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GIS Infrastructure in Japan — Developments and Algorithmic Researches

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ABSTRACT

Some activities of geographical data maintenance and standardization work in GIS infrastructures in Japan are first reviewed. Then, from the viewpoint of geometric and combinatorial algorithmics, applied aspects of GIS are described. Some spatial data mining technique is mentioned first, and then the problem of inferring topological information from digital map and the label placement problem are touched upon. As one of topics in ITS (Intelligent Transport System), finding useful detours in car navigation is discussed. These would illustrate some advanced aspects of GIS infrastructure and its high-level use in Japan.

1 Introduction

Geographical Information System (GIS) has two aspects: one is to create and maintain geographical data in digital form, and the other is to provide efficient ways of utilizing geographical data for various purposes based on the information technology. Concerning the former aspect, in these two decades, big efforts have been made to construct digital geographical data as GIS infrastructure. Traditionally, base geographical information is given as maps, available only on papers, which were hard to

handle directly on computers. With the evolution of digital geographical data, we are now at a high stage of using these data interoperably via networks throughout the world in a variety of fields. Here, standardization of GIS data plays a crucial role, and in fact several important standardization activities have been performed. In the first half of this paper, we survey GIS developments in Japan for maintaining geographical data and for contributions in standardization work. Some of activities of a representative governmental institute performing research and servicing on geographical data are described, together with some of typical digital geographical data maintained so far in Japan.

One of the most frequently used GIS systems in Japan would be the car navigation system. For example, dynamical traffic information newly becomes available such as ATIS (Advanced Traffic Information Service) and VICS (Vehicle Information & Communication System) besides compact car navigation systems attached to vehicles, based on the GIS infrastructure. In the latter half of this paper, we describe some of research results on GIS from the standpoint of spatial data mining, computational geometry, and network algorithms. These include demonstration of a k-means algorithm for spatial data mining, the problem of inferring topological information from digital map, and the label placement problem for node and edge features in maps. Also, as an interesting issue in ITS (Intelligent Transport System), the problem of finding useful detours in car navigation is discussed.

By covering the two aspects of GIS in the above-mentioned way, this paper tries to give outline of some of GIS infrastructure and GIS research in Japan.

2 GIS Developments in Japan

In this section, recent GIS-related activities in Japan are described. The section covers three subjects. The first subject is digital map preparation, which was initiated about 25 years ago. At that time, there was no such concept as spatial database, and efficient map digitization was a main research problem. The second subject topic is recent GIS-related activities by the Japanese government. Information on current activities and the policy of Japanese government are presented. The third topic is about the Spatial Data Framework, which was developed under the new concept of spatial database.

2.1 Development and Publication of Map Data

2.1.1 Outline

The development process of GIS infrastructure in Japan can be explained in four phases. Phase I began in the middle of the 1970s when the government started preparation of digital geographic data for only limited users such as central and local governmental organizations and researchers at universities. Phase II arrived when the Geographical Survey Institute (GSI), Ministry of Construction (MOC) began to publish digital cartographic data sets in 1993. Phase III started in 1995 when the

government reached a consensus that the active encouragement of GIS development was necessary. At present, Phase IV is progressing when the preparation of spatial database in accordance with a standard is important. Below, phases I and II are explained. Phase III is explained in section 2.2.

2.1.2 Development of Digital National Land Information

The Japanese government has been developing digital geographic information since the mid-1970s. As its initial activity, GSI began to develop the "Digital National Land Information" in 1974 in cooperation with the National Land Agency (NLA), and was nearly completed in 1980. Its accuracy corresponds to approximately 1:200000 paper maps. It consists of DEM, land-use data, boundaries of local governments, major roads, railways, rivers, coastal lines, public facilities, etc. The purpose of this project was to supply basic digital geographic data necessary for national land development planning and regional planning by the central governmental agencies and local governments.

It has also prepared the "Detailed Digital Land Use Data" to support the policy making of building land administration in collaboration with the Economic Affairs Bureau of MOC since 1981. It is a data set of grid cells for land use (10m square on the ground) for three major metropolitan areas (Tokyo area, Osaka area, and Nagoya area), and each area is surveyed repeatedly every 5 years.

