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GDF, A PROPOSED STANDARD FOR DIGITAL ROAD MAPS TO BE US

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Abstract

Dead reckoning and map matching car navigation systems as developed by Philips and Bosch, need a lot of detailed and dedicated geographical information.

The Demeter partners Philips and Bosch have worked out a proposed standard for the acquisition and representation of this information. This standard is called GDF, of which the first release has been published in october 1988.

The GDF is divided into 3 parts, respectively called SDC, SDA and EF. These 3 parts can be considered as being independent of each other:

- The SDC specifies which information is required for car navigation systems

- The SDA defines a set of features, attributes, and relationships for the representation of the non-spatial aspects of the required information. Further, the SDA defines a set of socalled cartographic primitives, meant for the representation of the spatial aspects. These primitives are related to the three different representation levels which correspond to the different needs of the different functions of a car navigation system.

- The EF finally, defines a collection of records and fields to enable the digital represention of these data.

GDF 1.0 is now in an evaluation phase. Wishes of other applications will be studied and may lead to additional SDC's and to an extension of the set of features, attributes and relationships.

Results of navigation tests will lead to the specification of quality requirements, actually completely missing in the GDF. Bench mark tests, as foreseen in the DRIVE projects "PANDORA" and "European Digital Road Database", will lead to an evaluation of the GDF and to a refinement or a revision of the acquisition and representation rules. They will improve the insight in the cost aspects of setting up a digital road data base.

Introduction

Several companies are working on electronical components for car navigation which can realize a safer and more relaxed driving environment. Some systems are already available on the market or will be introduced very soon. Others are expected at the beginning of the next decade [French, 1987].

Vehicle navigation systems can be classified in different ways. An important classification is the one into autonomous systems and infrastructure based systems.

The latter systems make use of the support of a satellite system, proximity beacons or radio communications, which provide the data that are needed for the determination of the location of the automobile or transmit information about the actual traffic situation.

Autonomous systems do not use the support of any infrastructure. All equipment needed for the determination of the automobile location is installed in the car. A computer combined with a mass-storage unit processes all information.

Autonomous systems use the dead reckoning method, known from ship navigation and aeronautics. This method is combined with the map-matching technique, which correlates the dead-reckoned location with the digital map data and corrects this location if needed.

Some systems are resticted to the determination of the location only, displaying this location on the background of a road map. More extended systems will also provide route planning and route guiding possibilities.

The functions of a car navigation system

A complete navigation system contains an Address Conversion, a Route Planning, a Route Following, a Route Guidance and a Position Display function.

The Address Conversion function enables the system to translate daily-life addresses (place name, street name, house number) into internal spatial addresses as used by the system.

Once the system knows the current position of the car and the desired destination of the driver, the Route Planning function will start planning the optimal route to that destination.

The route that has been determined is indicated to the driver by means of a series of audio-visual instructions. This function is called Route Guidance.

In the meantime, the actual position of the car is continuously kept up by the Route Following Function.

Finally, the Position Display function shows the current location of the car and a part of the planned route on the background of a road map.

The data needs of a car navigation system

All functions of a navigation system make their own particular demands on the on-board digital road map.

A common need however, is the position and the shape of the road network.

In many countries, addresses are usually specified in terms of street names. In these countries, the Address Conversion function must know what roads are identified by what names.

The knowledge of house numbers can be helpful to specify a more precise location on a street.

To guarantee the uniqueness of a street name outside the context of a particular municipality, also the municipality names and the names of administrative areas aof higher order are required.

Because the official municipality names are often replaced by the more fuzzy settlement names, the latter ones must also be known to the system. The same holds for the names of many objects like restaurants, cinemas, petrol stations etc. To reduce costs, the number of the objects that will be represented is restricted to the ones that have a direct relation to car driving.

An absolute requirement of the Route Planning function is the knowledge of the topology of the road network, i.e. knowledge of what roads are directly connected to each other by means of a junction and what roads cross each other by means of a bridge or viaduct.

The performance of the Route Planning function can further considerably be enhanced by means of a road classification i.e. a classification according to the degree of importance of a road in the total network. Typical class values are motorway, through way, main road, minor road etc.

To avoid that the Route Planner should plan a route which is not legal, information about traffic restrictions is required. The most important restrictions are: one way roads, banned turns, private roads and roads closed to motorized traffic. For trucks also dimensional restrictions (height, width, length and weight) are of importance.

For the production of clear instructions, the Route Guiding function is interested in a more aggregated and generalized representation of the road network.

Particular driving instructions have to be given on roundabouts. For this reason, the Route Guiding function wants to know what road elements belong to a roundabout.

Furthermore, the function is interested in the information presented by signposts, so that it can refer to this information in the guiding instructions.

