JUNCTION MODELING IN VEHICLE NAVIGATION MAPS AND MULTIPLE REPRESENTATIONS

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TS – PS: WG IV/3 Data Generalization and Data Mining

KEY WORDS: Cartography, database, generalization, navigation, automation.

ABSTRACT:

Generalization is certainly one of the most important current issues in cartography, with particular emphasis being placed on its automation. This paper considers the automation of generalization applied to road networks primarily urban roads. In this context car navigation is considered as main subject. As Timpf et al. (1992) stated car navigation require data at a wide range of scales and at different levels of abstraction so a case study on map design for car navigation is done in this work

Navigation Key problem areas are parts of the network where a topological change occurs based on scale. For example, single or multiple lane representation of the roads and junctions can cause many problems to both the navigating user and the cartographer who designs the map. So these different representations of the roads are examined in this study. Each possible representation of the highways and its junctions is considered as different representational level in the scope of multiple representational databases (MRDB). Fundamentals of the MRDB are developed for the urban road data, where the significant transformations are identified and tracked. Generalization tools that can be used for obtaining multi-scale representations from the base database are defined in this paper.

1. INTRODUCTION

1.1 General

Technological developments occurring in time affect cartography just as the other disciplines. Especially developments in computer technologies and the use of the Geographical Information Systems (GIS) made significant changes in map production and generalization processes. Managing full automation of these processes has become one of the main tasks of cartographers and related researchers. Fundamental studies were done from the beginning of the 1960s up to now by Töpfer and Pillewizer (1966), Douglas and Peucker (1973), Shea and McMaster (1989), and etc. on these subjects. In most of these studies different algorithms, which are used for the automation of map production (especially generalization), were developed. However, in this period, studies were done not only on algorithm development but also on acquisition, storage, and maintenance of spatial data. Multiple Representational Database (MRDB) is one of the significant products of these attempts.

Developments mentioned above have affected automobile industry so car navigation systems recently became one of the prime parts of this market. As a result, use of maps by the driver has evolved from the classical roadmaps to the screen maps while travelling.

1.2 Aim of This Work

This work is a product of a continuous study that aims to produce maps for navigation purposes in terms of MRDB. Car navigation is considered as the basic case among the different navigation concepts and different levels of representations of the highways, which will be displayed on in-vehicle devices, are examined. The problems that occur on the problematic parts of the road networks, junctions, while finding shortest path and optimal route because of topology are determined then optimal representations for any scale are proposed. Meanwhile the fundamentals of an MRDB for navigation maps are formed in this work. This work is an approach for solving a specific problem occurring in navigation map production process by using MRDB.

2. CARTOGRAPHY AND GENERALIZATION

Cartography is the science, art and technology of making, using, and studying maps. As a result of the technological developments, significant changes on cartographic process occurred in time. Digital map production became as important as classical methods by the help of computer technologies. Moreover Internet brought a new perspective to the cartography so Web cartography became an important and discussing subject for cartographers (Kraak, 2002). Nowadays, mobile mapping technologies and methods, which aim to design maps for mobile devices such as mobile phones or Personal Distiller Assistants (PDA), introduced mobile cartography or small display cartography.

Generalization, which is considered as the spatial equivalent of simplification by Bertin (1983), can be defined as selection and simplified representation of detail appropriate to the scale and/or purpose of a map (ICA, 1973). It is one of the most important and problematic subjects of cartography. It is problematic because, although the widespread use of GIS and spatial databases and the need for visualization of spatial data over a huge range of scales has stimulated much research and development effort in this direction, success in automation of the generalization progress has been limited. There are several definitions for generalization from different experts and associations but it is obvious that most of them consider generalization as one of the most difficult task of cartographer.

Spatial data obtained from the real world is generalized in two steps: Model and Cartographic generalization. These are the two main components of generalization process. Model generalization is the simplification of the abstract digital model represented by the geographic information and this stage consists of no artistic and intuitive components (Kilpelainen, 1997). It is applied in database and considered as a preprocessing stage for cartographic generalization. On the other hand cartographic generalization consists of both of these components as a complementary part of generalization process so it is one of the reasons why cartography is considered as an art. As a result, cartographic generalization has the leading role in the transmission of the data by using symbols to represent geographic reality and it is a significant stage of the map production process.