These data sets have been highly reputed for they have enabled quantitative analysis of national land. However, they have been specially prepared for administrative purposes, therefore they have not been disclosed to the public but used only by administrators within the central and local governments and researchers at universities.

2.1.3 Publication of Digital Geographic Information

In June 1993, GSI launched into the publication of digital cartographic data sets called the "Digital Map Series". It was extremely epoch-making. Since then, the variation and number of published digital cartographic data and software that apply those data have increased, and as a result, people have gradually come to recognize the benefits of geographic information.

Nine kinds of "Digital Map Series" are available at present. They are "Digital Map 10000 (total)," "Digital Map 25000 (shore lines and administrative boundaries)," "50m mesh (elevation)," "250m mesh (elevation)," "1km mesh (elevation)," "1km mesh (average elevation)," "Digital Map 25000 (Map Image)," "Digital Map 2500 (Spatial Data Framework)," and "Digital Map 200000 (shore lines and administrative boundaries)". They are text files and distributed via CD-ROM with simple software for quick browsing of the image of inside data.

2.2 Recent GIS-related Activities by the Japanese Government

2.2.1 Liaison Committee of Ministries and Agencies Concerned with GIS

A Liaison Committee of Ministries and Agencies Concerned with GIS was established in September 1995 to promote the efficient development and effective utilization of GIS within the Government with the close cooperation among the Ministries and Agencies. The Cabinet Councilor's Office, Cabinet Secretariat, was designated as the secretariat of the Liaison Committee, and assisted by the Geographical Survey Institute (GSI) and the National Land Agency (NLA). The Committee has two task force groups, i.e. Spatial Data Framework Task Force Group and Basic Spatial Data Task Force Group, each of which has a few working groups to discuss more specific topics in detail.

2.2.2 Long-term Plan for the Development of NSDI in Japan

The Liaison Committee developed a Long-term Plan in 1996 for the development of NSDI (National Spatial Data Infrastructure) in Japan. The Plan specifies actions to be taken by the Government during a two-phase period starting in 1996 up to the beginning of the 21st century. The first phase focuses on the definition of NSDI in Japan as well as standardization of metadata and clarifying the roles of the central government, local governments, and the private sector, rather than actual spatial data development. The implementation of NSDI including spatial data development for NSDI is expected to take place in the second phase. Approximately three years have been designated for each phase, i.e., first phase (1996-99) and second phase (1999-2001).

2.2.3 Pilot Study by Local Governments for the Implementation of the Long-term Plan

The definition of NSDI, one of the main subjects of the first phase of the Long-term Plan, requires intensive research on the availability, utilization, restriction and distribution of maps and spatial data in local governments, because they develop and maintain most of spatial data sets in Japan. GSI and NLA are conducting a collaborative pilot study in fiscal year (FY) 1997 with four local governments to do such research. The main topics of the pilot study include: which spatial data item should be included in the Spatial Data Framework of the Japanese SDI; who should develop and maintain such data items; and which information would be most suitable for indirect georeferencing. The result of this pilot study was summarized in Interim Report of the Long-term Plan at the end of FY 1997. Additional Ministries, i.e., the Ministry of International Trade and Industry (MITI), the Ministry of Posts and Telecommunications (MPT), and the Ministry of Home Affairs (MHA) joined the pilot study in FY 1998 starting in April 1998. The research topics of these Ministries in the pilot study are as follows: MITI will develop new information systems with GIS and foster related industries; MPT will focus on the development

of a spatial data search engine through computer networks, spatial data encryption methods to protect private information, and spatial data compression for efficient data distribution; and MHA will investigate technological and institutional issues of local governments related to NSDI development. The results of these pilot studies were incorporated into the final report of the first phase of the Long-term Plan, which will direct the implementation of NSDI during the second phase.

2.2.4 Interim Report on the Implementation of the Long-term Plan

The Committee compiled an interim report on the activities during the first two years of the first phase of the Long-term Plan. The report reviews the subjects specified in the Long-term Plan and the actions actually taken by the Committee. It also clarified the issues to be focused on by the Committee during the last year of the first phase. The report was published and distributed to the public at the end of March 1998.

