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Design of Hierarchical Tile Structure of Digital Road Map for Navigation Device

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I. Introduction

Currently, two different efforts are being made in regard to the development of digital road map systems in Korea. The goal of the first one, initiated by automobile industry and led by the Ministry of Commerce, is to provide a digital road map for terminals which will be mounted in the interior of cars and designed to supply drivers with static and dynamic information about the road-and-traffic-related. It is scheduled to provide design standard of a digital road map by the mid 1994 and to complete the core parts of the map by the end of 1995. The latter, organized by The Bureau of Social Overhead Capital, S.O.C. (jointly supported by the Ministry of Construction, Transportation and the Police Bureau), is being made as a part of Intellegent Vehicle and Highway System(IVHS) Development Project. Its goal is to provide a rich database of road and traffic-related spatial data for the development and operation of IVHS, concerning more about multi-sector-integrated aspects than the first option. This effort has begun this year and plans to complete the preliminary research by 1995, whenstandard specification process will begin to develop. In addition, it is known that some Korean auto companies and the Korea Highway Authority have made digitised maps of some localities for the purposes of various tests. These approaches should provide desired complementary functions. However, for the needs of auto industry are urgent and the latter is being just undertaken, it can be easily seen that these efforts are not in "sync" and an unbalanced evolution of digital road map system is forseeable.

For an auto navigation system to provide drivers with sufficient road and traffic related information, in addition to auto mounted terminals (say terminals), the system demands various static and dynamic data and it should be furnished with data collecting, information processing subsytems and contollers, communication devices and operational hadwares(HW) and softwares(SW). The function of each subsystem and HW/SW depends on the system design. That is, the system may be designed more like infrastructure dependent or autonomous. For example, the system design decides whether the terminal itself will process the

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computation for route guidance or traffic control center will do the job and transmit the information to an individual terminal via communication system. Given the undeveloped state of such infrastructure and urgent demand from auto industry In Korea, it is quite natural to design the systm as autonomous as possible, i.e. to place most of the system's component inside the terminal and minimize the functions of infrastructure, in order to put the auto navigation technology in practice.

The minimum functional qualifications for truely navigable terminal, set by the former effort, are the following:

1) Presentaion of Maps at Various Scales
2) Positionning
3) Route guidance

To meet these requirements at a proper level, it needs high performance equipments, which can be uneconomical. (The market price of a terminal in Korea, presumed by auto makers, is about 1,200,000 won) Therefore, a software system which can maximize utilization of limited hardware system should be a sought-for. The pertinancy of such endeavour can be easily seen by observing the digital road map system. When most of geogrphical and road informations are handled internally, the amount of data that a terminal handles can be extraordinary. Hence, functions of operating softwares and data structures are important for efficient data processing.

The types of data stored on digital road map system are shown below.

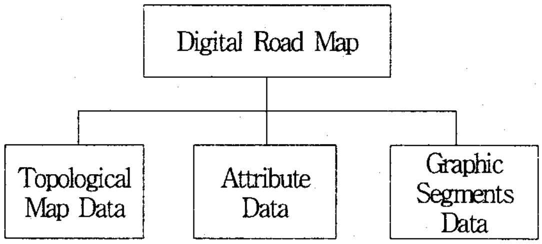


Figure 1.1 Data types in digital road map

* Topological map data is a collection of nodes, links and their relationships which describe the conceptual road network system.

* Attribute data is a collection of attributes, assigned to nodes and links

* Graphic segment data is a collection of coordinates and designated codes which represents locations or shapes of symbols, lines, linked lines representing curves, polygons indicating specific areas.

The following table shows estimated total digital road map data size to store the whole country' road network, compared to Japanese digital road map using 1:25,000 scale map.

