THE ENCODING OF CARTOGRAPHIC OBJECTS USING HBDS CONCEPTS

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ABSTRACT

In computer-assisted cartography, spatial data structures provide the means to organize digital data so that appropriate data can be accessed as needed. This spatial digital data includes representations of both primitives and compounds of cartographic objects and their associated spatial and nonspatial attributes and relationships. Current topological data structures are useful for encoding primitives of cartographic objects such as nodes, chains, and areas, but they do not serve as well for encoding compounds of cartographic objects representing such entities as counties, roads, and rivers. The Hypergraph-Based Data Structure (HBDS), through the use of the concepts of object, class, attribute, and link, provides a means of encoding both primitives and compounds of cartographic objects and their spatial and nonspatial attributes and relationships. This paper describes the concept of cartographic objects, discusses the basic units of the HBDS, and demonstrates the encoding of cartographic objects using these HBDS concepts.

INTRODUCTION

A map may be considered to be a "structured file in which entities [objects], conditions, and events are recorded" (Tomlinson, 1978, p. 181). As such, a map describes the spatial and nonspatial attributes of the individual map elements, and the selected spatial and nonspatial relationships between map elements (Nyerges, 1980a; Tomlinson, 1978; Youngmann, 1978).

In computer-assisted cartography, it is necessary to encode and to store these cartographic objects and their spatial and nonspatial attributes and relationships. McEwen and

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Calkins note that computer representations of cartographic data should "maintain the spatial relationships inherent in the data which are usually obvious to the human mind when visually examining a graphic or map representation of the data" (McEwen and Calkins, 1982, p. 19).

MAPS AND DATA STRUCTURES

The development of new methods of processing cartographic information has led to an expanded definition of what constitutes a map. Moellering (1984) recognized this expansion and described two types of maps: real maps and virtual maps. These types of maps are distinguished by two major attributes: (1) permanent tangible reality (or hard copy versus soft copy) and (2) direct viewability as a cartographic image (or graphic representation versus nongraphic representation). Moellering notes that the data contained in those map types that lack permanent tangible reality are extremely manipulable and form the mainstream of digital cartographic data processing.

When in the form of a graphic, the spatial attributes and relationships of the mapped phenomenon form the framework of the display. Nonspatial attributes and relationships of the data are represented by visual clues such as color, pattern, shape, size, and text. This graphic portrayal of the data yields the "surface structure" (Nyerges, 1980b) of the cartographic information. Spatial data structures encode the cartographic objects and the spatial and nonspatial attributes and relationships (or "deep structure" [Nyerges, 1980b]) inherent in the map graphic.

THE CONTENT OF SPATIAL DATA STRUCTURES

The purpose of a spatial data structure is to provide a model of spatial knowledge (Chrisman, 1978). The spatial data structure provides a basis upon which spatial queries may be performed; these queries entail an examination of the encoded spatial entities and their attributes and relationships (Lehan, 1986; Tomlinson, 1978; Touri and Moon, 1984). To understand the concept of spatial data structures, an examination of these entities and relationships is in order.

Cartographic Entities and Objects

Cartographic entities are the real world features that are represented in a spatial data structure. These entities include such features as roads, rivers, and political units. Cartographic objects are used to represent these entities in the spatial data structure.

Extending the concept of cartographic objects, Youngmann (1978) and Nyerges (1980a) distinguish between primitives and compounds of cartographic objects. In topological data structures, the primitives include nodes, chains, and areas.

The compounds of cartographic objects are composed of collections of these primitives. For example, an object representing a lake may be composed of a area and a bounding ring; the ring, in turn, is composed of nodes and chains.

Cartographic Attributes and Relationships

As noted above, a map describes the spatial and nonspatial attributes of the encoded objects and the spatial and nonspatial relationships between these objects. Three types of attributes and relationships have been defined: geometric, graphic, and phenomenological (Nyerges, 1980a; Youngmann, 1978). The spatial aspect of attributes and relationships is included in the geometric and graphic concepts; the nonspatial aspect of attributes and relationships is included in the phenomenological concept.