2.2.5 Final Report of the First Phase

The Committee adopted the Final Report of the First Phase of the Long-term Plan on March 30, 1999. The Final Report entitled "Standards and Development Plan of National Spatial Data Infrastructure"[1] includes two standards of Japanese NSDI (i.e., a technical standard that is based on ISO/TC211 standard drafts, and a list of data items adopted as the framework data) and a development plan for the second phase of the Long-term Plan.

The technical standard included in the Final Report was developed through collaborative research between the Geographical Survey Institute and 53 private companies during the three-year research period starting 1996. Together with these activities, GSI has prepared a new type of digital cartographic data sets called a Spatial Data Framework for city planning area for all of Japan since 1995. The characteristics of these data sets are that they:

1) are structured by several very simple items;
2) distinguish each block as a polygon (suitable for address matching, only for some areas and not for all areas);
3) contain road network structure; and
4) can be used on a personal computer and easily transferred.

The data sources for these files are:

1) data converted from digital maps already held by GSI;
2) newly digitized data from the 1:2500 base map for city planning which local governments keep; or

[1] `http://www.gsi-mc.go.jp/REPORT/GIS-ISO/LCGIS/honbun.pdf` (in Japanese)

3) newly digitized data from the 1:500 map for road management held by some local offices of the MOC.

The data sets have been published from April 1997 for the use of unspecified individuals at an appropriate price, just as the Digital Map Series. They are also distributed free of charge to every local government that provided data sources.

2.3 Other Activities of the Geographical Survey Institute

2.3.1 Research on GIS Standardization

Based on the need to develop a GIS standard for Japan, which is in accordance with that of ISO/TC211, GSI started research on Japanese GIS standard in 1996. This research was also intended to provide a technical backbone for the Japanese SDI standard discussed by the Liaison Committee of the Government. Fifty-three private companies joined this three-year research project funded by the Ministry of Construction as one of the projects of the collaborative research program with the private sector. Two kinds of standards were developed through this research: spatial data exchange standard and spatial data development standard. Six working groups were established for the exchange standard to discuss 8 work items including data structure, data quality, georeferencing, metadata, and cataloguing. Spatial data development standard includes a guideline to develop specifications for spatial data development contracts. The final draft of the standard was developed at the end of FY 1998 and adopted as part of the NSDI Standards by the Government Liaison Committee.

2.3.2 Research on Geographic Information Directory Database (GIDD)

The Long-term Plan developed by the Government pointed out the necessity for National Spatial Data Infrastructure and specifies the need to establish a clearinghouse system for spatial data.

GSI has been developing a Geographic Information Directory Database (GIDD) as a five-year research project since April 1994. This database is designed to provide directory information (i.e., metadata) of spatial data through computer networks, and to become a clearinghouse node by developing a search environment of distributed databases.

The metadata standard, which is currently used in the GIDD, is developed as one of the work items of the Spatial Data Exchange Standard of "Research on GIS Standardization" described above. This standard can be considered as the Japanese

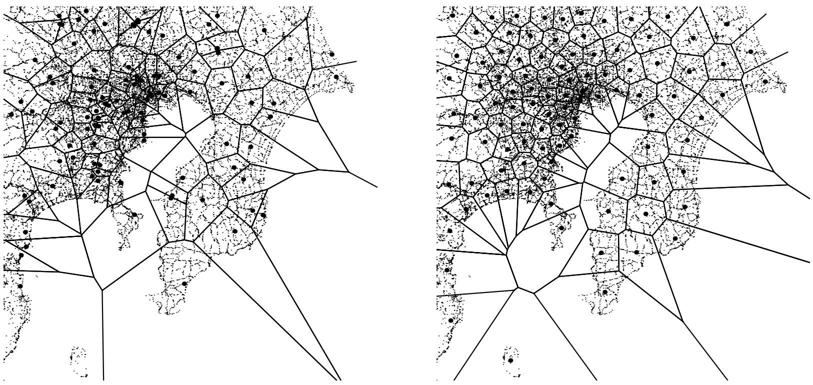
A prototype of GIDD with limited search capability has been in the process of practical testing. This prototype provides 229 records, experimental metadata of Digital Map 10000 (Total) in Japan. GIDD has the ability to make a query using 12 attributes such as title, keyword, longitude, latitude, and producer as well as a combination of these attributes using logical operators. Based on the result of these tests, enhancing its search capability and support distributed environment is planned. A prototype is made public at the GSI homepage.