Table 1.1

	Total land area (km^2)	Total length of highway (km)	Data ($Mil. Bytes$)
Korea	99,274	56,652(+290,000)	300 (estimated)
Japan	377,000	178,115(+920,812)	800

In order to store and manage this huge amount of road network data and to provide needed services to a driver via limited HW sources, an efficient data structure must be imported. Database of tile structures are often used for acquisition and management of spatial data, where each tile corresponds to a sub-area of cartographical map. This study will concentrate on the tile structure of graphical segment data which is the major part of the database.

II. Necessity of hierarchical tile structure

When the whole country are divided by a grid system, the location of a spatial object can be represented by the relative location in some element of a grid, called tile. "Tile structure" means a way of storing spatial data in a storage device by which spatial objects are grouped by tiles to which they belong and their graphic segment data are recorded collectively in a block of the storage device.

Based on the assumption that the hierarchical tile structure is used as the basic data structure of digital road map which will be stored and retrieved in the terminal, we will, firstly, study the effects of a hierarchy of layers, geographical size of a tile in a layer, the amout of storing data in a tile, the mapping between tile layers and display scale on the legibility on a terminal monitor, the required time for searching and display, and the efficiency in using its HW. And this study will discribe a methodology to expolit these correlations.

II.1 Present status of road and map production in Korea

Area and road length of each city and province in Korea at present are shown in table 2.1.

Table 2.1 highway-status in Korea

Div City	Area(km^2)	Total length	National Express way	National Highwqy	Special City Road	Provincial Road	City Road	Country Road
Total	99,274.69	56,562	1,551	12,161	12,235	10,672	6,686	13,347
Seoul	605.34	7,374	16	169	7,189	-	-	-
Busan	529.37	1,769	24	88	1,657	-	-	-
Daegu	455.68	1,127	38	71	1,018	-	-	-
Incheon	317.19	956	18	42	896	-	-	-
Kwangju	500.92	788	26	93	669	-	-	-
Daejeon	537.19	937	44	87	806	-	-	-
Kyonggi	10,772.88	6,263	188	1,293	-	1,615	1,735	1,432
Gangwan	16,897.85	5,230	181	1,918	-	1,021	543	1,567
Chung-puk	7,437.11	3,602	146	935	-	936	445	1,140
Chung-nam	8,318.12	4,032	66	1,111	-	1,119	285	1,451
Chon-puk	8,042.95	4,015	145	1,165	-	1,179	600	926
Chon-nam	11,813.70	5,372	143	1,457	-	1,351	417	2,004
Kyong-puk	19,447.01	6,354	184	1,953	-	1,836	382	1,999
Kyong-nam	11,773.77	6,626	332	1,349	-	1,459	1,557	1,929
Cheju	1,825.61	2,207	-	430	-	156	722	899

* as of DEC. '90. Unit in km

Currently, the largest scale map covering the whole nation is on the scale of 1:5,000 and total number of subarea maps available in each scale is summarized in table 2.2

Table 2.2

scale	number of subarea maps
1:5,000	about 20,000
1:25,000	940
1:50,000	235

II.2 Necessity of the hierarchical tile structure

The primary advantage of tile structure for spatial data is the speed in searching and retrieving data. By using this structure, we can calculate the physical address of recorded data in the storage device directly from the coordinates of place of interest and, as a result, the searching time is minimal. And, since the graphic segment data around the place of interst are all in the corresponding block and the neighboring blocks, the searching and retrieving process can be simplified to the utmost level. In addition, by storing spatial data with a relative coordinates system on a tile, instead of a real coordinates system requiring more significant digits, storage space can be reduced significantly. Furthermore if parallel processing units would be on the market at significantly lower cost in the near future, the processing time will be greatly reduced by processing data of each tile in a parallell way.

When some part of the road network and relevent information surrounding current position is requested by a driver at some screen-scale, corresponding tiles should be found and displayed. For simplicity, assume that the monitor size be N_x*N_y and the geographical size of a tile be kN_x*kN_y. If the monitor-scale requested by a driver is over $1:k$, data of 4 tiles should be loaded on RAM. And if $1:nk$, $(n+2)^2-2(n+2)+1$ tiles are needed. Then three problems, first legibility, second display speed, and third waste of hardware, arise.

