Paper

Effective Representation of Road Network on Concept of Object Orientation

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A country-wide Integrated Geographic Information System (IGIS) is very useful in providing good access to essential geographic information, and making sound decision. The primary objective of such a system is to ensure that users of spatial data should acquire consistent datasets to meet their requirements, even though the data is collected and maintained by different authorities. In this paper, we analyse the relations among map information in a country-wide GIS, and address a Multi-scale/Multi-theme (M^2) map information model for manipulating country-wide integrated maps of different scales for different themes. This information model is powerful to integrate various scales of maps uniformly and possesses advanced extensibility. We give the representation of road network in the model, and evaluate our model with a prototype system.

Keywords: Integrated Geographic Information Systems (IGIS), map information model, multi-scale model

1. Introduction

A country-wide Integrated Geographic Information System (IGIS) is very useful in providing good access to essential geographic information (spatial data), and making sound decision in country's economic growthes and its social activities. The primary objective of such a system is to ensure that users of spatial data should acquire consistent datasets to meet their requirements, even though the data is collected and maintained by different authorities. However, there are many problems in developing a country-wide system, such as:

1) Information consistency. The system consists of spatial data varying in regions, map scales and themes, and is managed by individual custodians, distributedly. For instance, highways and national roads are managed by the national organization and the local roads within a city may be managed by the city. To keep information consistent is quite important under the distributed environment;
2) Extendibility. The system cannot only provide public spatial data for end-users, but also can provide a platform for GIS developers to generate their theme of spatial databases in consistence with the public data. So, the database is not only large and distributed, but also possesses the extendibility at the directions of either map regions, map scales or themes.

In this paper, we analyse the relations among map information in a country-wide GIS, and address a Multi-scale/Multi-theme (M^2) map information model for manipulating country-wide integrated maps of different scales for different themes. The model can be regarded as a forest consisting of two kinds of trees: one is a directory tree, which is obtained by recursively decomposing the region of a country into a sequence of increasingly finer tessellations with regard to the granularities of administrative units; and another is a series of theme trees, which are obtained by uniquely dividing spatial objects into different themes and then in every theme, by dividing them into different scales in regard to the important degree, ownership or display needs of them [1]. Also theme trees are divided into different tessellations in regard to the directory tree. This information model is powerful to integrate various scales of maps uniformly and possesses advanced extensibility.

In this paper, we formalize our model and also give the representation method for managing road network. At the end of this paper, prototype systems and evaluation of our model are given.

2. Related Work

In a country-wide map management system, the need for multi-resolution and multi-theme arises. At different resolutions, the same information is usually drawn differently (not just magnified or reduced). Because cartographic generalization cannot be fully automated [2], map production systems have to explicitly store several representations of the geometry of objects. This can be done either by keeping a separate database per scale range, or by using a multi-scale database [2]. Several multi-resolution models have been proposed. Leung, et al. [3] proposed a model which is capable of representing space in multi-scales in an integrated way. They discussed the abstraction of space via three interrelated hierarchies: the spatial conceptual hierarchy, the entity hierarchy and the feature hierarchy. According to these hierarchies, only the shapes of simple entities at every scale are stored, and the shape of the composite entity can be obtained from the simple entities. The model assures that maps can be displayed customarily. However, every entity pocesses spatial information for every scale, respectively, and there is no relation among entities belong to different scales. To keep information consistency is complicated when there is modification in a specific area at a specfic scale. Timpf [4] also proposed a hierarchical data structure for managing map objects at different scales, and specified the behavior of map objects over scales. They built a multiple presentation database with capabilities for rapid zooming. However, the hierarchy they used to arrange spatial entites is too simple: for example, their trans-hydro network is represented only by a filter hierarchy, road segments displayed at every scale based on the same road segment set. To represent country-wide map information in this model will be result in two problems. One is that at the less detailed scale the road network is displayed by using the most detailed data. Comparing to the customary map at that scale, there are too many nodes (which split road into road segments) on the road network. Another problem is that too many nodes would make the road search less efficient. Spaccapietra, et al. [5] and Parent, et al. [6] proposed the MADS conceptual model for managing multiple representations of the same real world entity at different scales. In this model, the spatiality may be associated to object types, attributes, relationships, and aggregation links, and topological relationships between objects are described explicitly. However, the redundancy among multi-representations and the complications of modifying topological relations exist.

So, we propose M^2 map information model. In our model, the directory tree provides hierarchical subdivisions to encode the decompositions of regions at multiple resolutions, and theme trees take responsibility for their theme map information in accordance with the region decomposition defined by the directory tree. Two kinds of hierarchies ensure the extendibility and consistency of the system, and efficiently support extraction of information satisfying a given level of detail for a specific region or themes.

3. Framework

In this section, we address M^2 map information model for manipulating country-wide integrated maps of different scales for different themes. We first give the basic definitions of spatial entity and map, and then discuss maps via two kinds of interrelated hierarchies: namely, the directory tree and theme tree. We also give a set of definitions for our model, formally.