2.1 Generalization Operators

Studies done by Shea and McMaster (1989) resulted with a conceptual model for generalization process. They modeled this process based on three main questions; why, when and how we should generalize? First two questions include steps needed while deciding generalization but third one is about utilization step. Generalization operators are the answer of the third question. Different authors name these operators as steps, tools or processes of generalization. They are all correct because these operators are the methods used to generalize data. Shea and McMaster (1989) made a detailed definition of 12 operators while answering the third question of their model. 10 of these operators are defined for spatial transformations. They entitled as simplification, refinement, smoothing, displacement, amalgamation, exaggeration, aggregation, enhancement, merging, and collapse. On the other hand rest of these twelve operators, classification and symbolization, consist of attribute transformations. Although the authors studying on special issues define different additional operators as Kilpelainen (1997) did for MRDB system, these 12 operators form the basic infrastructure of generalization process.

2.2 Needs for Generalization

Generalization has always played an important role in map production. However the scale is an important and determining concept for map contents so it is generally agreed that scale is the most important constraint of the generalization (Bildirici, 2000). Another limitation for the generalization is the aim of the map. In addition to the scale and aim of the maps, quality and quantity of data and graphic limitations are considered as the factors that affect generalization process by Robinson et al. (1978). Moreover, Kilpelainen (1997) emphasized the effects of the human factor, the cartographer, over the generalization process by her research succeeded with Finnish cartographers.

As it is known, generalization process is a set of rules. Especially these rule bases are very important for automation of the process. Maintenance of the topological consistency during the generalization is one of these rules. Topology is the mathematical concept of spatial structure, sometimes defined as "characteristics of geometry that do not change when the coordinate space is deformed" (Hardy et al., 2003). In other words, topology is a structure that defines geometrical relationships between objects. Hardy et al. (2003) state that:

- Shared edges between land polygons,
- Junctions between streets in the road network,
- Colinearity of administrative boundaries with roads and streams,
- Adjacency of buildings to roads,

need to be defined explicitly for good generalization. Moreover, topology is very important for road networks. If any model is tried to be set up for roads, first its topological relations should be defined then this topological structure should be formalized by using an appropriate method. However, Such an approach is followed in this work.

3. MULTIPLE REPRESANTATIONAL DATABASES (MRDB)

Although there is just one world reality, its representations vary with different aims, contents or display scale so different levels of representations of real world become a requirement for the experts. This requirement is increased by the development of the technologies on GIS, which is an inter-disciplinary work. However, generally different representations are aimed as an output in different GIS applications. Researches done for covering these kinds of needs resulted with the MRDB. The National Center for Geographic Information and Analysis began discussion of objectives and process of developing a research agenda in MRDB in the late 1980s (Buttenfield &Delotto 1989).

Multiple Representations are the different representations of the same spatial database. These representations can be in different scale, aim and resolution. MRDB is a spatial database, which can be used to store the same real world phenomena at different levels of precision, accuracy and resolution (Kilpelainen, 1997). A comprehensive description of the MRDB is done in Kilpelainen (1997) and she formed an MRDB model for generalization of geo-databases for topographic maps. According to the Kilpelainen's model MRDB consists of three main components: representation levels, connectivities and reasoning process. Representation levels cover the base level, which has the most detailed representation of the objects, and higher levels in which object representations vary with the scale, aim or resolution. Number of the higher levels change in terms of application so they can be defined as application dependent levels. MRDB aims to provide the propagation of the updates applied on base level to the other representational levels automatically so connectivities should be described and formalized between objects in the same or different levels. Kilpelainen (1995), separate the relations between different objects at one level, relationships, from the relations between the different representations of the same object at different levels, connectivities. Finally, the reasoning processes are needed to provide full functionality in the MRDB. It means that the updates can be propagated from lower level representations by using the model generalization operators applied automatically in the modules to be generalized (Kilpelainen, 1997).

Today MRDB is one of the most important subjects of concerning disciplines. Because this is a different database approach developed to cover the current problems on data management, automatic generalization and map production. Because data sets and map series are obtained in different European countries, many projects for adopting MRDB are implemented and MRDB applications start to be expansive during this adaptation process.

4. CASE STUDY

As Timpf et al. (1992) stated, navigation is a fundamental human activity and an integral part of everyday life. People navigated themselves while there is no computer or map. They early on used different techniques to find their roads but technological developments made this activity more interesting and easy in time with paper maps. Nowadays, it can be managed by the help of special navigation systems including integration of developing positioning and communication techniques, digital maps, computer and handheld device technologies. Today, these systems are used in different applications, so navigation is entitled according to its application area just as aircraft, marine, nautical, personal, and car navigation etc. Although these navigation types have significant differences because of their application dependent constraints and purposes, way finding demand forms the core of them (Timps et al., 1992).