A. Legibility

The legibility problem arises largely from two sources. Under the assumption that the equal amount of data is in each tile, the first source is that as the reqested scale gets smaller, number of tiles necessary for a display grows in order of n^2. It results that excessively displayed graphic segments on a limited screen disturbes legibility. On the contrary, when a large scale is requested, there must be very little data on screen, providing insufficient information.(refer to figure 2.1-1)

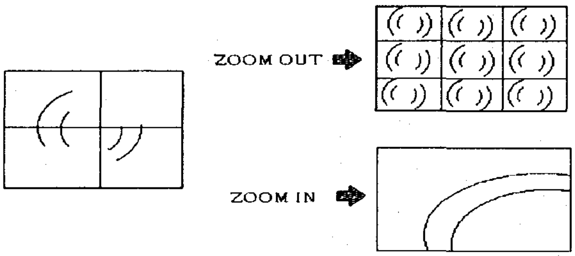


Figure 2.1-1

The second sources is related to the digitisation rate of graphic segment data. If a road map data is digitized in more detail than required, it is difficult to obtain clear road configuration on a screen. In reverse case, a curve section of a road does not appear naturally.(refer to figure 2.1-2)

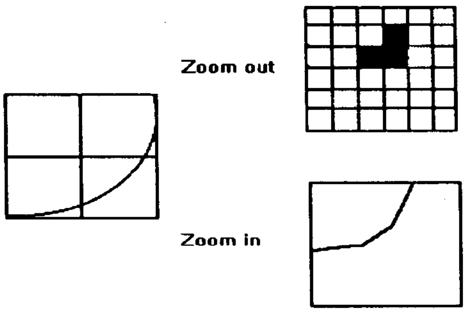


Figure 2.1-2

B. Display speed

The smaller a requested scale is , the larger the number of tiles gets in the order of n^2. So, the I/O time from storage device and the time taken to compute screen coodinates gets large in more than n^2 order. The expected delay due to it may push some drivers to their limits of patience.

C. Waste of HW

If the computing capacity of the terminal is enlarged so that the terminal handles more data on a small scale, we may waste HW capacity on a large scale. It also costs the economy of the terminal.

We may solve the three problems mentioned above by adopting a well-designed hierarchical tile structure. Hierarchical tile structure consists of several tile layers , starting with a tile layer in which whole country is displayed on one tile, with layers of $nx_1 * ny_1, nx_2 * ny_2, \cdots, nx_m * ny_m (na_i < na_{i+1})$

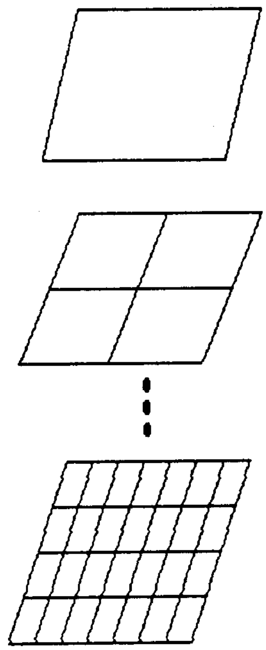


Figure 2.2 Hierarchical Tile Structure

tiles, each layer covering whole country. (The amount of stored data per unit area is smaller in a higher layer.) (See Figure 2.2)

With a well-designed hierarchical tile structure for graphic segment data, we can solve the above problems by creating proper projection map between the spectrum of layers and screen scale requested. Since each layer covers whole country, the redundancy of data may be an issue. However, the problem is not important because the amount of higher layer data are far smaller than lowest layer data and the price of storage device is not considerable on account of the appearance of smart card.

III. Design Methodology of Effective Hierarchical Tile Structure

III.1 Design goal of hierarchical tile structure

The following is the list of design(control) variables which should be determined carefully in order to design an effective hierarchical tile structure.