3.1 Spatial Entity and Map A **spatial entity** is a term in our model to refer to a phenomenon with a shape. The shape of an entity may be one of, or a combination of three basic types in two-dimensional Euclidean space R^2: node, link and polygon,

1) Node is a point in two-dimensional Euclidean space R^2;
2) Link is a straight-line segment whose endpoints are nodes, and no two links intersect except a common endpoint;
3) Polygon is a union of links whose interior is a closed simple-connected polygonal region.

A **map** can be defined as a collection of spatial entities, and is drawn according to a given scale and for a specific region: e.g., a city map on 1:15,000 scale. A **theme map** is a kind of map which can be defined as a collection of homogeneous spatial entities: e.g., a road network map in a city of 1:15,000 scale. A **multi-theme map** can be got by overlaying several theme maps with common region.

3.2 Map Region and the Associated Hierarchy Every map has boundary, which limits the map extension to a specific region. Usually, a map region is defined by the administrative units, and can be decomposed into a sequence of increasingly finer tessellations.

In our model, a division Σ is defined by a polygon R, called region. A directory tree DT is obtained by recursively decomposing a region into a sequence of increasingly finer tessellations. To define it formally, a sequence of conditions $l_0,...,l_h$ is given. A directory tree DT, based on a sequence of l_0,...,l_h, is a pair ($\sum$,$\leq_d$), where $\sum$ =$\{\Sigma_0,...,\Sigma_m\}$ is a collection of divisions:

1) Σ_0 satisfies conditions $l_0,...,l_h$;
2) The condition l_k such that k = min{q |Σ_i satisfies conditions $l_q,...,l_h$} is called the level of division Σ_i, and denoted by $Level(\Sigma_i)$;
3) For every $1 \leq j \leq m$, Σ_j with region R_j satisfies $Level(\Sigma_j) = l_k$. If there is Σ_i, whose region R_i covers R_j, Σ_i is an ancestor of Σ_j ($\Sigma_i \in Ancestors(\Sigma_j)$), and Σ_j is a descendant of Σ_i ($\Sigma_j \in Descendants(\Sigma_i)$). This relationship is denoted by $\Sigma_j \leq_d \Sigma_i$. If Σ_i satisfies $Level(\Sigma_i) = l_{k-1}$ and R_i covers R_j, Σ_i is the parent of Σ_j, and Σ_j is a son of Σ_i. This relationship is denoted by $\Sigma_j = Son(\Sigma_i)$ or $\Sigma_i = Father(\Sigma_j)$;
4) $\leq_d$ is a partial order on $\sum$ (e.g., reflexive, antisymmetric and transive). For every Σ_i, $l_0 < level(\Sigma_i) \leq l_h$ and $\Sigma_i \leq_d Ancestors(\Sigma_i)$. For every Σ_i, $l_0 \leq level(\Sigma_i) < l_h$ and $Descendants(\Sigma_i) \leq_d \Sigma_i$.

The sequence of conditions l_0,...,l_h defines the desired level of administrative units: e.g., l_0 for the country level and l_1 for prefecture level.

We give an example in Figure 1. Figure 1(a) shows a map series of Japan, Aichi prefecture, Nagoya city and so on with only map boundaries, and Figure 1(b) gives a hierarchy of the map series, which is exactly an example of directory tree for the country-wide GIS.

3.3 Map Theme and Theme Hierarchy There are many themes in a country-wide GIS, and even inside one theme there are many different detailed maps. For example, a national organization manages the highways all over the country on a country map scale, and a prefectural organization manages more detailed road information including the highway information and prefectural roads information inside the prefecture. There is also a hierarchy consistent to the directory tree. We formalize this kind of hierarchy as theme tree. In a country-wide GIS there are many theme trees.

A section ε is defined as a set of spatial entities {se}. Co is a function defined as:

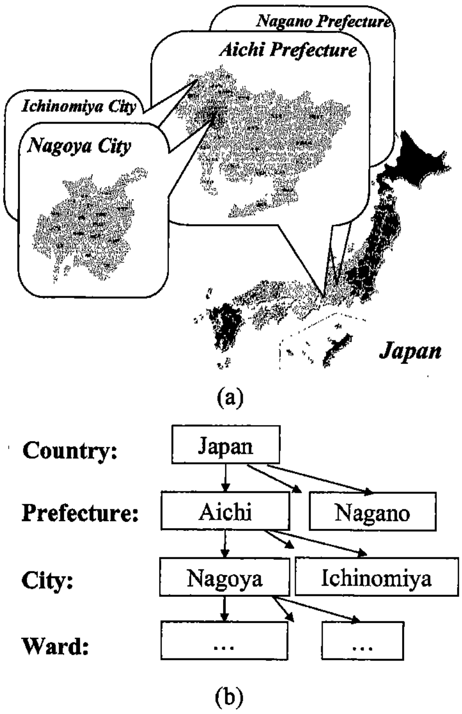

Fig. 1. Example of maps and corresponding directory tree.

$$Co : \Sigma_i - > \{..., \varepsilon_j, ...\}$$

and means that there may be many sections (on theme trees) corresponding to a division (on directory tree) of a specific region at a specific level. An example is given in Figure 2. The highways in Japan are defined as a set of highways, which are located inside the region of country "Japan", and are managed by an organization at the country level. So, the section of Japan highways corresponds to the country level of division "Japan"; and the prefecture road in Aichi prefecture corresponds to the prefecture level of division "Aichi".

