A1-D4

Ontology of Transportation Networks

Project title:	Reasoning on the Web with Rules and Semantics
Project acronym:	REWERSE
Project number:	IST-2004-506779
Project instrument:	EU FP6 Network of Excellence (NoE)
Project thematic priority:	Priority 2: Information Society Technologies (IST)
Document type:	D (deliverable)
Nature of document:	R (report)
Dissemination level:	PU (public)
Document number:	IST506779/Munich/A1-D4/D/PU/a1
Responsible editors:	Bernhard Lorenz
Reviewers:	Mike Rosner
Contributing participants:	Munich
Contributing workpackages:	A1
Contractual date of deliverable:	31 August 2005
Actual submission date:	31 August 2005

Abstract

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Keyword List

semantic web, geospatial notions, ontologies, transportation networks, intelligent transport systems

Project co-funded by the European Commission and the Swiss Federal Office for Education and Science within the Sixth Framework Programme.

Ontology of Transportation Networks

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This deliverable consists of three main parts. The first part is a comprehensive survey on standardisation efforts for geographic information. The second part contains a description of the Geographic Data Files (GDF) standard. This is an ISO specification of how to store geographic information for intelligent transport systems. The structures in GDF, although primarily developed for storing data, are already a sophisticated ontology for transport networks. They are, however, still described on paper, and not with a formal system for representing ontologies. Therefore we turned the more informal description of the GDF ontology in a formal OWL-based ontology. The result is OTN, an Onotology for Transportation Systems. OTN is very similar to GDF, with some extras. It is described informally in the third part of this deliverable. The precise technical details of OTN can be obtained online at http://www.pms.ifi.lmu.de/rewerse-wga1/otn/OTN.owl.

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Chapter 1

Introduction

For thousands of years people have been collecting geographic data. Until a few decades ago these consisted mostly of painted maps. A little legend was usually sufficient to explain how to read the map. The first step away from maps on paper was to store digitised maps on computers. This way maps could be distributed and duplicated more easily. Digitised maps, however, allow for only simple transformations, scaling and rotating, for example. Therfore, in a second step, one did no longer store the graphical representation of the maps, but the information which is contained in the maps. For example, instead of the graphical representation of a road, one could store the coordinates of the road junctions, together with some further information about the road type. This way, one could use the data not only for producing maps, but for quite a number of further applications, navigation assistants, to name just the most prominent example.

Institutions in many different countries, however, struggled with the details of how to store graphic data. If everybody stored the data in their own way, it was not easy to combine data from different sources. This was recognised very early and therefore standards for storing geographic data have been developed. Unfortunately, there is not one single standard, but several more. Graphic Data Format (GDF), an almost binary data format is one of the most prominent and widely used ones. Geographic Markup Language (GML), an XML based standard, is a more recent development.

Each such standard structures the information in a certain way, and this standard represents a particular view of the reality. This view is a model which approximates the reality to a certain degree. Unfortunately, as there are different standards, there are different models of the reality. In GDF, for example, a road is modelled as the set of road segments between the road junctions. The road segments are in principle treated as straight lines, such that the road modelled is a polyline. An alternative could be to represent the road with splines and to store the control points of the splines. The control points need not be road junctions, but can depend on the curvature of the road.

The point we want to emphasise here is that the storage structures for geographic information implicitly define a logical structuring of a domain. There are nowadays formal systems which allow one to encode the logical structuring, which is usually described on thick and expensive ISO reports, in a form which makes it subject to further computer manipulations. An important part of the logical structuring can, for example, be encoded in the OWL ontology language. This has in fact been done to some extent for GML in a few research projects.

Since there are different standards for geographic information, there are different logical structurings, and thus, there are different ontologies for the same domain, transportation networks in our case. The ontologies which are directly extracted from the standards model the standard's view of the reality, but not the reality itself. This has the big advantage that the ontology can be used directly with the data which are stored according to this standard, but to according to another standard.

Ideally, however, one should step away from the standards and develop an ontology for transportation networks, which models the reality directly. Such an ontology can, however, not easily be used with any of the existing geographic data files. It is not clear whether there is a mapping possible between this abstract standard and the concrete data. A formal ontology, which more closely follows the standard would definitely be very useful as an intermediate between the abstract ontology and the data.

In this work we therefore extracted the GDF ontology and formalised it in the OWL ontology framework. The result is OTN, an Ontology for Transportation Systems. OTN is very similar to GDF, with some extras. A first application of OTN is described in a system which uses the concepts of OTN for visualising GDF data in Scalable Vector Graphics (SVG). This is described in the deliverable A1-D5. Before we describe GDF and OTN in Chapter 4, we give an overview on the standardisation efforts in the area of transportation systems.

