag{7}$$

A translation of the line **AB** is given by

$$X_A = BU\, x_A + BU \quad dx, \quad Y_A = BU\, y_A + BU \quad dy$$
$$X_B = BU\, x_B + BU \quad dx, \quad Y_B = BU\, y_B + BU \quad dy \tag{8}$$

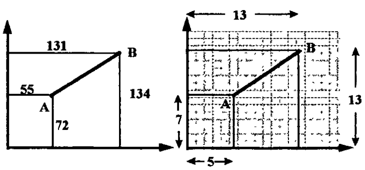


Figure 5. Distance **AB**

The scaling of the line **AB** by a factor S can be defined as follows,

$$d_S = S\, d_{AB}, \tag{9}$$

and the coordinate values of the end points of the scaled line are given by

$$X_A = S \;\; BU\, x_A, \quad Y_A = S \;\; BU\, y_A$$
$$X_B = S\, BU\, x_B, \quad Y_B = S \;\; BU\, y_B \tag{10}$$

If we compute the coordinates of the line **AB** in a coordinate system rotated by an angle **α**, the resulting line is given by

$$X_{ar} = BU\, x_A \cos\alpha + BU\, y_A \sin\alpha, \quad Y_{Ar} = BU\, y_A \cos\alpha - BU\, x_A \sin\alpha$$
$$X_{Br} = BU\, x_B \cos\alpha + BU\, y_B \sin\alpha, \quad Y_{Br} = BU\, y_B \cos\alpha - BU\, x_B \sin\alpha \tag{11}$$

DESCRIBING FEATURES IN THE GLOBAL MODEL

In the previous sections we presented a global model that encompasses the geometric aspect of the traditional raster and vector model The description provided by this model is equivalent to the skeletal representation developed by Ramirez (1991) for vector data. In order to provide a complete global model, three additional aspects need to be considered (1) a way to describe features in the raster model, (2) graphic variables (or graphic attributes) for raster and vector features, and (3) nongraphic attributes We will discuss them next

Description of Features in the Raster Model. Traditionally, raster images are composed of "dumb" pixels. "Dumb" pixels have no connectivity, or geometric or feature-related information. Each pixel carries only positional two-dimensional (I,J) information and an attribute. Orthophotos are a typical example of "dumb" pixel images. They show the surface of a particular area of the Earth in an orthogonal projection (distances and angles are equivalent to the one on the ground). They carry a large amount of implicit information but little explicit information. Ideally, we would like to have images with "smart" pixels. "Smart" pixels of an image carry a large amount of explicit information (similar in some fashion to the information in the vector model). The concept of "smart" pixels will be expanded in the following paragraphs.

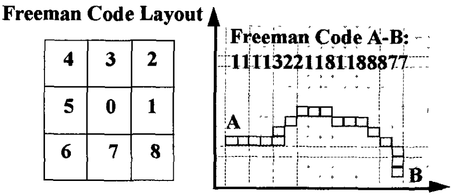


Figure 6. Freeman Code.

A simple way to define linear features in the raster model is using the Freeman code. The Freeman code carries connectivity and geometric information. The skeletal representation of features in the raster model can be expressed by the Freeman code. Figure 6 illustrates the description of skeletal representation of features using the Freeman code.

In order to relate the Freeman code with expressions (5) through (11), let us assume the center of each pixel as the origin. In that case, two different distances, as indicated in Figure 7, for BU (see expression (5)) need to be considered. The distance between two pixels connected side by side is P. The distance between two pixels connected by a corner is equal to $P\,(2)^{1/2}$.

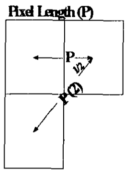


Figure 7. The Basic Distances in a 2-D Pixel

Therefore, expression (6) can be rewritten as:

$$BU = \text{Pixel Length, or } BU = \text{Pixel Length } (2)^{1/2}, \qquad (12)$$

and all the previous equations can be extended to express Freeman code relations. For example, the Cartesian distance of the raster skeletal representation AB of Figure 6 is $d_s = 5P + 2(2)^{1/2}P + 2P + (2)^{1/2}P + 2P + 3(2)^{1/2}P + 2P = 19.46\,P$. This distance is computed by subdividing the line into its seven straight segments, computing the length (in pixels) of each one, and adding them.