3 Applications of Computational Geometry to GIS

3.1 Spatial Data Mining in Geographical Databases

Data Mining, or Knowledge Discovery in Databases (KDD) is to find interesting, previously unknown and useful information from large databases. There have been many studies of data mining in relational as well as transaction databases as the first targets of this field. Now, data mining has been extended to other types of databases such as data mining spatial databases, or, spatial data mining [4)], and our related results in this setting [6)]. Then, we discuss issues to investigate for data mining in geographical databases, especially topological geographical data.

Data mining in spatial databases, or spatial data mining has been proposed; see [?, 4)]. Spatial data mining refers to the extraction of implicit knowledge, spatial relations, or other patterns not explicitly stores in spatial databases.



(a) (b)

Figure 1: Application of the k-means algorithm for 20726 points at Kanto district in Japan with $k = 100$: (a) initial random solution, (b) solution obtained by the k-mean

In the existing spatial data mining, basically part of geographic information having strong connection with remote sensing, image databases exploration seems to have been investigated, and a clustering approach is adopted to derive knowledge. Main algorithmic tools used in this approach are k-mean, k-medoid and their extensions. The basic algorithms for them are well-known and have been used in many areas. Especially, in connection with geographical databases, the so-called geographical optimization approach provides a general algorithmic framework in terms of mathematical programming and computational geometry [10)]. To give an idea about these, we here show an example in Fig.1, taken from [6)], of applying the k-mean algorithm to about 20,000 points corresponding to big crossings of road network in Kanto district in Japan. This clustering itself is basically intended for experimental use, and not for some specific data mining, and yet this example would illustrate how

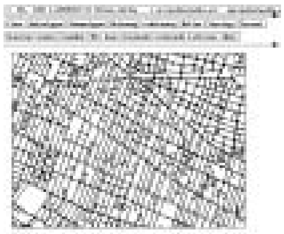


Figure 2: Town map data near JR Nishiogikubo station)

Figure 3: Enlarged map of Town map data in Fig.2 near the south exit of the station)

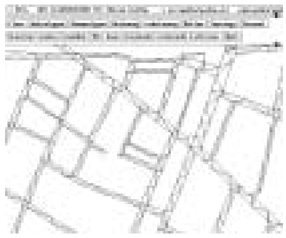


Figure 4: Inferred road network

large the amount of geographical data even in this restricted area and its geometric nature. The k-means algorithm work in higher dimensional space, and, general theoretical background is investigated in [7)].

3.2 Inferring Topological Information of roads from Map Data

This section describes an application of computational geometry to infer topological information of roads from town map data [13)]. Here, an example of town map data is shown in Fig.2. This kind of map data is available as "Digital Map 2500 (Spatial Data Framework)"[2] as described in section 2. In the town map, each town block is represented by (a set of) polygon(s) (Fig.2).

By using these data, enlarging/reducing the size of maps can be performed easily. However, even with these data structures, some sophisticated topological information is not available directly. In order to list all roads incident to a town block or list town blocks incident to a road, topological incidence relations among polygons should be inferred.

Here, by using the above-mentioned Digital Map 2500 as raw data, it is demonstrated that road information can be obtained from only town block boundaries by using computational-geometric algorithms.

Road areas are obtained by erasing town blocks from the map plane. However, with this operation, no topological information about roads is obtained. See a town map near JR Nishiogikubo station south exit of Digital Map 2500 Fig.3. From this data, if the road regions can be triangulated as in Fig.4, we can construct topological network of roads; each triangle represent adjacency.

To derive such a triangulation, Delaunay triangulation and Voronoi diagrams can be used. We here used a program by Prof. Sugihara of University of Tokyo [15)] which can handle large-scale geographical data efficiently and correctly.