The attributes of an object serve to locate, to orient, and to identify the object. The geometric aspect of the attribute describes the form or shape of the object. The graphic aspect describes the location and orientation of the object. The phenomenological aspect gives the object meaning; this aspect includes such information as the name, properties, and valuation of the object. These attributes provide the most basic description of the object and are common to all spatial data structures.

The relationships between map objects describe the linkages between objects. The spatial aspects (graphic and geometric) include the topological and metric information about the relationships between objects, including the qualities of distance, adjacency, and connectivity. The phenomenological aspect serves to link objects through their meaning or valuation. An example of a phenomenological relationship between objects is the link between objects representing counties of a particular state.

THE HYPERGRAPH-BASED DATA STRUCTURE (HBDS)

Current vector-based data structures (such as the spaghetti model and topologic model described by Peuquet [1984]) emphasize the encoding of the spatial attributes and (or) relationships of the primitives of cartographic objects. In the discussion about the contents of spatial data structures, it was noted that the phenomenological (or nonspatial) aspect of attributes and relationships of these objects is essential to the complete representation of the cartographic information. The Hypergraph-Based Data Structure (HBDS) (Bouillé, 1981a, 1981b, 1982, 1984) is one mechanism for representing this information.

HBDS Concepts

The HBDS is based on two fundamental concepts: the set and the hypergraph. The set "consists of elements which are capable of possessing certain properties and of having certain relations between themselves or with elements of different sets" (Bourbaki, 1968, p. 347). A hypergraph is "defined to be a family of hyperedges which are sets of vertices of cardinality not necessarily 2" (Berge, 1973, p. viii). Thus, a hyperedge may link more than two vertices. The concept of the set allows for the grouping and relating of objects; the concept of hypergraph allows a method of representing these groupings and relations.

There are six fundamental units used to define the phenomenon represented in the HBDS: the class, the object, the attribute of the class, the attribute of the object, the link between classes, and the link between objects (Bouillé, 1981a, 1981b, 1982, 1984; Rugg, 1983).

The class is a set of elements; these elements have some common properties that provide the definition of the set. The class is graphically represented by an edge of the hypergraph enclosing the vertices representing the elements of the set.

The object is an element of the set (class). The object has properties corresponding to those used to define the set. Objects are represented graphically by individual vertices on the hypergraph.

The attributes of the class are the properties which define the class. These properties are verified (and valued) by the objects placed in the class. The attributes of the object are the particular values of the attributes of the class provided by the individual objects inserted in the class. It is possible that some of these attributes may contain a null value for some of the objects in the class.

A link between classes indicates the possibility of a relationship between the objects of the same or different class(es). These links encode the underlying relationships between the different components (classes) of the phenomenon. There may be multiple links between two classes; each link, however, indicates a different relationship. Graphically, these links are represented by arcs connecting the classes of the hypergraph. Links between objects encode the relationships actually present between objects used to describe a particular phenomenon. Thus, the links between objects confirm the links between classes hypothesized in the model of the phenomenon.

Additional constructs, such as the multilink, hyperlink, and the hyperclass, are used to simplify the hypergraph-based description of a phenomenon. These constructs are based on parallel links between classes.

Representation of Cartographic Objects

Primitive Objects. Three classes of objects (nodes, chains, and areas) contain the objects used to define the line graph representing the map. The attributes of these classes include spatial (positional) and nonspatial (classification) information. The links between the classes represent the topological relationships (connectivity and adjacency) between the objects of these classes.

An example of the hypergraph for these topological primitives is given in Figure 1. The classes and links between classes in Figure 1a show the objects and relationships encoded. The links between classes include: (1) chains beginning and ending at nodes (link I), (2) nodes having chains entering and exiting them (II), (3) areas bounding

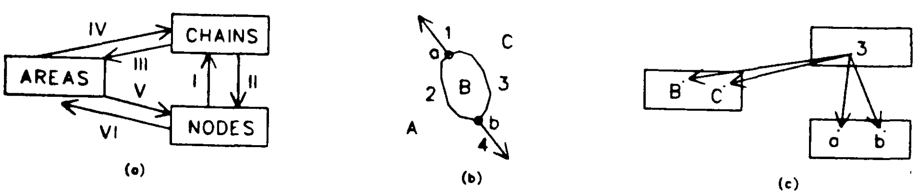

Figure 1. Classes, objects, and links between classes for primitive objects (after Bouillé, 1981a).

chains to the left and right of their direction of travel (III), (4) chains bounding areas in clockwise/counterclockwise directions around their perimeters (IV), (5) nodes surrounding areas (V), and (6) areas surrounding nodes (VI). A portion of a line graph is given in Figure 1b (nodes labeled with lowercase letters, areas with block letters, and lines with numbers). The objects and links between objects for line 3 are illustrated in Figure 1c.