The theme tree TT is a triple $(\epsilon, \leq_t, f)$, where

1)ϵ is a finite set of sections $\{\varepsilon_0, ..., \varepsilon_m\}$;

2)$\leq_t$ is an order on ϵ defined as: $\forall \varepsilon_i, \varepsilon_j \in \epsilon$, $\exists\ \Sigma_i$, $\Sigma_j \in \sum$, $\varepsilon_i \in Co(\Sigma_i)$, $\varepsilon_j \in Co(\Sigma_j)$,

$$\Sigma_j \leq_d \Sigma_i \Leftrightarrow \varepsilon_j \leq_t \varepsilon_i$$

and there are corresponding definitions of Descendants and Ancestors. We define $Region(\varepsilon_i) \equiv R_i$ and $Level(\varepsilon_i) \equiv Level(\Sigma_i)$;

3)f is a set of refinement functions defined as: $\varepsilon_i, \varepsilon_j \in \epsilon$, $\varepsilon_j \leq_d \varepsilon_i$,

$$f(\varepsilon_i, \varepsilon_j) \rightarrow \varepsilon_{ij}.$$

It refines a section of a theme tree: all the spatial entities of ε_{ij} are represented in $Region(\varepsilon_j)$ and at the scale the same as $Level(\varepsilon_j)$. The set of spatial entities of ε_{ij}, SE_{ij}, is a union of SE_i and SE_j based on predefined relations (supplement and generalization, which are defined in the next section) between the subsets of SE_i and SE_j.

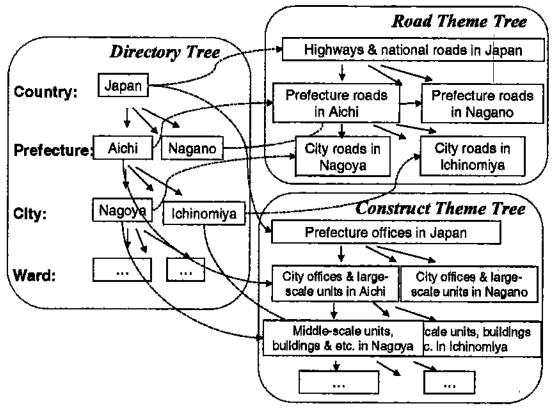

Fig. 2. Example of directory tree and theme trees.

3.4 Formulation of the Model

To represent and manage map information for a country-wide integrated GIS, we address a Multi-scales/Multi-themes (M^2) map information model, which does not only meet the need of integration and retrieval for GIS but also possesses the extensibility and scalability. In M^2 model, map elements are looked upon as objects (the same as spatial entities be used in this paper) and are uniquely assigned to the appropriate theme, scale and region without being duplicated among them.

Informally, the model composes a directory tree, which defines the map regions with corresponding scales, and some theme trees, which define a series of specific theme maps hierarchically. We give a definition of our model in UML (as Figure 3). The structure of the model mainly consists of two kinds of separated and related hierarchies: the directory tree and the theme tree, which can be expressed by a triple

$$M^2 = (D, T, Co)$$

Here, D is a set of directory trees (DT), T is a set of theme trees (TT), and Co is a mapping from D to T, which are defined previously.

The model is powerful to integrate various scales of maps uniformly. However, it is necessary to aggregate and arrange different scales of data derived from different levels adaptively and then propagate the information from upper levels to lower level. For the purpose of propagating the objects of upper levels to the lower level, inheritance functions are developed. With the input of upper levels' objects on a small scale and relations between upper and lower levels, inheritance functions produce lower level's theme map on a large scale, and at the same time overlay functions are developed to merge the map elements in different themes into one multi-theme map. That is to say, for a particular application, map information on needed scale can be prepared dynamically by using inheritance functions and overlay functions. Figure 4 shows the aspect of multi-scales/multi-themes for point and line objects. In each theme (theme (i) and theme (i + 1)), inheritance functions propagate management data in upper level (level (j)) to lower level (level (j + 1)) and get the display data of level (j + 1). Then, overlay functions

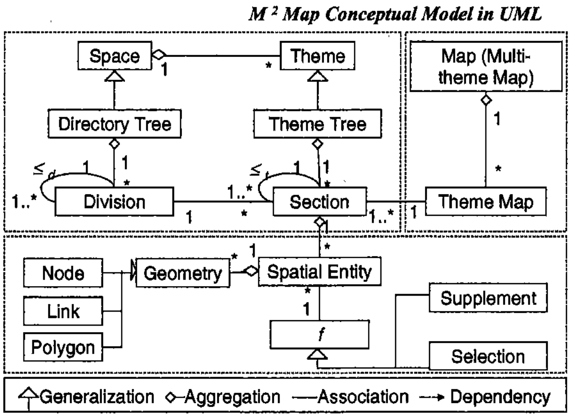

Fig. 3. M^2 map conceptual model in UML.

merge multi-themes and get a multi-theme map on the scale of level (j + 1).