[2] `http://www.gsi-mc.go.jp/MAP/CD-ROM/cdrom.htm` (in Japanese)

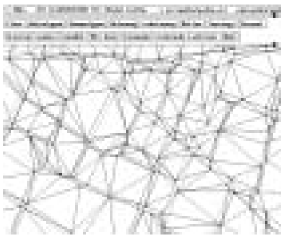


Figure 5: Delaunay triangulation for points of the boundaries

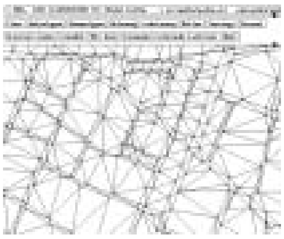


Figure 6: Delaunay triangula-
tion for points densely placed on boundaries

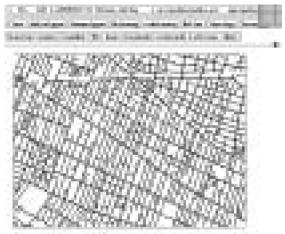


Figure 7: Inferred road network

3.2.1 Topological Inference

To derive a good triangulation as mentioned above, we may use Constrained Delaunay Triangulation (CDT) [2]. However, we here adopt another approach of using Conforming Delaunay Triangulation [3] in order to make full use of the robust and efficient Delaunay triangulation algorithm for point sets.

When we simply compute the Delaunay triangulation for points of polygons in Fig.3, the result looks like Fig.5. In this figure, dotted lines represent a boundary edge of town block which does not become an edge of the Delaunay triangulation. In order to remove such edges, we simply add internal points of such polygon edges so that the resulting Delaunay triangulation for points become conformal to the town block boundaries.

Fig.2 is a town map data consisting of 4168 nodes and 568 town units. Fig.3 gives an enlarged map of some part. For nodes in the map, Fig.6 is a Delaunay triangulation after adding the middle point of each edge which does not become an edge in the Delaunay triangulation for the given nodes (now the number of points increases to 5060).

Starting with the original data in Fig.2 and adding middle points appropriately on the boundaries, we can construct a triangulation of at most twice number of points from which the topological information can be derived. See results in Fig.7 (Fig.4 is its enlarged map).

3.2.2 Inferring Medial Line

From the viewpoint of computational geometry, the above method may be viewed as approximating the Voronoi diagram for polygon edges by the Voronoi diagram of points on the polygon boundaries [15]. With this interpretation, the medial line of roads can be derived directly.

The problem of finding the medial line of road has strong connection with inferring topological structure of roads. A well-know method is to use the Voronoi diagram for

boundaries of town unit; then, lines equidistant from adjacent town units are medial lines [9].

Figure 8: Voronoi diagram when edges are divided into pieces further

Figure 9: Voronoi diagram

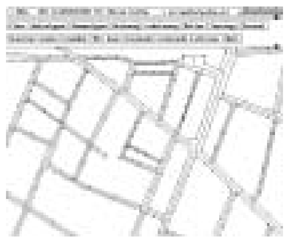


Figure 10: Connecting the centroid and the middle points of triangle edges

The Voronoi diagram for boundary line segments can be approximated by the Voronoi diagram for points densely placed on the boundaries, as depicted in Fig.8, although, when the density is low, edges of the Voronoi diagram may oscillate as in Fig.9. Except crossing points of roads, a method of connecting the middle points of edges of triangles obtained as above may approximate well the Voronoi diagram, which is easier to perform in practice. Practically, we may construct the Voronoi diagram for line segments only near crossing points, and, in other places apply the triangulation method.

3.3 Map Labeling

In maps, labels (or, names) of regions, rivers, and stations, etc., are placed in appropriate places so that the corresponding features in the maps can be understood. Where to place such labels is quite important for readability of maps. The problem of placing such labels are called the map labeling problem, and has been studied intensively [1, 11, 12, 16]. Here, we describe some recent approaches for edge labeling version of this problem.

The problem of placing a label to a point is call the NLP (Node Label Placement) problem. We can consider may types of candidate positions near the point for placement of the label. Even for the case of fixing the label position uniquely to each point, the problem of placing the maximum number of labels so that no two placed labels do not intersect is NP-hard.

The problem of placing labels for edges is called the ELP (Edge Label Placement) problem. The label for an edge may be placed at any place along the edge, and in this respect there is more freedom than in the NLP problem. One approach to solve this problem is to select a set of points on the edge and place the label of the edge at one of points. Recently, a unified approach of placing labels for edges and nodes

simultaneously (called Graphical Feature Label Placement problem; GFLP problem for short) is proposed [12)]. The unified approach provides a general algorithm, but, to specific applications, detailed parts of the algorithm should be newly determined. Imai and Kameda [8)] propose generalized algorithms for train maps, etc. We here outline these algorithms and show some computational results.