Compound Objects. Compound objects represent real world entities. A class is established for each set of similar compound objects. The attributes of each class include spatial and nonspatial descriptions of the objects in the class. Links between classes include (1) those between the classes of compound objects and classes of (component) primitive objects and (2) those between the same or different class(es) of compound objects. The first set of links serves as a directory to the primitive objects of the line graph; this ability is especially useful where a single line graph is used to portray several themes of data. The second set of links allows a compound object to be expressed in terms of related compound objects. These links may encode the phenomenological relationships between objects of these classes. These links are useful in a variety of queries.

An example of the description of the form of compound hydrographic objects is shown in Figure 2. The hypergraph in Figure 2a describes the classes and links between classes. Linear portions of hydrographic objects are linked to their constituent nodes and chains (link I). Areal portions of hydrographic objects link to a class of bodies of water (II). This class links to a class of constituent area primitives (III), and to a class of enclosing shorelines (IV). The class of shorelines links to the classes of constituent nodes and chains (V). Using links between classes and objects (VI), compound objects of one class are related to compound objects in the same or different class(es). The compound objects represented by a portion of the line graph is shown in Figure 2b. The objects and links between objects for the object representing Lake Z is shown in Figure 2c.

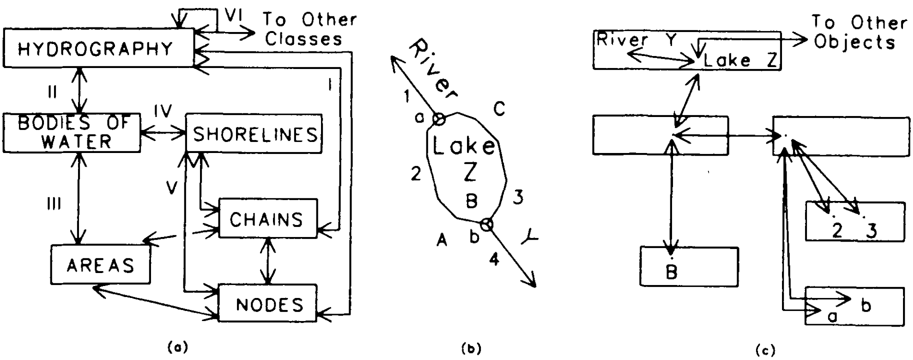

Figure 2. Classes, objects, and links describing compound objects.

SAMPLE IMPLEMENTATION

Using these HBDS concepts, a data set containing selected political units, federal reservations, roads, and hydrography for the State of New Mexico was collected as a single line graph. The political units (States and counties) and the federal reservations were encoded using the hypergraph shown in Figure 3a; the roads were encoded using the hypergraph in Figure 3b. The hydrography was encoded using the hypergraph illustrated in Figure 2.

A small query program was written to exercise this data set. Queries are handled by examining appropriate portions of the hypergraph representing the classes, objects, attributes, and links describing the mapped phenomenon. Some sample queries, and portions of the hypergraph required to respond to the query, are given below.

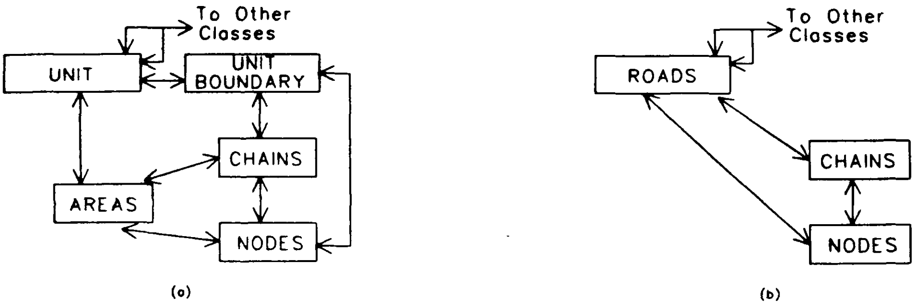

Figure 3. Portions of the hypergraph used to describe political units, federal reservations, and roads.