Chapter 2

Standards for Geographic Information

The collection, storage, management, and analysis of geospatial data are critical components of many business activities. Unfortunately, geospatial data can and have been stored in a number of ways (i.e., paper, microfilm, and/or electronically) that may not be readily accessible and usable, or easily shared with, or reported to others. The countermeasure is *standardisation.* There are many factors that drive the need and desirability for standardisation.

From the GIS perspective, the key benefits of standards are:

- Data sharing/communications: standardised data is more easily understood; standardisation allows countries and agencies to exchange data freely when based upon a common set of definitions and understandings about the data and its features.
- Elimination of redundancy - standardisation contributes directly to the reduction and in some cases the elimination of duplication and redundant gathering of similar data and database construction.
- With GIS standards as a major component, technology, data policy, and institutional framework are four necessary components for the realization of a spatial data infrastructure.

From the Navigation and Telematics Market perspective, standards help spur growth by:

- Reducing consumer confusion.
- Reducing costs to vendors and prices to consumers.
- Providing better uniformity in applications.
- Improving time to market by standardising data access and delivery processes.
- Levelling the playing field by removing barriers to competition.
- Providing the technological framework that will enable future applications and products.

2.1 Standardisation Bodies

There are standards at the international level (ISO), the European level (CEN) or at the national level.

At the international level, the International Standardisation Organisation (ISO), a world-wide federation of national standardisation bodies from 130 countries, one from each country, has established several Technical Committees, e.g. ISO Technical Committee Number 211 (ISO/TC 211) Geographic information/Geomatics, which is responsible for the ISO geographic information series of standards. These standards may specify, for geographic information, methods, tools and services for data management (including definition and description), acquiring, processing, analysing, accessing, presenting and transferring such data in digital/electronic form between different users, systems and locations.

The following ISO technical committees (ISO/TC), through their corresponding working groups, are of particular importance to traffic and transportation networks:

- ISO/TC Road Vehicles: compatibility, interchangeability, and safety, with particular attention to terminology and test procedures for motorcycles, motor vehicles, trailers, semi-trailers, light trailers, combination vehicles, and articulated vehicles.
- ISO/TC204 Intelligent transport systems with Working Groups, e.g.
  - WG 1 Architecture
  - WG 4 Automatic vehicle and equipment identification
  - WG 8 Public transport/emergency
  - WG 9 Integrated transport information management and control
  - WG 10 Traveller Information systems
  - WG 11 Route guidance and navigation systems
  - WG 14 Vehicle/roadway warning and control systems
  - WG 15 Dedicated short range communications for TICS applications

Furthermore, two technical committees ISO/TC 211 (Geographic information/Geomatics) and ISO/TC 145 (Graphical symbols) work closely with ISO/TC 204.

The Open GIS Consortium or OGC is also a leading organisation at the international level. OGC is a not-for-profit, US-based, international industry standardisation organisation that addresses interoperability in the realm of geoprocessing and brings geospatial technologies and their users to the mainstream IT marketplace.

The most important OGC specifications are:

- GML - Geography Markup Language
- WFS - Web Feature Service
- WMS - Web Map Service
- WCS - Web Coverage Service
- CS-W - Catalog Service Web
- SFS - Simple Features - SQL

Especially, OGC and ISO TC/211 have developed GML together, which is an XML encoding in compliance with ISO 19118 for the transport and storage of geographic information modelled according to the conceptual modelling framework used in the ISO 19100 series and including both the spatial and non-spatial properties of geographic features. The GML specification defines the XML Schema syntax, mechanisms, and conventions that provide an open, vendor-neutral framework for the definition of geospatial application schemas and objects.

At the European level, the Comité Européen de Normalisation (CEN), the European Committee for Standardisation, was founded in 1961 by the national standardisation bodies in the European Economic Community and European Free Trade Association (EFTA) countries. The work of the CEN Technical Committee Number 287 (CEN/TC 287) is defining standards in the field of digital geographic information for Europe, in particular, defining a structured framework of standards and guidelines, which specify a methodology to define, describe and transfer geographic data and services. This work will also be carried out in close co-operation with ISO/TC 211 in order to avoid duplication of work. The working group Road Transport Telematics of CEN/TC 278 has developed the Geographic Data File (GDF)-standard, which provides the basic module of OTN.

Important organisations at the national level are for example: AFNOR, BSI, DIN, NTS, SCC, ANSI, SABS, and SA. Besides the international and national organisations, many international initiatives, programmes, and institutions are working on this subject, e.g. GSDI, DGIWG, FIG, ISPRS, ICA.

2.2 Road Network Models

There are many road network models developed by different countries. In this report two models will be introduced.

2.2.1 The Road Network Model in ISO 19107

The fundamentals of a road network model, geometry and topology, is standardised in ISO 19107. ISO 19107 defines geometry and topology as two different and independent packages which model these two aspects of geographic data.

The geometric packages define many classes for geometric primitives (points, lines, surfaces and solids) and geometric complexes. Simple geometric representations like straight lines between vertices as well as more sophisticated representations like splines and TIN surfaces are covered. Geometric complexes are collections of primitives and other complexes where no geometry overlaps or intersects other geometry within the complex or itself.