Expanding the Freeman Code. The traditional representations of features in raster images by Freeman codes, are still inadequate, by several factors of the equivalent vector representations. Some of these factors (graphic variables or graphic attributes, and nongraphic attributes) were mentioned earlier. A factor not mentioned yet, is the geometric dimension of conventional raster data (two-dimensional) as opposite to spatial vector data (three-dimensional). A simple solution to this problem is to extend Freeman from two-dimensions to three. This can be accomplished as follows (see Figure 8).

The planar representation of the Freeman code can be extended to a volumetric representation by considering the cube (instead of the square) as the fundamental representational unit. In this particular case, a three-dimensional pixel will have twenty-six (and only twenty-six) adjacent three-dimensional pixels. These three-dimensional pixels are located at a level (Level 1) below the pixel of interest, at the same level (Level 2) as the pixel of interest, or at a level (Level 3) above the pixel of interest. Figure 8 shows the basic unit (the three-dimensional pixel), the pixel of interest (pixel 10), the twenty-six adjacent pixels, and the three levels and identification number for each pixel.

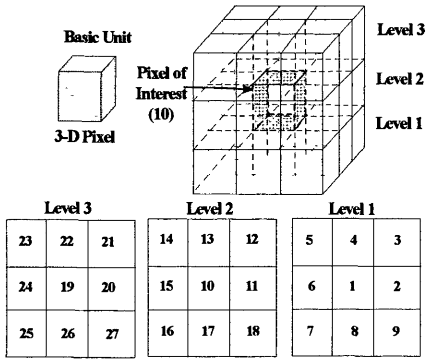


Figure 8. 3-D Freeman Code

Use of the Three-Dimensional Freeman Code Spatial features can be expressed by a three-dimensional Freeman code Figure 9 illustrates one such feature. The darker blocks indicate the skeletal representation of the feature A-B The three-dimensional Freeman code describing this feature is·

25 19 15 15 15 15 15 24 19 22 15 15 24 24

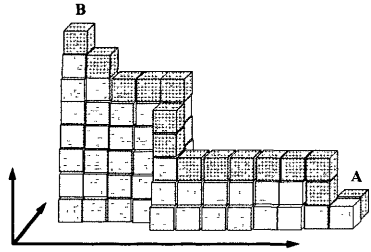


Figure 9. A 3-D Feature

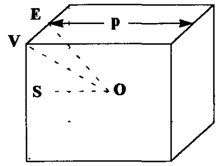
The length of this feature is computed by adding the space distances (Cartesian distances) of the different straight segments This is accomplished by expanding equation (3) to three dimensions, as follows·

$$d_{AB} = BU [(x_A - x_B)^2 + (y_A - y_B)^2 + (z_A - z_B)^2]^{1/2} \quad (13)$$

The length of the feature AB of Figure 9 is d_{AB} = 16 37 P (applying expression (13)). This is the result of computing the length of the eight straight segments of AB (in function of P) and adding the results

For three-dimensional computations, an additional value for BU needs to be considered. Figure 10 illustrates this, where OV is the new value. Notice that OS, OE, and OV in this figure are one-half of the distances between the centers of the pixels

Graphic Attributes As discussed by Ramirez (1991), the graphic characteristics of a feature in the vector model are defined by Bertin's (1983) visual variables: space dimensions **(SD)**, size **(SI)**, value **(VA)**, patterning **(PA)**, color **(CO)**, orientation **(OR)**, and shape **(SH)** The space dimensions **(X, Y, Z)**, the spatial locations of any geometric outline (skeletal representation), are covered by the geometric discussion of the previous sections.