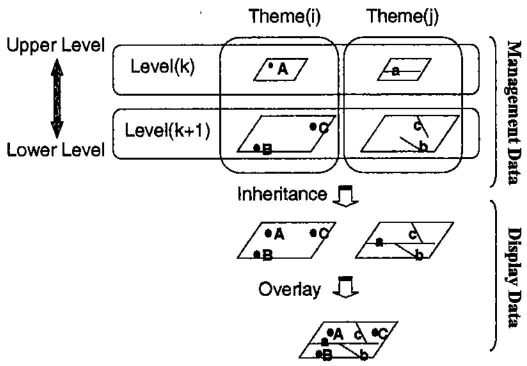

Fig. 4. Aspect on multi-scales/multi-themes with point and line objects.

We define theme map as TM_ε, which is a map of a theme on the section ε, and denote it by a triple $(SE_{TM}, R_{TM}, L_{TM})$: $SE_{TM} = \{se | se \in SE_\varepsilon \cup SE_{Inherit(\varepsilon)}\}$, $R_{TM} = Region(\varepsilon)$, $L_{TM} = Level(\varepsilon)$.

To generate a theme map for a required region at a specific scale consists of two steps: one is a filter step, which records division series $\Sigma_0, ..., \Sigma_i$ on the directory tree. The regions of these divisions cover the required region. Another is a generation step, which generates the theme map by using inheritance functions, based on the corresponding sections in the theme tree. The inheritance function, $Inherit(\varepsilon_i)$ (Table 1), uses the refinement function f defined in the previous subsection to tansfer all the spatial entities in ancestors of ε_i from the root level ($Level(\varepsilon_0)$) to $Level(\varepsilon_i)$, recursively.

Multi-theme map (MTM) $(SE_{MTM}, R_{MTM}, L_{MTM})$ can be generated by overlaying several theme maps (as Figure 4) .

Table 1. Inherit function.

```
function Inherit(ε : section):section;
begin
   if ε == ε0
        then return ε
        else
            return f(Inherit(Parent(ε), ε);
end.□
```

$$MTM = Overlay(TM_{\epsilon_i}, ..., TM_{\epsilon_j})$$

$$SE_{MTM} = \{se | se \in SE_{\varepsilon_i} \cup ... \cup SE_{\varepsilon_j}\},$$

$$R_{MTM} = Region(\varepsilon_i) \cap ... \cap Region(\varepsilon_j),$$

$$L_{MTM} = min(Level(\varepsilon_i), ..., Level(\varepsilon_j)).$$

Data maintenance is as important as data generation. We keep the data consistent among the distributed datasets by predefining relations among spatial entities of these datasets. There are two kinds of relations defined on the spatial entity subsets of sections which belong to different levels:

1) *Supplement*: the spatial entity subset of lower level is a supplement of the subset of upper level. In other words, the objects in the upper level are needed by the lower level, while objects in the lower level are not needed by the upper level when generating theme map.
2) *Generalization*: the subset of upper level can be derived from the subset of lower level by merging some objects so that some distinct objects in lower level are regarded as indistinguishable objects and become just one object in the upper level.

4. Road Representation

Road network is an important theme in a country-wide GIS. The representation of road network under M^2 model leads to no-redundance management of road network on several scales and supports efficient spatial query on them.

4.1 Relations Among Objects in Road Theme

There are two kinds of relations among road objects, belonged to two different level theme maps: selection and generalization. Selection means that the objects in upper level theme map can be derived from the lower level by selecting certain objects, and possibly leaving out others; generalization is the same as *Generalization* defined in the previous section (Figure 5).

Since in our model the information of a spatial entity is stored only once theoretically, road objects are divided into appropriate sections without redundance. There are four kinds of relations defined among the objects, belonged to different sections (see Figure 6). The first three kinds ((a), (b) and (c)) are *supplement* relations, which are defined based on the *selection* relations between corresponding theme maps, and the relation defined in (d) is *generalization* based on the corresponding relation between corresponding theme maps.