In this study, car navigation considered as the basic activity and an approach for the production navigation maps tried to be proposed in terms of MRDB. However the system needs systematic updates in attribute and geometric level. Although changes in navigation conditions can be updated by using different technologies just as Internet or radio waves, geometric changes on the structure of road networks should be automatically updated in the system so database for the system should be available for update propagation. However this database should be formed based on MRDB (Ulugtekin et al., 2004).

Map design for navigation purposes is not scanning or digitizing existing paper maps. While designing such maps, usage conditions (psychological factors, external impacts, road conditions, etc.) should be considered in addition to design criteria. In this context, requirements for navigation map design are determined. As a result, this process considered as a part of small display cartography because of the technology used in navigation systems especially for representation. This makes the production process more complex and difficult.

4.1 Work Steps

After determining the requirements of the process representation levels are determined for different part of roads. Than topological relations for different representation levels are formalized and generalization operators that will be used in the process are selected. All representational levels are tested in different GIS and mapping software in terms of their consistency for the basic queries used in the navigation process, such as finding shortest paths or optimal routes. The results of these tests then permit the selection of the most appropriate representation level on which the standard algorithms can be used without any additional capabilities.

4.2 Representational Levels

Finally, desired cartography for map production should support the purpose, provide the aims and satisfy user requirements (Nissen et al., 2003). For example, a driver using a navigation system on a foreign city or country wants the system to navigate him as well as possible so system maps should display world reality in correct scale and resolution. Especially in road networks complex junction types should be visualized in detail. In this context, representation of junctions, which are the most complex parts of the road networks, is considered as key problem and different representation levels, where single and two lane representations of roads containing complex and basic junction views are determined (see Figure 1). Timpf et al. (1992), states that the existence of the multiple lanes is assumed but it is not needed for locating correct exits and entrances on road network. These different representational levels are examined by considering different aspects just like formalization difficulties, exchangeability among all software, usage and design costs to get an absolute result. The city of Istanbul is taken as the study area: Europe's largest city provides a challenging range of road features for consideration, in challenging quantities.

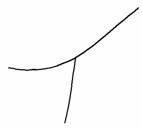
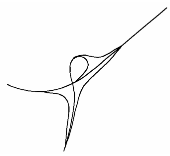
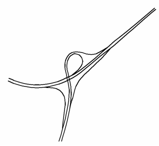
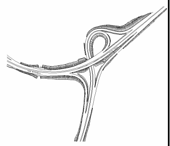
4th Level		Road network is represented by single line. The junction is visualized by using a single point (node) at the intersection of two roads. This level is generally used current navigation maps.
3rd Level		Road network is represented by single line. Details of the junction are basically visualized.
2nd Level		Road network is represented by two different lines for each direction. Junctions have as much detail as possible in this representational level.
Base Level		Road networks are represented in detail. All other representational levels are derived from this level or higher levels. Scale: 1:5000.

Figure 1. Representation Levels

4.3 Data Formalization and Reasoning Processes

Data formalization should be considered as one of the most important stage for an MRDB system, because mathematical definitions of the spatial objects and their relations were done using a consistent formalization language. Unless they were defined, the MRDB system cannot cover the aim of automatic generalization and update propagation. Different mathematical methods as Graph theory can be used in this process then they are expressed by using an appropriate formalization language. Studies on formalization of the representations continue. For example following relation definitions were written by using predicate calculus.

$$\forall x,y \ (Connect(x,y) \ \text{->} \ On((StartPoint(x) V EndPoint \ (x)),y) \ \Lambda \ (x \neq y)$$

$$\forall x,y \ (Intersect(x,y) \ \text{->} \ (\exists n(On(n,x) \ \Lambda \ On(n,y)) \ \Lambda \ n \neq (StartPoint \ \Lambda \ EndPoint))$$

The first of these statements means that if a road x is connected to road y, the end or start point of the road x is on the road y. The second means that if a road x intersects road y then there is at least one point, a node, on both of the roads but this point can not be a start or end point.

After formalizing the representations, generalization operators that will be used during the process were determined and object representation types defined in reasoning processes. Following figure briefly illustrates the reasoning processes in this work. Although only displacement, merging and refinement considered in the Figure 2, smoothing, simplification are significant operators, which are used in line generalization.