To improve the readability of the map image produced by the Position Display Function, the database should also contain a number of land use units (forest, sea, built up area), railways, rivers, canals and other landmarks (towers etc.)

The GDF data model

A data model is the whole of concepts and expression tools that enables the description of a complex set of data-items.

The main concepts in the GDF (= Geographic Data File) data model are features, attributes and relationships. A feature is a formalized entity that is used to represent a topographical object. The properties and particularities of the objects are represented by means of attributes. Properties involving more than one feature, are described by means of relationships.

A group of features that is strongly related, is called a layer.

The names of features, layers, attributes and relationship will be written with a capital first letter.

. Layers

Seven layers have been defined: Roads & Ferries, Administrative Areas, Settlements, Buildings, Bridges & Tunnels, Railways and Waterways.

. Features

The Roads & Ferries layer contains three elementary feature types and three complex ones. The elementary feature types are Road Element, Ferry Connection and Junction. The complex ones: Road, Ferry and Intersection. The complex features allow for a more generalized view of the road network by aggregating two or more elementary features.

The Administrative Area layer has a nested set of features, the highest one of which is called Country, the highest but one Region and the lowest but one Municipality. The other features have a generic name to which a more specific name can be given in a particular country (e.g department, cercle, Kreis).

The Settlements layer consists of the Town, Village, Hamlet and Industrial Area features.

The Buildings layer has only the Building feature.

Also the Bridges & Tunnels layer contains only one feature called Brunnel (a contraction of bridge and tunnel). It is meant to represent also objects like fly-overs, elevated highways etc.

The Waterways layer consists of the Waterway Element and Waterway Junction feature.

The Railways layers contains the Railway Element and Railway Junction features.

. Attributes

A Road Element can have the attributes Direction of Traffic Flow (to represent one way roads and roads entirely closed to motorized traffic), Form of Way (motorway, dual carriageway, roundabout, square, parking place), Road Class (primary road, secondary road etc.), Route Number (A-56, E-34), Maximum Height, Maximum Length, Maximum Width, Maximum Weight, Special Traffic Restrictions (closed to dangerous loads, private roads), House Number Range and Traffic Sign along Road Element.

A Ferry Connection can have the attributes Road Class and Route Number (ferries are considered to be an integral part of the whole road network), Maximum Height, Maximum Length, Maximum Width and Maximum Weight. Furthermore, it can have the attribute Ferry Type (to enable the distinction between boat ferries and train ferries).

The Country feature can be given the ISO-3166 Country Code and the CCC Country Code. To a Region the CCC Region Code can be attached.

Furthermore, all feature types of the Administrative Areas layer can have the Type Name attribute (county, state, Kreis, arrondisement etc.)

The Building feature can have the attributes Building Class (Hotel, Theater etc.), Opening Days followed by Opening Hours and Brand Name (Hilton, Renault).

The Brunnel feature can have the attribute Brunnel Type to distinguish between bridges, viaducts, aquaducts or tunnels.

. Relationships

Some relationships have been defined to represent traffic-related information involving more than 1 feature. It concerns the relationships Prohibited Turn, Right of Way and Sign Post Information (meant to represent the place names and route numbers that occur on the signposts related to a particular turn).

Other relationships are created to enable the description of situations in which the logical tie between two features is not equivalent to their spatial one, e.g. a Building that has its entrance at a Road Element other than the one which is closest.

The relationships that have been defined for these situations are: Road Element in Municipality, Junction in Municipality, Building in Municipality, Settlement in Municipality and Building along Road Element.

A third type of relationship is created to describe what Road Element is on top of another Road Element. The relationship that was defined for this purpose, is named "X over Y through Brunnel" where X and Y may stand for a Road Element, a Waterway Element or a Railway Element.

. Proper names

In GDF proper names are represented in a different way than attributes, because of their special characteristics (long character strings).

Proper names can be attached to the Road Element, Ferry Connection, Intersection, Building and Brunnel features and to all features in the Administrative Areas and Settlements layers.

. Geometry and topology

Common properties of all geographic features is that they have an (almost fixed) location relative to the earth and often also a shape. These properties are commonly known as the geometry.

For some features (e.g. Road Elements), an explicit knowledge of the mutual connectivity and the relative spatial positions between the individual elements is of vital importance. This knowledge is called topology.

The GDF admits in principle the representation of a geographic feature without the description of the geometry. This option can be used if one is only interested in the logical relationship between features (e.g. Road Elements that belong to a Municipality) and not in the location and shape.

The cartographic representation model

The next important choice to be made is how each feature type shall be represented by means of points, lines and other kinds of cartographic primitives and how names and attributes shall be attached to them.

The choice for such a set of primitives, together with the representation rules for each feature, is known as the cartographic representation model.