4.2 Road Representation and Inheritance Mechanism In our M^2 model, road information is managed in several levels with different scales according to the road classes in the road theme: i.e., highways are stored in the country level on a scale of 1:20,000,000; prefecture roads are in the prefecture level on 1:200,000; and city roads are in the city level on 1:15,000, respectively. Though the scales of levels are different, roads are represented by nodes and links in every level. Figure 7 shows the schema diagram of road theme in two levels. There are two kinds of nodes: real node and

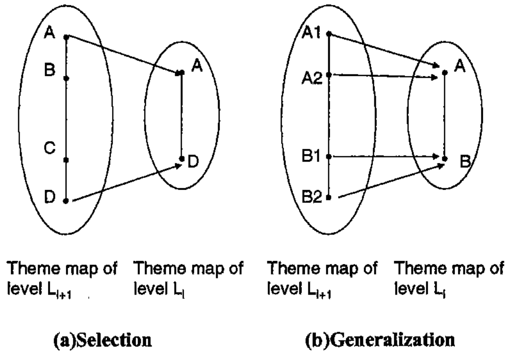

Fig. 5. Relations among road objects belonged to two road theme maps.

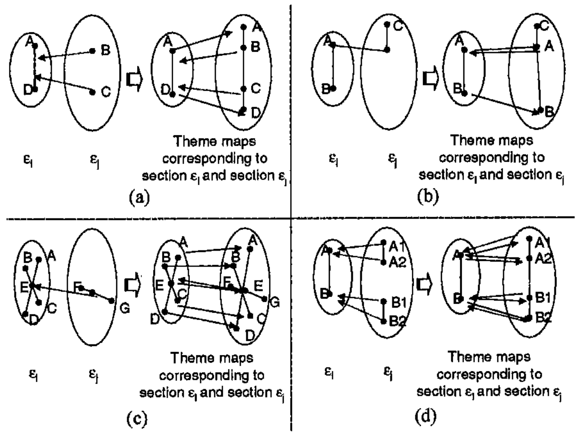

Fig. 6. Relations among road objects belonged to two road sections.

virtual node. A real node is a spatial entity in M^2 model with point geometry and non-2-D feature. It describes a point in the road network where traffic conditions change. It can be a crossroad, a traffic circle, a toll, a dead end, an intersection with boundary line, or a point where some values of road attributes change. A node can delimit several road fragments; and each road fragment has only one begin-node and only one end-node. A virtual node is an object in the lower level without any of attribute values, but points to the corresponding real node in the upper level. To access a virtual node is actually to access a real node in the upper level. The definition of real and virtual nodes reduces the representation redundancy in the model. Table 2 lists out the main classes of node properties concerning the process among levels. The node with " intersection with upper level " property is a kind of node managed in the lower level, but extend the road of upper level. We can see its effect in the example of road network with two levels, given in Figure 8. The links in the upper level are represented by bold lines, the dotted circle with heart point represents that it is a real intersection of upper level and lower level (e.g., N22 and N29), and the dotted circle without heart point represents that it is an intersection between two levels but the two points are on different 2-D space (e.g., N23 and N28). The node N26 in the lower level is a virtual node and the

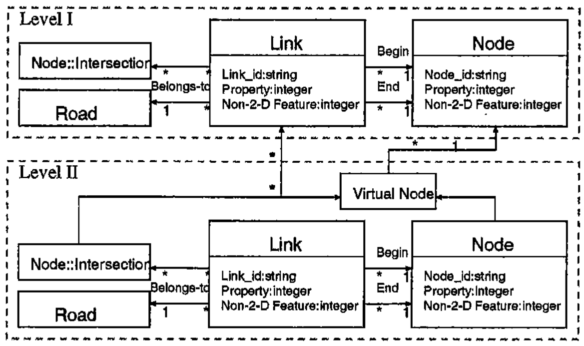

Fig. 7. Schema diagram for road-theme database.

Table 2. Properties of nodes.

Class	Property	Meaning
0	Heritage from upper level	Virtual node; Upper level's end or intersection node. There is at least one link connected to it in lower level.
1	End	Degree of node is 1 or 2 in lower level.
2	Intersection	Degree of node is more than 2 in lower level.
3	Intersection with upper level	Node points link of upper level, if they are on the same 2-D space. The link is split when inheritance function works.
4	(1+3)	End-node which is intersection with upper level as the same time.
5	(2+3)	Intersection which is intersection with upper level as the same time.
6-9	Property change tag	Other properties except 0-5 property-change points.

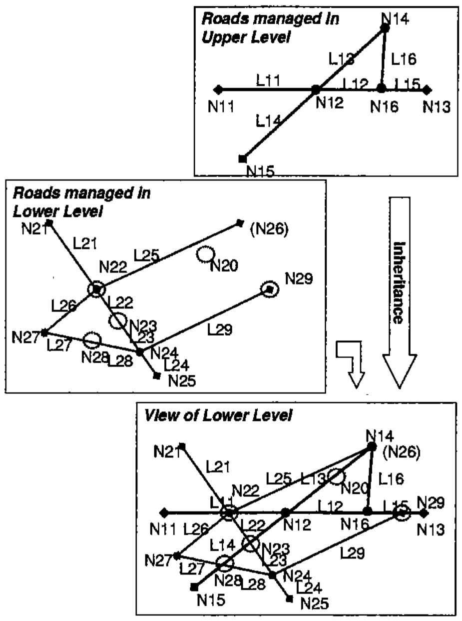

Fig. 8. An example of road network with two levels.

corresponding real node is N14 in the upper level.