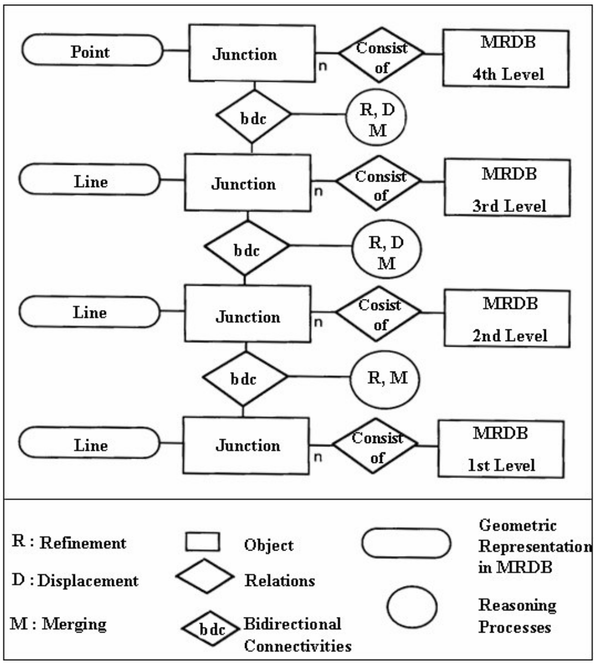


Figure 2: Reasoning Processes (Modified from Kilpelainen, 1997)

4.4 Tests for the Representations

Single and two-lane representations of the junctions were tested to determine which representation level is more consistent to the current software in which navigational calculations can be done. In this context network topology is created in three different programs than same queries are done for different representations of the junctions in the name of finding shortest path. One of the test results is given in Figure 3 According to this figure, arrows on the single lane representation show the road directions. While query result points the wrong way for this representation because of wrong directionality, it is possible to obtain the correct result in two-lane representation(Ulugtekin et al., 2004). As a result of these tests, it is understood that although two-lane representation of the roads have some problems, it is more consistent to the navigation programs and their current solutions for the problems.

5. CONCULUSION AND FUTURE WORKS

Navigation systems take more places in automobile industry and everyday life day by day. Future works on intelligent transportation systems aiming to manage the full-automated drive, so future systems should be designed based on artificial intelligence and expert systems. It is obvious that a user, driver, wants the system to represent the world reality as detailed as possible. But it should not be forgotten that the lack of detail makes the map unreadable. However, limits of the details should be determined by considering constraints of small display cartography.

In this study it is proposed that using two-lane representation of roads in navigation maps would be more convenient for several reasons. First of all it represents the world reality, especially junctions, better than single one. At the end of the formalization process it is understood that there is a significant differences between formalization of two lane and single lane representations because of the one or two-way distinction in single lane representation. Finally, while standard topological algorithms can run on two-lane representations additional programs are needed for single representations. This means that exchangeability of the two-lane representation is better than the single one.

