A FORMAL MODEL OF A CARTOGRAPHIC INFORMATION BASE

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Introduction

A hierarchical web grammar for a cartographic information base combines a web grammar (graph grammar) introduced by Pfaltz and Rosenfeld [6] with a phrase structure grammar discussed by Youngman [9]. A web grammar is appropriate because of its natural two-dimensional character; and a phrase structure grammar is appropriate because it conveys conceptual notions about internal cartographic structure. The combination of these grammars provide a linguistic formalism for a cartographic information base. An information base is an extended notion of the data base concept; it integrates conceptual information and program modules into a data base to increase data processing flexibility.

Data Base Models

The three types of data base models are: hierarchical, network and relational [3;4]. The hierarchical model is a subset of the network type, and can be formulated as if it is a directed network. The relational model has been shown to be relationally equivalent to the network model under certain transformations. That is, when the relational model is inverted so that an attribute, rather than a relation, is a primary key a psuedo-pointer structure is set up. This pointer structure is similar to that in a network model [1;5].

The fundamental building block of a data base is a record type. A record type consists of one or more data items. The data items name actual data in a record occurrence of a given record type. A one-to-many relationship defined between two record types is called a set. One of the record types is declared the owner of the set and the other the member. Each record occurrence of the owner record type "owns" zero, one or more record occurrences of the member record type.

The schema of a data base consists of data items, record types and set relationships between record types. Actual data is related to the schema through the data item names and record types. The schema, depicted by a graph, is thus a logical description of the actual data occurrences.

Two properties of a data base can be characterized by a linguistic model: (a) the structure of the data base and (b) the storage and retrieval capabilities of the data base. It must be emphasized that a grammar derived for a data base does not necessarily describe a data base in a unique manner, but what is important is that it is a formal characterization.

Linguistic Models and Data Bases

A linguistic model for a hierarchical data base is a context free grammar [1;9]. The grammar G_H is a triple: $G_H = (V,I,R)$, where V is a set of vocabulary elements; $I = 1$ is an initial symbol; and R is a set of production rules. The set V is composed of two, non-empty, finite, disjoint subsets; $V_N = \{1,2,3,4,5,6\}$ is the set of non-terminal labels denoting record types; and V_T is the set of terminal elements representing data. The symbol I initiates a set of productions which generate a schema for a hierarchical data base (See Figure 1).

The drawbacks to the hierarchical model are obvious. There is no provision for sharing data elements between records, thus redundancy may occur. The network model ameliorates this problem because it provides for a relationship whereby data can be shared. Consequently, the primary difference between the hierarchical model and the network model is that a member of a set may have only one owner in the hierarchical case, but a member record may have more than one owner record in the network case.

A grammar for directly modelling a network data base is context sensitive because two different record types may own the same member record. This situation produces a particular context of ownership, hence a production of record types transpires only in this context. The formulation of such a context sensitive grammar would require a different rule for every set relationship. However, an alternative way of viewing a network data base is as the intersection of one or more hierarchical data bases. This viewpoint has an historical basis. Since sequential file processing is a form of hierarchical storage processing, a collection of interrelated sequential files constitute a network data base. Therefore, given a data base it is sufficient to find a group of hierarchical structures of which the network data base is the intersection (See Figure 2). If a hierarchical data base is described by a context free grammar then an interrelationship of hierarchies (which is a network) is capable of being described by an interrelationship of context free grammars. Thus, to represent the network structure as a hierarchical structure a transformation is required. This transformation is simply the computation of all maximal hierarchical paths through the network as is performed in Figure 2b. It should be emphasized that the hierarchical form produced in Figure 2b is accomplished through a process of path determination, and not by storing the data in this manner. A drawback in this model of a network data base, as pointed out in the grammar, is that it is a single level network, i.e. the productions of the grammar only generate relationships on a single conceptual level. A single conceptual level is inappropriate for a cartographic data base because it limits the potential of utilizing "conceptual information" for query processing.

A Cartographic Information Base

Two features added to a network data base extend it into an information base: (a) the introduction of conceptual levels and (b) the ability to handle the integration of programs into its logical structure (only the former is discussed in this paper, see [2]). With the introduction of conceptual levels to a data base, a new type of set relationship is added. This relationship is called a "vertical set". A vertical set relationship is different from the set relationships discussed in the previous sections. Those discussed previously are of the CODASYL set type, and refer to what will now be called a "horizontal set" relationship. These horizontal set relationships occur on a single, conceptual level of a network. The vertical set is used to identify a relationship between one conceptual level and another (higher to lower). A horizontal set is a functional relationship whereas the vertical set is more like a mathematical set. In a vertical set an owner is a record type while a member is a data item occurrence. These vertical sets become the production rules of the linguistic model (discussed in the next section).