The main attributes of nodes in the level 1 and level 2 are given in Table 3 and Table 4. In this example, the value of non-2-D property means overpass (1), regular

Table 3. Nodes managed in level 1.

Node-id	Geometry	Property	Non-2-D feature	Pointer
N11	Point	1	0	
N12	Point	2	0	
N13	Point	1	0	
N14	Point	2	0	
N15	Point	1	0	
N16	Point	2	0	

Table 4. Nodes managed in level 2.

Node-id	Geometry	Property	Non-2-D feature	Pointer
N21	Point	1	0	
N22	Point	5	0	L11
N23	Point	3	0	L14
N24	Point	2	0	
N25	Point	1	0	
N26	Point	0	0	N14
N27	Point	2	0	
N28	Point	3	0	L14
N29	Point	4	0	L15
N20	Point	3	0	L13

Table 5. Links managed in level 1.

Link-id	Geometry	Non-2-D feature	Begin-node	End-node
L11	Line	0	N11	N12
L12	Line	0	N12	N16
L13	Line	0	N14	N12
L14	Line	1	N12	N15
L15	Line	0	N16	N13
L16	Line	0	N14	N16

(0) and underground (-1).

Also, there are two kinds of links: regular link and inherited link. A regular link is an atomic object of M^2 model with linear geometry and non-2-D feature. It is a road fragment. An inherited link is a line between one level's or two different levels' nodes when there is a link produced by the inheritance function. It is not persistently stored in the database of road network, but only is produced when needed. The main attributes of links in level 1 are given in Table 5 and the inherited links in level 2 are given in Table 6. In Table 6, the inheritance functions of road theme propagate both links and nodes of upper layer to the lower layer with regard to the properties and non-2-D features of nodes and links. The nodes N22 and N29 of lower level, which are the real intersections of upper level and lower level, split into L11 and L15; the nodes N23 and N26 do not split L14 because they are not in the same 2-D space as L14; the node N20 splits L13(N14,N12) into two links (N14,N20) and (N20,N12) when inheritance function works; and the other links are inherited directly.

In the hierarchical road model the road information is managed in several levels with different scales according to the road classes, and relations among layers are managed in the lower layer. Thus, there are advantages in:

1)It is easy to extend the system. The road hierarchy is implemented from the top level with the smallest scale, and then the lower levels with larger scales and the relations (pointers) associated with upper levels can be implemented. There are no scale limits in the system;

2)It is easy to get needed scale view of the map. One can easily access map elements up to the top of the hierarchical levels by using inheritance functions;

3)It is possible to manage road network in multiple scales by using smaller space; and at the same time, it is promise to enforce consistency between scales and reduce the global update load.

Table 6. Inherited link in level 2.

Link-id	Geometry	Non-2-D feature	Begin-node	End-node
L11	Line	0	N11	N22
	Line	0	N22	N12
L12	Line	0	N12	N16
L13	Line	0	N14	N20
	Line	0	N20	N12
L14	Line	1	N12	N15
L15	Line	0	N16	N29
	Line	0	N29	N13
L16	Line	0	N14	N16

4.3 Topological Search The capability of computing path queries is essential in the database manipulation for many advanced applications such as navigation systems, Geographical Information Systems (GIS) (7) and so on. The key of computing path queries is to find out the topological relations among roads. Topological relations are those that are invariant to topological transformations: i.e., relations which are not changed after transformations like rotation, translation, scaling and rubber sheeting.

In our model, the topological relations between map elements through the inheritance and overlay operations may be different from the relations before the operations: e.g., in Figure 4, the place "A" is "joint" with road "a" in the upper level of small scale and is changed to "disjoint" with it in the lower level of large scale. The method of associating topological relations directly with the defined geometry can compute out the spatial relations among map components on the same scales, but cannot process the map components on different scales. On the other hand, the method of looking upon spatial relations as attributes, proposed by (5), (6) and (3), would bring complicated relations between levels and themes, and break the easy extendibility of the model. As a result the topological relations between map elements in M^2 model should be computed dynamically.

5. Experimental Evaluation

In this section, we introduce our prototype systems and give an evaluation of the effectiveness of our model. We compare our model (M^2) with the models proposed by Leung, et al. (3)(L-model) and Timpf (4) (T-model).

5.1 Prototype System We have implemented our prototype system in Java for ensuring its portability over different platforms. The system manages themes of country, prefecture and city levels, based on the maps of Japan, Aichi Prefecture and Ichinomiya City. We have also developed inheritance function, overlay function and query functions on the road theme and the architecture theme.

We stored highways and national roads in the country level (the first upper level), prefecture roads and main local roads in the prefecture level (the second level), and city roads in the city level (the third level). The node stored in the upper level may be referred by the lower level through the pointer of a virtual node in the lower level, and the node in the lower level splits the road segment of the upper level when using the inheritance functions to propagate the road information on a small scale of upper level to the lower level on a large scale.