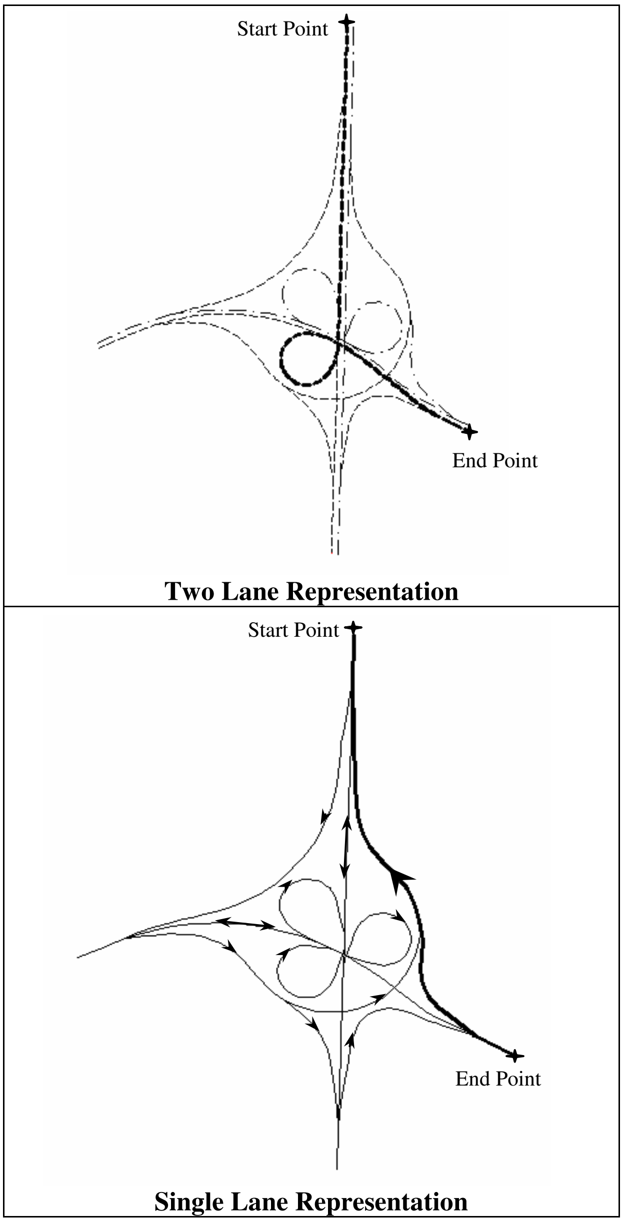


Figure 3. Shortest path query results in two and single lane representations

In this work, actual scales of the representations were not explicitly determined, because only road network were considered as a problem. Thus roads should be considered with their surrounding objects. This work should be developed and applied on the all road network of Istanbul. Derivation of these road maps automatically is another task that will be done in the next steps of this work.

6. REFERENCES

Bertin, Jacques, 1983. *Semiology of Graphics: Diagrams, Networks, Maps.* Traslated by William J. Berg, University of Wisconsin Press, USA.

Bildirici, I. O., 2000. Generalisation of Buildings and Roads in Scale Range 1:1000-1:25000, *PhD Thesis*, ITU Institude of Science and Technology, Istanbul. (in Turkish)

Brassel, K. and Weibel, R., 1988. A Review and Conceptual Framework of Automated Map Generalization, *International Journal of Geographical Information Systems*, Vol. 2(3), pp. 229-244.

Buttenfield, B.P. and Delotto, J.S., 1989. Multiple Representations. *Scientific Report*, National Center for Geographic Information and Analysis, NCGIA, Buffalo, 26p.

Douglas, D. and T. Peucker, 1973. Algorithms for the reduction of the number of points required to represent a digitized line or its caricature. The Canadian Cartographer, 10 pp. 112-22.

Hardy, P., Hayles, M. and Revell, P., 2003. A New Enviroment for Generalisation Using Agents, Java, XML and Topology, *ICA Generalisation Workshop*, April, Paris.

ICA (International Cartographic Association), 1973. *Multilingual Dictionary of Technical Terms in Cartography*. Franz Steiner Verlag, Wiesbaden.

Kilpelainen, T., 1995. Updating Multiple Representation Geodata Bases by Incremental Generalization, *Geo-Informations-Systeme,* Jahrgang 8, Heft 4, Wichmann, pp. 13-18.

Kilpelainen, T., 1997. Multiple Representation and Generalization of Geo-Databases for Topographic Maps, *PhD Thesis,* Finnish Geodetic Institute, Finland.

Kraak, M-J., 2002. *Web Cartography:Developments and Prospects*. edited. by M-J. Kraak & A. Brown. ITC Division of Geoinformatics, Cartography and Visualisation, Enschede, The Netherlands.Taylor&Francis, London and New York. pp. 53-72.

McMaster, R. and Shea, K., 1992. Generalization in Digital Cartography, *Association of American Geographers.*

Nissen, F., Hvas, A., Swendsen, J.,and Brodersen, L., 2003. Small-Display Cartography *GiMoDig Scientific Report.*

Robinson, A., Sale, R. and Morrison, J., 1978. *Elements of Cartography*, John Wiley & Sons, Inc, 448 p.

Shea, K.S. and McMaster, R., 1989. Cartographic Generalization in a Digital Environment: When and How to Generalize. *In: Proceedings for Auto-Carto 9*, Baltimore, pp. 56-67.

Timpf, S., Volta, G.S., Pollock, D.W. and Egenhofer, M.J., 1992. "A Conceptual Model of Wayfinding Using Multiple Levels of Abstractions." *In Theories and Methods of Spatio-Temporal Reasoning in Geographic Space*, Frank, A.U., Campari, I. and Formentini, U. (Eds). 639. Heidelberg-Berlin: Springer Verlag, pp. 348-367.

Töpfer, F. and Pillewizer, W., 1966. The Principles of Selection, *The Cartographic Journal,* Vol. 3, pp. 10-16.

Ulugtekin, N., Dogru A.O., and Thomson, R., 2004. Modeling Urban Road Networks Integrating Multiple Representations of Complex Road and Junction Structures, 12^{th} International Conferences on Geoinformatics, 7-9 June, Gavle , Sweden. (Accepted paper as oral presentation)