$OS = (1/2)\,p$, $OE = (1/2)\sqrt{2}\,p$,
$OV = (1/2)\sqrt{3}\,p$

Figure 10. The Basic Distances in the 3-D Pixel

The variable **size** uses the change in the dimensions of a graphic sign to communicate a specific meaning to it, for example, the width of a line as shown by Figure 11-a The variable **value** expresses the different degrees of grays used in the representation of a graphic sign Figure 11-b is an example The variable **patterning** represents the design or pattern used in the construction of a graphic sign. Line types, line symbols, cross-hatching, and area patterning are examples of this variable, its use is illustrated in Figure 11-c The variable **color** represents the use of colors in graphic signs to attach a specific meaning to them. For example, in a map, the color blue is used to indicate water Figure 11-d shows the outline of three buildings with the words red, blue, and green to indicate the color of each one The variable **orientation** uses the alignment of graphic point signs as a way of communicating a particular meaning to them, Figure 11-e illustrates this Finally, the variable **shape** uses the outline of a graphic point sign to represent a specific feature as demonstrated in Figure 11-f

In the raster model only the variables **value** or **color** are used to express the graphic characteristics of pixels In the case that the Freeman code is used to describe a feature, additional Bertin visual variables could be used, such as **size**, **patterning**, etc In general, we can state that Bertin's visual variables are enough to express the graphic attributes of features in the raster and vector model, including those cases where the Freeman code is used

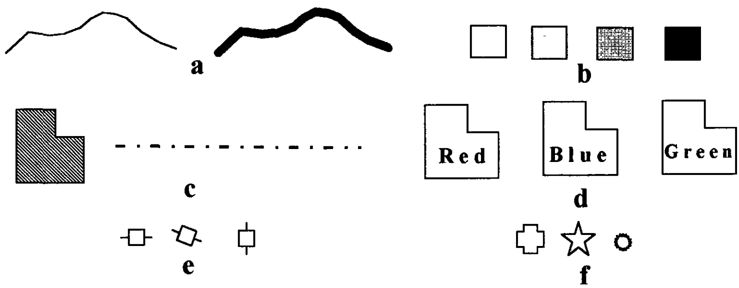


Figure 11 Bertin's Visual Variables

<u>Nongraphic Attributes</u> Nongraphic attributes are widely used in the vector model to carry additional information about the geographic features represented Typical examples of nongraphic attributes are the Digital Line Graph (DLG) codes (major and minors) used by the U S Geological Survey (USGS) Nongraphic attributes can be a combination of text and numeric characters In the case of the DLGs, for example, mostly numerical values are used The major code 50, for example, indicates that the corresponding feature belongs to the hydrographic category

In the raster model, in general, there are no nongraphic attributes at the individual pixel level In that case when the Freeman code is used to describe a feature, nongraphic attributes similar to the one for the vector model may exist

THE CURRENT STRUCTURE OF VECTOR AND RASTER MODELS

In the previous sections we have argued that raster and vector data can be expressed by a single global model and have proposed a framework that allows us to carry similar information for vector and raster ("smart" pixels) data On the other hand, we recognize that currently, raster and vector are considered different models and that software applications are developed for only one model In the following paragraphs we will present a summary of the major characteristics of practical implementations of the raster and vector data models today in order to understand better how the global model could be used. This will be followed by the outline of the new geographic data model

Raster and vector files carry positional and graphic information differently In the raster model, positional values are carried implicitly and graphic values (usually Bertin's **value** or **color** only) are carried explicitly for each **BU** From the viewpoint of the files' structure, generally in the raster model, there is one or more computer record (header) carrying common information for the geographic area represented In these records, at least the size of the **BU** and the extent of the area are defined Then, a value is carried for each **BU** (ignoring in this discussion any attempt to compress the data) Data are stored by rows or columns (not by feature).

In the vector model, positional values are carried explicitly by **significant points** Significant points are those positional points needed to define a feature uniquely, for example, the end points of a straight line, the center point and two arc points (and a direction convention) of an arc. Positional values may describe a complete feature, or different segments of a feature, depending on the data organization (spaghetti vs topology). Graphic values are carried per feature (not per **BU**) and, generally, there is a header with common information.