Figure 9, 10 and 11 show the roads managed in the country, prefecture and city level (in the interest of clarity, these roads are shown at the same display scale), respectively. Figure 12 shows road network composed in the city level, which contains the roads, managed inherently in the city level, and the inherited roads, produced by inheritance functions. The right part in Figure 13 shows multi-theme map (shown at the city-level scale) composed on the city-level. The map contains road and architecture themes, and is produced by inheritance functions and overlay functions. The left part shows the multi-theme map of the upper level.

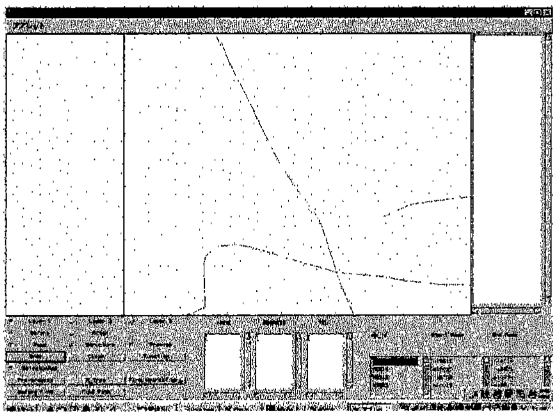

Fig. 9. Roads managed in nation-level.

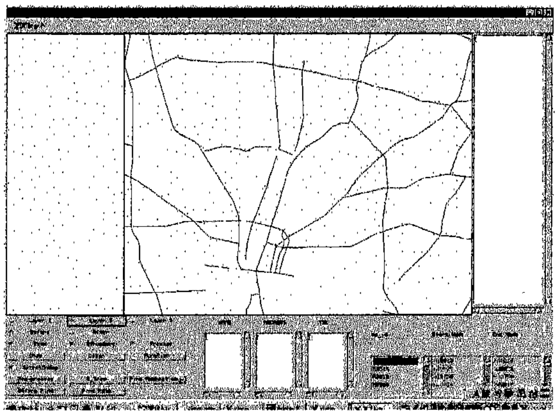

Fig. 10. Roads managed in state-level.

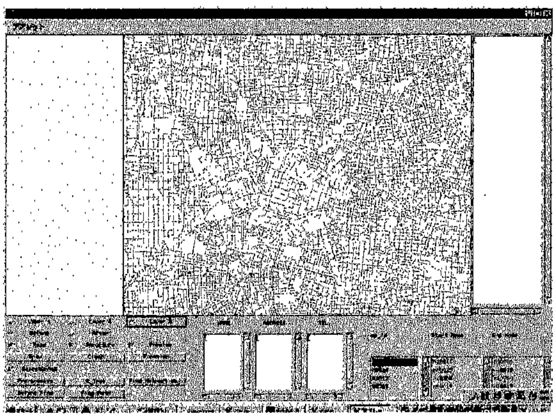

Fig. 11. Roads managed in city-level.

5.2 Evaluation of Road Network Representation and Path Searching In order to evaluate our model in representing road network, we measured the quantity of storage links and display links, and also the execution time of path searching based on the road network. Here, we compare our model to the L-model and T-model.

1) *Quantity of storage links* In our prototype system, we divide the road network into 3 levels without redundance with regard to our M^2 model. In L-model, road network are managed on different levels with redundance with regard to a customary law. In T-model, road network are managed on the most detailed level. From Figure 14, we can observe that the numbers of storage links of M^2 model is smaller than those of L-model on every

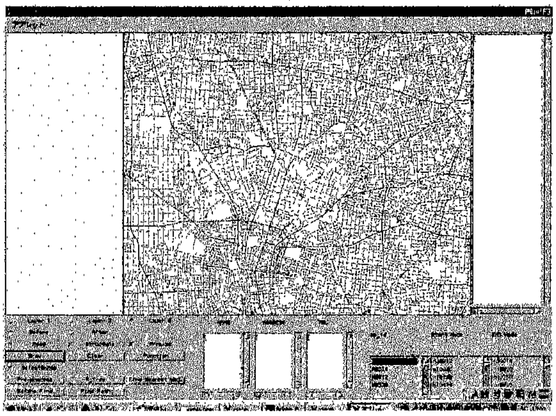

Fig. 12. Road network composed in city-level.

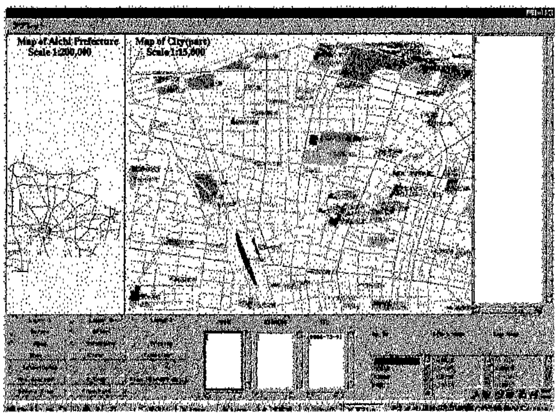

Fig. 13. Multi-theme map composed on city-level.