A different notation, i.e. different than the schema graph, is utilized to simultaneously display vertical and horizontal set relationships in an information base (See Figure 3). The nested boxes represent vertical sets of an information hierarchy. Each set is an information parcel. In each parcel a record type encloses the data item occurrences which are related to that record type on a given conceptual level. In turn, each of the data item occurrences may become a record type on the next lower conceptual level (lower in a sense of being closer to primitives). The horizontal set relationships are denoted by the dotted-line arrows, with the tail emanating from the owner and the head pointing at the member. The portion of the information base shown is that which directly concerns cartographic entities. However, a dummy record, labelled "Thematic Identification", is included to incorporate thematic data from another data base. This is accomplished by using a horizontal set relationship.

A Grammar for a Cartographic Information Base

A hierarchical web grammar serves as a formal linguistic model for a cartographic information base. The grammar generates a multi-level, network structure of cartographic information. Webs represent the levels in the derivational process of the information hierarchy. A web W on a vocabulary V of labelled elements is a triple: $W = (N_W, A_W, f_W)$, where N_W is a set of nodes in W; A_W is a set of arcs that represent relationships between unordered pairs of distinct nodes; and f_W is a function from N_W into V which labels each node of N_W as a record type. A web $\alpha = (N_\alpha, A_\alpha, f_\alpha)$ is a subweb of W if: N_α is a subset of N_W; A_α is a subset of A_W; and f_α is the function f_W restricted to N_α into V. This notion of subweb is crucial to the production of web nodes (record types) in the grammar.

An underlying graph which carto-graphically depicts a web W is defined by the pair (N_W, A_W); hence a web is a graph with labels. If a pair of nodes (m,n) is in A_W, the pair forms a horizontal set relationship. These pairs are usually defined only in the terminal web of the hierarchy because nonterminal, conceptual elements are only weakly related through a process of cartographic inference. The terminal web becomes a general spatial data structure which allows spatial-query processing (See [7;8]).

Formally, the grammar is a triple G = (V,I,R). The set V is a vocabulary consisting of two, finite, non-empty subsets: V_N, the set of labels for nodes, and V_T, the set of data. The symbol I initiates the productions in the grammar. The set R is composed of production rules which rewrite the subwebs, i.e. generate the host web W. A production rule is a quadruple: R = (α, β, C, E), where α and β are the subwebs of W (β is to replace α in the rewrite operation), C is a logical function acting as a contextual condition for replacing α with β in W, and E is an embedding function which specifies the linkage of nodes N_β in the subweb β to nodes $N_{W-\alpha}$ in the subweb $W-\alpha$, the complement of α. These neighboring nodes become members of A_W.

Productions are documented in two ways: (a) by an ordered listing of the production rules which are employed (See Table 1); or as a tree diagram (See Figure 4). The nonterminal elements of the production rules are record types in the information base. Primitive object-types are the record types associated with occurrences of primitive objects. These occurrences are the terminal elements of the grammar. It is the primitive object occurrences which are manipulated in a cartographic query and viewed as the cartographic objects on a cartographic display (See Table 2).

References

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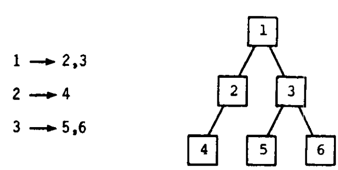

Figure 1. Production Rules and a Hierarchical Schema

Table 1

Subweb Production Rules

	α *		β **		α *		β **
(1)	I (Initial Element)	→	R M	(9)	Sc (Scale)	→	Sym
(2)	R (Reference Base)	→	Gb Rl	(10)	Mb (Map Border)	→	Li
(3)	M (Message Theme)	→	T S	(11)	Ll (Lat./Long.)	→	Sym
(4)	Gb (Geographic Base)	→	Fo Sc	(12)	Tm (Tic Marks)	→	Sym
(5)	Rl (Reference Lines)	→	Mb Gl	(13)	T (Title)	→	Nd
(6)	S (Symbolization)	→	L D	(14)	L (Legend)	→	Sym Nd
(7)	Gl (Grid Lines)	→	Ll Tm	(15)	D (Data Domain)	→	Sym Nd Ch Li Po
(8)	Fo (Feature Objects)	→	Sym Nd Ch Li Po				

*Definition of nonterminal node labels given in parentheses.