The unified approach for the GFLP problem in [12)] consists of the following three steps.

1. Determining a finite set of candidate places for the label to each feature (feature is either a point or an edge)

2. Define the cost of each candidate place.

3. Find a minimum-cost set of candidate places, at most one for each feature, which do not intersect each other.

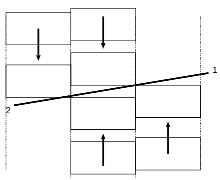


Figure 11: Candidate places of a label for an edge (vertical division case)

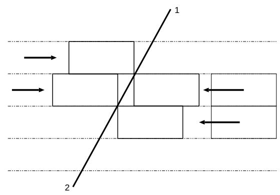


Figure 12: Candidate places of a label for an edge (horizontal division case)

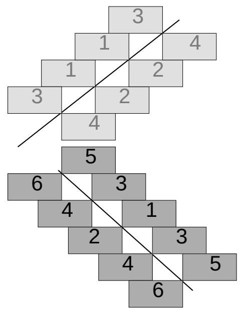


Figure 13: Costs of candidate places of a label for an edge

In order to apply this general framework, we have to determine how to design candidate places for each label, and further how to set the cost of each candidate place. Imai and Kameda's approach [8)] works as follows. Suppose that an edge is given as a line segment. For simplicity the size of each label is fixed. Denoting the width and height of an edge by W and H, we compare the slope s of the edge with H/W, and when

$$-\frac{H}{W} \leq s \leq \frac{H}{W},$$

we divide by vertical lines of interval W; otherwise by horizontal lines of interval H, so that a label position incident to the edge is considered as candidate places, as in Fig.11 and Fig.12, respectively. Candidate places intersecting with other edges are deleted. This extends the method in [11)].

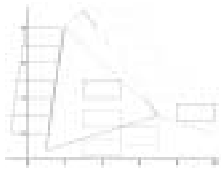


Figure 14: Computed candidate places by the cost-first method

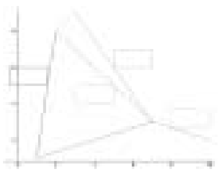


Figure 15: A final result by the cost-first method

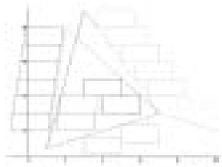


Figure 16: Computed candidate places by the intersection-first method

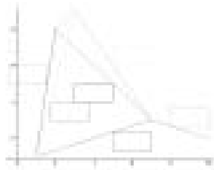


Figure 17: A final result by the intersection-first method

Next, the cost is determined by the following strategy: The closer a candidate place is to the middle point of the edge, the smaller its cost is set. Also, positions in the upper side of the edge is set to have less cost. See Fig.13.

We then apply a greedy approach which maintains a set of candidate places as processing edges one by one in some fixed order. In processing an edge, this set may be made smaller by deleting candidates in the following two manners:

Cost-first greedy approach In processing an edge e, for any intersecting pair of a candidate place for e and a candidate place for some other e', the place having the higher cost among two is removed from the set. Fig.14 is an example output. After processing all edges, we select the lowest cost candidate place among remaining candidate places for each edge. The result for Fig.14 is Fig.15.

Intersection-first greedy approach In this approach, each candidate place is associated further with the number, called the intersection number, of other candidate places, in the current set, intersecting with it. Then, the algorithm proceeds in a similar way by removing the candidate place having higher intersection number. Fig.16 is an example output, for the same data set in Fig.14. As in the case of the cost-first greedy approach, at the end, we select the least cost candidate place among remaining candidates for each edge. For Fig.16, a result becomes as in Fig.17.

Comparing Fig.14 and Fig.16, the final candidate set in Fig.14 is of size 16, while 18 in Fig.16. Concerning the final results, the intersection-first method is superior in this case. Also, it gives a well-balanced placement.

The above method can be extended to place a label to a polygonal line. A subway line may be represented by a polygonal line whose nodes are stations and edges are subway lines connecting adjacent stations. In such cases, just one placement of a subway line label suffices in the subway map. The above method can be extended to this case.