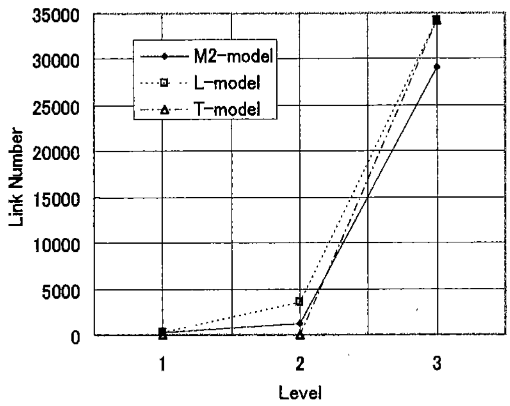

Fig. 14. The link numbers managed on levels.

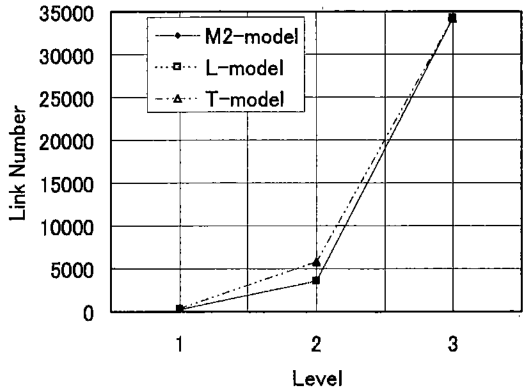

Fig. 15. The link number displayed on every levels.

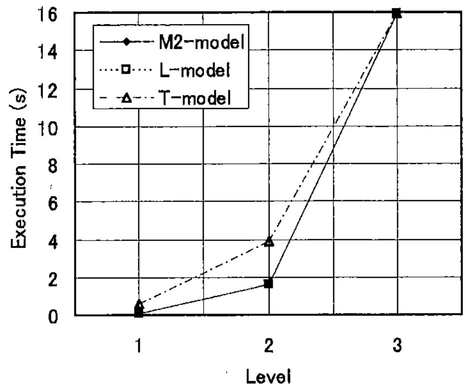

Fig. 16. Path searching speed on levels.

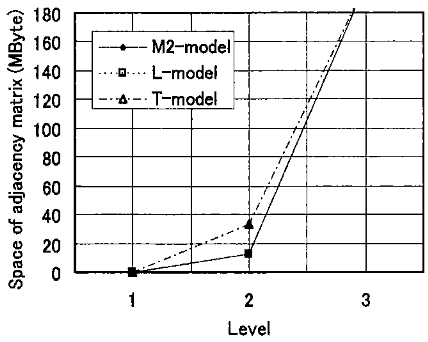

Fig. 17. The space of adjacent matrix for path searching.

level. Though on the upper levels (level 1, 2) M^2 model stores more links than T-model, the total number of storage links of M^2 model is the smallest one: 32,663 for real data in the prototype system (36,039 in L-model and 34,235 in T-model).

2) *Quantity of display links* In M^2 model, we generate display links on lower levels by using inheritance functions, and display them customarily. The number of display links of M^2 model is the same as that of L-model, while there are more links displayed on the upper levels of T-model (see Figure 15). The shortcomings is obvious in the following path searching comparisions.

3) *Performance of spatial query* To compare the performance of spatial query, we implemented path searching (algorithm A^*) and nearest object finding functions on an SGI O2 R5000 SC 180 entry-level desktop workstation. Here, we give the comparision results of speed (Figure 16) and space (Figure 17) in path searching. The performance of our model is the same as L-model's, but better than T-model's on the upper levels.

In general, our model outperforms L-model and T-model in supporting the effective storage, displaying of road network, and efficient spatial query on road network.

6. Conclusion

In order to represent map information of GIS smartly, especially for a country-wide integrated GIS, we proposed the Multi-scales/Multi-themes (M^2) map information model, in which map elements are composed as a hierarchical structure with multi-scales so as to deal with various types of or different classes of scaled maps successfully. The model is powerful to integrate various scales of maps uniformly in comparison with those in the traditional GIS. Because the map elements are uniquely assigned to a special level on a particular scale, we should propagate the map elements in the upper levels to lower level and compute the topological relations between them effectively. We have successfully assigned the road network of Ichinomiya City to the road theme among three different levels in our prototype system with inheritance functions, and compared our model with other two models. Based on those comparisons, we can say our model outperforms L-model and T-model in managing road network and path searching.

For our future work, the distributed system under our model would be developed, and the cost of maintenance would be measured.

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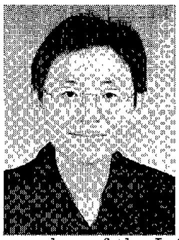

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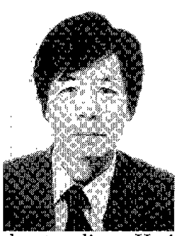

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