**Definition of primitive object-types given in Table 2.

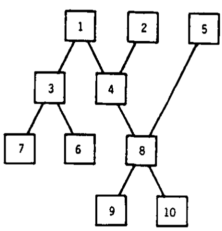

Figure 2a. Network Schema

Table 2

Primitive Object-Types

Label	Object-Type*	Attributes
Nd	Node	Pt,L
Sym	Symbol	Pt,T,V,L
Ve	Vector	Pt,Rho,D,V,L
Ar	Arc	Pt,Pt,Rad,V,L,
Sec	Sector	Pt,Rad,Rho,Theta,V,L
Ch	Chain	Nd + Str + Nd
Li	Line	Ch + Ch + Ch ...
Po	Polygon	Pt,V,L,Li

where the attributes are defined as:

Pt (point) : an x,y coordinate pair
Str (string) : a list of coordinate pairs
V : a numeric value
L : a text label
T : a symbol prototype
RHO : an angle of rotation
Theta : an angle of openning
D : a distance
Rad : a radius

*Based on Bracchi and Ferrari, 1971 and Youngman,1977

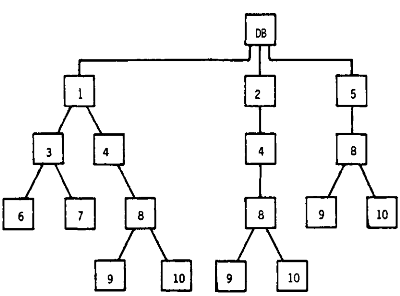

Figure 2b. Transformed Network Schema

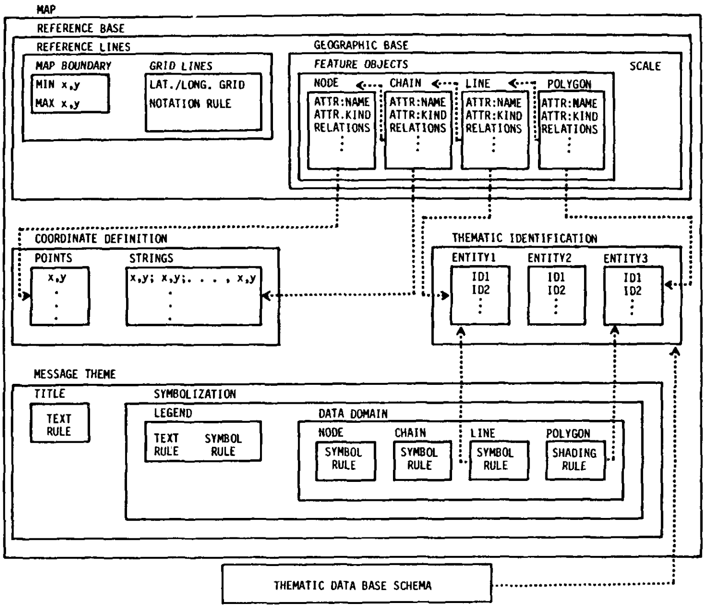

Figure 3. Information Base Schema

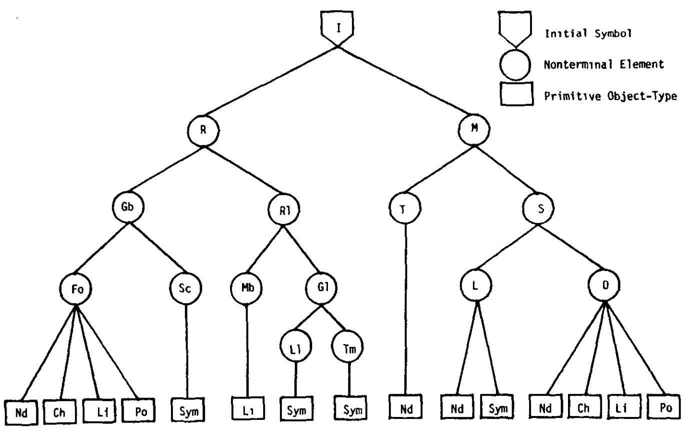

Figure 4. Hierarchical Web Marker