. The three levels of representation

A main property of the GDF model is that it distinguishes three different representation levels, called Level-0, Level-1 and Level-2. These levels should not be considered as completely separated representations, but as different structures in one and the same representation, the higher ones embedded in the lower ones. However, these structures are all transparent in the sense that they all have a meaning of their own. It is in fact a kind of Trinitiarism: three and yet one.

Level-0 is also called the Geometry Level. It contains the 2-dimensional, topologically structured description of the location and shape of the features.

Another name for Level-1 is Object Level. On this level, semantic information (feature codes, names and attributes) is added to the pure geometrical description. On the Object Level, it is also possible to represent the 3-dimensional topological relations between features that form networks (e.g. Road Elements).

Level-2 is the Aggregated Object Level, which is meant to aggregate Level-1 features into one compound feature, to which semantic information can be added. Furthermore, this level allows for the representation of the 3-D topological relations between compound features.

An illustration of the different representation levels is given in figure 1.

The Cartographic primitives

Each representation level has a corresponding set of primitives:

A Level-0 representation is built up of Segments, Intermediate Points, Nodes and Chains.

Nodes and Intermediate Points are represented by exactly one pair (XY) or triplet (XYZ) of coordinate values. A Segment is bounded by exactly two Intermediate Points and/or Nodes.

A Chain contains always one or more Segments and is always bounded by exactly two Nodes. Nodes and Chains together form a planar graph.

The elements of a Level-1 representation are Spots, Lines, and Polygons.

A Line is related to 1 or more connected Chains and is bounded by exactly two Spots. A Polygon is bounded by one or more Lines, describing the outline of the Polygon.

Lines and Spots together may form non-planar graphs (see figure 1). However, the graph of Lines and Spots which are used to describe the outline of a Polygon has to be planar.

The cartographic primitives at Level-2 are called Composite Spots, Composite Lines and Composite Polygons. These primitives are meant to aggregate Level-1 primitives: a Composite Spot may contain one or more Spots and zero or more Lines, a Composite Line one or more Lines and a Composite Polygon one or more Polygons.

How the different cartographic primitives are related to each other, is illustrated in figure 2.

The global data in a GDF

In the GDF specifications, much attention has been paid to the so-called "global data", .i.e. data that are needed to interpret the feature data in a correct way. It was and is both Bosch and Philips' wish that these data should be included as much as possible in the GDF file itself, so that external documentation can be reduced to a minimum.

A first important group of global data items is the so-called "header information". Each GDF is considered as a Dataset which is physically subdivided into Volumes, and logically into Sections and Layers. The Dataset and each of these subsets have to be be preceded by a corresponding Header that identifies and briefly documents the data collection in question.

A next group of global data concerns the explicit description of the format of the fields and record types that are used in a particular file. This description allows the development of self-adapting test and conversion software so that the format of individual fields can be changed and fields and record types can be added (under some conditions) to the existing ones, without any manual adaptations of the program that reads the GDF.

The group of bibliographic data is also important. These data describe all the source documents (maps and books) upon which a particular GDF is based.

A fourth group of global data gives an overview of how many Sections a GDF contains, what the size (in bytes) of each Section is and to what geographical area each Section relates.

Next, there is the set of geodetical data. These data give information about items such as the horizontal datum, projection system, projection parameters, origin of the coordinate system, coordinate off-sets, vertical datum, geoid ondulation and the magnetic declination.

Last but not least, there is a group of global data describing the quality of the feature data. The quality aspects that are addressed are: geometrical accuracy, up to dateness, completeness of features and attributes and error rates in attribute values.

The GDF Exchange Format

To enable the transfer of feature data and the accompanying global data in a digital form, a set of records and fields has been defined. This set is called the Exchange Format because it is especially developed for the exchange of data.

The Demeter Working Group, which has worked on this format, has looked for a suitable prototype that could be used as a basis. This prototype had to fulfill a number of requirements, of which the following were the most important:

- It should have enough representational power to cover the special needs of navigation systems

- It should have the possibility of representing topologically structured data

- It should allow for independence between the representation of the semantic, topological and geometrical information of a particular feature.

- It should be open ended so that it can be extended with new fields, records, feature codes and attribute types, without the need to redesign the format completely.

The National Transfer Format (NTF) Release 1.0, as worked out by the British Ordnance Survey and other mapping organizations in the United Kingdom, was found as a suitable prototype. It fulfilled the requirements mentioned above and, furthermore, it already contained a first step towards the concept of the three different representation levels and the corresponding cartographic primitives.

The Demeter Working Group adopted this concept and worked it out to the ideas defined in the GDF.

For the new primitives, as for the extra global data items, additional fields and records were defined in NTF style.