One query involves the compound objects and their attributes and links. For example, to list all of the roads in county J involves searching the objects of class counties until the object with the name attribute J is found. This object is linked to related objects in class roads (in this example, roads M and N). The name attributes of these objects are used to generate the list of roads in the county. The links used are shown in Figure 4.

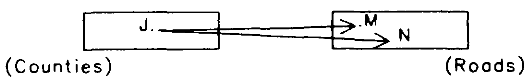

Figure 4. Objects and links exercised in a compound object query.

Similarly, queries concerning the graphic depiction of a compound object exercises the objects, attributes, and links of classes containing compound and primitive objects. To draw the State of New Mexico, the class of State objects is searched to find the object with the name attribute New Mexico (Figure 5). This object is linked to the object representing the boundary of the State, which is linked to the component chains. The positional attributes (coordinates) of these objects are retrieved to generate the display.

More advanced queries involve the objects, attributes, and links between compound objects and between compound and primitive objects. The results of one such query are illustrated in Figure 6, which depicts all counties in New Mexico traversed by interstate highways.

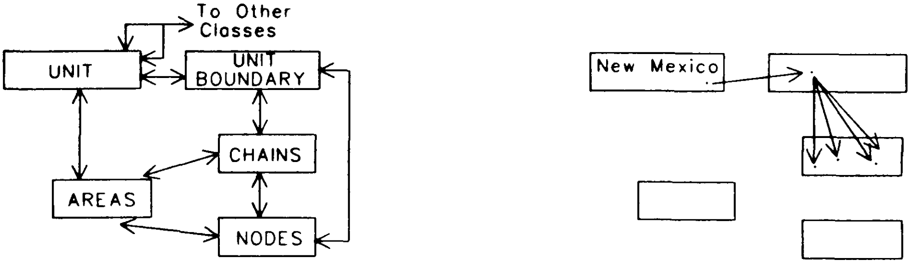

Figure 5. Objects and links exercised in a compound object-primitive object query.

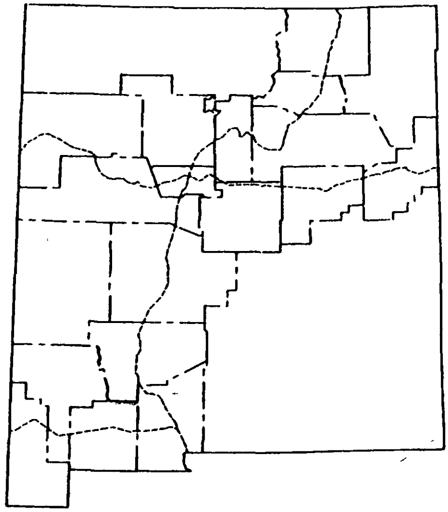

Figure 6. Results of query to display all counties in New Mexico traversed by interstates highways.

SUMMARY AND CONCLUSIONS

In spatial data structures, real world entities are represented by cartographic objects. These objects have attributes that describe the object and relationships to other objects. Both spatial and nonspatial attributes and relationships may be associated with these objects.

The concepts of the Hypergraph-Based Data Structure have been demonstrated to be suitable for the encoding of cartographic objects. Classes, objects, attributes of classes, attributes of objects, links between classes, and links between objects have been employed to encode cartographic objects and their spatial and nonspatial attributes and relationships. Queries are resolved by using appropriate portions of the hypergraph describing the mapped phenomenon.

The HBDS approach allows compound cartographic objects to be described directly in terms of topological primitive objects, as well as by related compound objects. This ability is an advantage over the basic topologic model described by Peuquet (1984). In addition, these classes of compound objects may serve as directories to component topologic primitives for integrated line graphs representing different themes of data.

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