For the vector model, nongraphic attributes are combined with the positional, and the graphic attributes, in some cases, or in other cases may be combined only with the graphic attributes, or they may be stored in a different file.

It is obvious that current raster files are unable to carry the wealth of information of images of the future. On the other hand, vector files that have a less rigorous structure may be able to carry all type of additional information But, this will always require the conversion of raster information into vector. Either situation is not ideal. We want to be able to use all the information of the images of the future directly This is our motivation to present next the outline of a new geographic data model

THE OUTLINE OF A NEW GEOGRAPHIC DATA MODEL

It was indicated earlier that new mapping concepts are in development One of them, the TMS, at the Ohio State University Center for Mapping, will support real-time acquisition of raster images. It was also pointed out that such a concept will integrate many different sensors which provide additional information per pixel. It is expected that combining these pieces of information will allow the user to develop specific signatures for the identification of terrain features. All of this will be done in a highly automated fashion

Because digital images will be acquired, and because each pixel of these images will have a large amount of new information (compared with current pixels), it makes sense to consider an alternative to conventional raster and vector data models The new model must be raster based but it should have "smart" pixels "Smart" pixels are three-dimensional primitives which will allow the user to perform, in raster images, similar manipulations to those performed with current raster images, plus those manipulation and queries performed with vector data. Ideally, this model should allow the generation of images with "dumb" pixels only, "smart" pixels only, or with a combination of "dumb" and "smart" pixels.

The fundamental relationships for this model will be given by expressions (5) and (6), extended to a three-dimensional space. The raster primitives will be point, line, area, and volume. Their skeletal representations will be expressed by three-dimensional Freeman codes (see Figure 12 for examples of some of these primitives) Graphic and nongraphic attributes will be attached to them In this framework, these primitives will be used to generate more complex elements. Terrain features will be described as a whole, or as a set of segments. The last description will allow topological structuring of features

In this model we can conceptualize each pixel as a cube carrying information about the surrounding pixels and about the terrain it represents. Information will be spatial information in the form of spatial coordinates in a user-selected system, connectivity to other pixels, topologic relationships, graphic attributes, and nongraphic attributes.

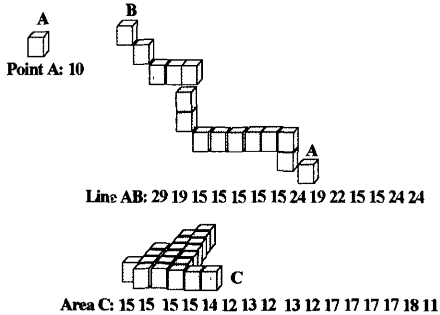


Figure 12 Point, Line, and Area Basic Raster Primitives

CONCLUSIONS

A conceptual framework to express raster and vector datasets has been presented This framework has been called a "global" model and allows us to express locations and geometric relation in both raster and vector domain by a single set of expressions From this, a framework for a new raster data model with "smart" three-dimensional pixels has been proposed. This raster model allows us to perform all current raster and vector manipulations and queries This new format will satisfy the requirement of the mapping systems of the future

The ideas presented here are being implemented at the Center for Mapping The new raster model is implemented as an extension of the Center for Mapping Database Form (Ramirez, at al., 1991), (Bidoshi, 1995)

REFERENCES

Bidoshi, K. (1995) Application of the Center for Mapping's Database Form (CFMDBF) for Evaluating DLG Road Coverages Using GPSVan Data, Internal Report, The Ohio State University Center for Mapping

Bossler, J D. (1996) Airborne Integrated Mapping System. An Initiative of the Ohio State University, *GIM*, Vol 10, 32-25

Heipke, Ch., Toth, Ch. (1995). Draft for Design of Total Mapping System, Internal Document, The Ohio State University Center for Mapping

Ramirez, J R (1991) Development of a Cartographic Language, *Proceedings COSIT'91.*

Ramirez, J.R., Fernandez-Falcon, E Schmidley. R , Szakas, J (1991) The Center for Mapping Database Form, Internal Report, The Ohio State University Center for Mapping