The GDF Release 1.0

The GDF Draft Standard has been divided into 3 different parts which can be defined and updated independently:

- **The Data Content Specification (GDF-SDC)**

  This part of the GDF specifies what features and attributes have to be included in an exchange file for car navigation systems. The current SDC was compiled at the beginning of 1987 and covered the requirements of Bosch's and Philips' car navigation prototypes at that time.

- **The Data Acquisition Specification (GDF-SDA)**

  The SDA specifies the conceptual data model of a GDF file. It describes how the features and attributes shall be represented in terms of cartographic primitives (Spots, Lines, Polygons, Composite Spots and Composite Lines) and how these primitives shall be represented geometrically by Nodes, Segments and Intermediate Points.

  The SDA furthermore gives detailed rules on how to survey the features and attributes in the draft standard.

- **The Exchange Format Specification (GDF-EF)**

  The EF specifies the physical data model of a GDF file. It describes the file, record and data field layout and defines the global and meta data of the exchange file.

Use of GDF

GDF was released in October 1988. Until now only small GDF test files have been compiled by Philips and Bosch. But both companies will demand GDF as the exchange format of digital road network data.

Evaluation of GDF

GDF must now be tested in practice. The following points will be taken into account:

- **Data Capturing**

  Capturing GDF data will show whether the survey rules specified in the GDF-SDA are suitable and unambiguous and whether the way of describing data quality is sufficient.

In addition the comprehensibility of the text will be examined.

- Implementation

Software implementation of GDF, e.g. writing interface programs for Geographic Information Systems or creating conversion programs, will show if refinement is needed to make GDF more easy to implement.

- Extending GDF

The implementation of change requests of applications other than car navigation will show whether these requests can be easily realized within GDF. If important change requests do not fit into the current structure of GDF, the structure will be extended or redefined.

The evaluation of GDF will take place during the DRIVE projects Task Force European Digital Road Map (TFEDRM) and PANDORA.

DRIVE projects TFEDRM and PANDORA

The DRIVE project TFEDRM (Task Force European Digital Road Map) includes basic research work to create a common European Road Map Database. The major parts of this project are:

- Technical Framework

This part deals with technical and organizational problems connected with puting up and running a European Road Map Database. It includes logistic problems of data capturing and updating as well as problems concerning database architecture.

- Benchmark Test

This part contains data capturing in 11 European test areas using different data sources and data capturing methods. The evaluation of the Benchmark Test will show the costs and efficiency of each data capturing method.

GDF is used for data capturing and exchange within the Benchmark Test.

- Standardization

Based on GDF, a standard for exchanging data for digital road maps will be developed which fits the needs of both the data suppliers and the users of a European Road Map Database.

The DRIVE project PANDORA (Prototyping a Navigation Database of Roadnetwork Attributes) provides the UK element (Task 12) of the Benchmark Test. Furthermore it includes the integration of map- and traffic-related attribute data and the use of these data in a field test with autonomous and infrastructure based navigation systems. GDF is used as exchange format.

Standardization Part of TFEDRM

The standardization work on DEMETER has been carried on within the DRIVE project TFEDRM. But the decision as to which extensions developed during the DRIVE project will become part of a further release of the draft standard still rests with DEMETER. The main tasks of the standardization part of TFEDRM are:

- Preparation of Data Capturing

  Since road network data will also be collected for logistic management systems, an extension of GDF has been created which is only valid for Benchmark Test purposes.
  The extension includes:

  - Services. This new layer contains spot features which can be used for car navigation systems. Services can be constructed in a hierarchical manner, eg. a Harbour having subservices Store House and Ferry Terminal. The Buildings layer is used for visualization purposes only.

  - Traffic-related attributes for the Roads & Ferries layer. Additional attributes concerning traffic density and speed potential have been added.

  - Positions of Signposts.

- Evaluation of Benchmark Test Results

  All Benchmark Test results which are relevant for the development of GDF will be evaluated.

- Analysis of commercial and public data sources

  This part investigates the availability of data in public and commercial databases which might be of interest to road database users. In addition, the effort to convert these data into an exchange format is checked.

- Analysis of other standards

  The analysis of other existing standards for transferring spatially referenced data might yield tips for the improvement of GDF.

- Analysis of the requirements of other applications

The requirements of other road database applications like infrastructure based navigation systems, traffic and logistic management systems might result in an extension of the GDF.

The results of the analysis given above yields to a check for a revised version of the GDF structure. A revised structure of GDF could include:

- Alignment of GDF-EF with ISO 8211

- Multiple SDC's for different applications

- More modularity of the draft standard to ease the implementation of requests of different applications and to make it possible to implement subsets of the whole standard.

After that, a new version of the GDF draft standard will be created.
Finally a European standardization procedure will be started within the DRIVE project.

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