1. Hierarchy of layers
2. Geographical size of a tile in a layer
3. Amount of data of a tile in a layer
4. Mapping between scales and layers

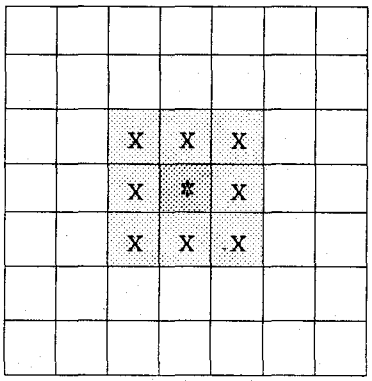
The objective to achieve through a good selection of design variables is to minimize the expected(mean) gap between the size of displayed information(data) and most efficient data size on a monitor under constraints of display speed, storage capacity, and legibility.

III.2 Mathematical model for optimal design

Our optimal design methodology assumes the following:

1. The data size of tiles in a layer(layer k), S_k, are identical.
2. The total data size of the lowest layer is set to be TN.
3. The maximal data size for a display is S.
4. The most effective data size for a display is S_c.
5. The highest layer consists of a tile which covers the whole country. (therefore, the size of total data is S.)
6. Total processing time taken from searching data to displaying should be less than T.
7. The processing speed of a data unit is u.

On the assumptions above, if an arbitrary display scale, $1 : x$, is requested, the total geographical size to display is $xN_x * xN_y$. If the tile size of the corresponding layer k is $kN_x * kN_y$, the required number of tiles is at least $([\ x/k]\ +1)^2+2([\ x/k]\ +1)-1$. ($[\ y]$ is the maximal integer which is less than y .) Let's assume that we retrieve $([\ x/k]\ +2)^2$ neighboring tiles in advance instead of required tiles to display promptly . (see figure3.1)



* : selected tile,
x : neighboring tiles

Figure 3.1

On the assumptions described above, the projected tile layer k should satisfy following:

$$S_k * (\frac{x}{k})^2 \leq S \qquad \cdots(2.4)$$

$$([\frac{x}{k}] + 2)^2 * S_k * u \leq T \cdots(2.5)$$

And, if $1 : x$ display scale is requested, to among layers satisfying equation (2.4) and (2.5), the layer k which minimizes $|Sc - \frac{S_k}{k^2} * x^2|$ should be selected to deliver information most effectively. Let's note the projection rule between spectrum of layers and display scale by $(x \rightarrow k_{Cm}(x))$.

Hence, the problem of minimizing the expected(mean) gap between the size of displayed information(data) and most efficient data size on a monitor under constraints such as display speed, storage capacity, and legibility is identified as the following mathematical symbolic equation:

$$Minimum_{Cm \in C} \int \left\{ \left| Sc - \frac{S_{k_{cm(x)}}}{k^2_{cm(x)}} * x^2 \right| \right\} * f(x) dx$$

constraint: $\sum_{i=1}^{K} \frac{S_{k_{cm(x)}}}{k^2_{cm(x)}} * A \leq \text{CAP}$

$f(x)$: Density function of scale demand
A : Total geographic area
CAP : Storage capacity
C : Set of hierarchies

This symbolic optimization model can be used as a tool for comparison tests of hierarchy design alternatives and it shows the list of required parameters for proper designs of hierarchical tile structure. Required parameters are the following:

1. Demand patterns(or distribution) for scales,
2. Maximal amount of data, the most efficient amount of data per a display for readability
3. Maximal tolerable time for a display in user's view.

With a careful estimation of these parameters and demand distribution, the symbolic model can be transformed into a real simulation model for effective comparison tests of design alternatives.

IV. Conclusion

By way of developing this mathematical symbolic optimization model, our study sorted out the main design goal of hierarchical tile structure for spatial data and required input parameters for design process. Also, we developed a testing tool for design alternatives. For a better design and, as a result, a more attractive digital map inside a car for Korean custommer, the required parameters mentioned above should be more carefully studied.

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