Fig.18 and Fig.19 are results for the Tokyo metropolitan subway map by the cost-first and intersection-first greedy algorithms, respectively. In this case, many lines

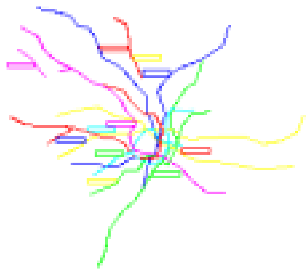


Figure 18: Cost-first method

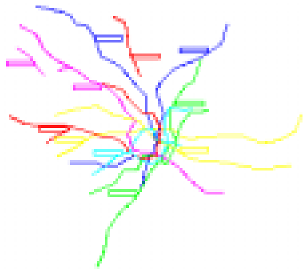


Figure 19: Intersection-first method

Figure 20: Station and line names of circular and central JR train lines

passes the central part of Tokyo, the cost of candidate places are slightly modified in such a way that one-third and two-third positions of a polygonal line has zero cost. In this case, the intersection-first greedy algorithm performs better.

So far, we have dealt with the ELP problem for edge labels. In concluding this subsection, we show a result for the GFLP problem for node and edge labels for the train map with line names and station names. For point labels, four natural candidate positions (NW, NE, SW, SE) of a point are considered. Since line names have more freedom, the point labeling is put higher priority. Fig.20 is a result for JR lines, circular line and central line, in Tokyo. For 47 out of 48 stations, together with two line labels.

4 Finding Detours in ITS

For the car navigation system, the most typical query is a shortest-path query. This query is very important in mobile computing environments based on GIS [5)]. As dynamical traffic information newly becomes available such as ATIS and VICS mentioned in the introduction, more sophisticated queries come to be required. Also, the static geographical database of roads itself has grown up further, and similarly in this respect advanced types of queries are necessary to realize a user-friendly interface meeting the current circumstances. One important query among them is a detour query which provides information about detours; for example, enumerating

several candidates for useful detours. We have proposed an efficient algorithm for enumerating meaningful detours [14)].

'Detour' is not so clear concept. Thus we must define it precisely. The k-th shortest paths for moderate k have severe overlap with the shortest path in most cases, and are not suitable as good detours. Taking such overlaps into consideration, we define 'detour' as follows [14)]:

Definition 1 *'Detour' is Δ longer than the shortest path at most, branch off and join the shortest path only once, and has the smallest overlap with the shortest path among such paths. If several paths satisfies these constraints, choose the shortest one.*

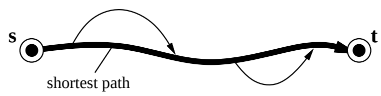
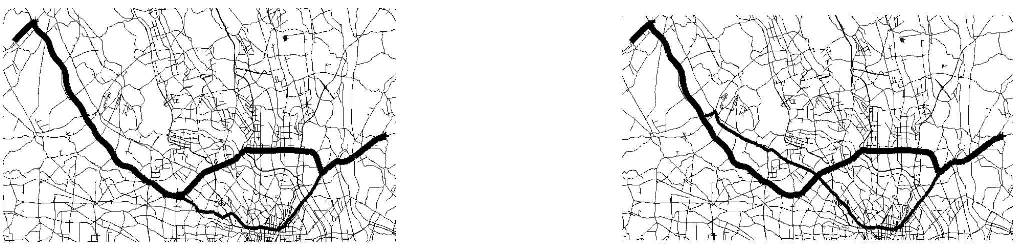


Figure 21: Explanation of the definition of 'detour'

In Fig.21, there are two 'branchings', and each may be used separately in our detours, but, the path using both of them is neglected in our approach, since it can be generated from the previous two paths.

In Shibuya et al. [14)], an efficient network algorithm is given to find thus defined detours. We here only show computed examples by this algorithm. Fig.22 shows the obtained detours from Sayama to Matsudo, on an real road network database of Kanto district area in Japan, when Δ is 100 seconds and 120 seconds. In the figure, the thickest line is the shortest path, and the relatively thinner line which branch off it is the obtained detour.



(1) $\Delta = 100$ (2) $\Delta = 120$

Figure 22: Detours between Sayama and Matsudo

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