The topological packages define classes for explicit topology according to the boundary representation principles. This means that topological entities are defined by their boundary. The topological classes are nodes, edges (bounded by nodes), faces (bounded by edges) and solids (bounded by faces).

In this way ISO 19107 defines a set of basic resources which should be used for the definition of a road network model but it does not define the specifics for road data.

2.2.2 The Swedish Standard Proposals SS 637004, SS 637006 and SS 637007

Based on a number of standards from ISO/TC211, the three specifications SS 637004, SS 637006 and SS 637007 together define a conceptual model for the representation of road and railway networks. The specifications cover the following:

- SS 637004 contains a definition of the classes used to represent a network, topologically and geometrically, and the linear referencing mechanisms to relate attributes and objects to the network (i.e. the network itself serves as a reference system)

- SS 637006 contains a definition of classes to represent geographic features in a type independent manner.

- SS 637007 contains a definition of classes to represent updates at instance level (new, modify,delete) to a dataset.

All specifications use UML according to ISO 19103 to allow for XML encoding according to ISO 19118.

Other than the network itself, the standards do not specify any specific features related to the road application domain. Instead, the specifications are actually frameworks and it is up to users of the specifications to define the specific features for a certain application domain. One such example is the Swedish National Road Database (NVDB).

NVDB covers many, but not all, application demands. But, by use of SS 637004 it has defined a common road network representation for Sweden which can be referred (by the usage of linear referencing mechanisms) from several different applications.

2.3 GDF

For modelling transportation and traffic networks several formats are available. In this report we investigate just GDF and XGDF, because OTN is derived from GDF. Furthermore, XGDF is being developed by ISO and improves on GDF.

2.3.1 Introduction to GDF

GDF was developed within a technological research and development project known as European Digital Road Map (EDRM). It is the European standard CEN/TC 278 [1] and the international standard ISO/TC 204 [7].

GDF is the leading Business-to-Business (B2B) map delivery format for high-end map-dependent Intelligent Transportation System (ITS) applications and services that require detailed, rich and accurate geographic data. Its primary use is for car navigation systems, but it is also very usable for location-based services and many other transport and traffic applications like fleet management, dispatch management, traffic analysis, traffic management, etc. The European Union promotes the use of the GDF format. Maps in GDF are typically provided by map vendors such as Tele Atlas and NAVTEQ. Bosch, Philips, and Volvo use GDF for their car navigation systems.

2.3.2 History of GDF

By the late 1980s, producers and users of digital road map data became increasingly aware of the need for a common data interchange standard. Lack of such a standard was seen as an impediment to the commercial growth and success of industries using such data. Before the advent of the ITS industry, development of spatial data interchange standards was done mostly on a regional basis and not designed for the specialised requirements of road transport-related applications. Furthermore, the 1990s saw the expansion of the number of ITS applications developers who needed map data vendors to supply their products in an economical, efficient and non-ambiguous manner. Moreover, the ITS applications suppliers and developers were largely deploying systems in Europe, Japan, and the USA, marking the essential need for standardisation on a global level.

The establishment of ISO/TC204 in 1993 sought to remedy the lack of international standards for ITS. The technical committee is divided into 16 working groups. Working Group 3 (WG3) was charged with the responsibility of developing standards to promote interchangeability of map data and interoperability of systems using map databases. Since its constitution, the GDF sub-group is convened by Rob van Essen, Tele Atlas.

The work of WG3 started in 1994 with a review of the available regional standards documents. Considerable differences were identified. The Japanese standard developed by the Japan Digital Road Map Association (JDRMA) was oriented towards navigation applications with much emphasis placed on access speed and file size. The developments in the US had resulted in the Spatial Data Transfer Standard (SDTS), a highly generalised approach. Of this standard, the Topological Vector Profile was of particular importance. Next to SDTS the US provided the SEA Truth-In-Labelling standard that provided a standard way of describing the contents of a geographic data set rather than on standardising its content. The work in Europe resulted in a standard called GDF3.0, featuring an application independent data model, traffic and transport related extensions, flexibility, and extendibility. This European standard became the base specification for the internationalisation effort of WG3.

The actual GDF version 4.0 was published as an ISO standard in the spring of 2004. Through its extensive dictionary of standardised semantic definitions, GDF 4.0 forms an excellent foundation for interoperability between map-based ITS applications and services.

2.3.3 The GDF Specifications

This section presents a concise description of GDF 4.0. First, the conceptual data model will be briefly dealt with, after which the level concept in GDF will be described. In the final part of this section the GDF data model will be elaborated.

2.3.3.1 The conceptual data model

The conceptual data model identifies:

- Features, an example can be a Road Element which represents a certain road section,
- Attributes which can refer both to Features and Relationships, an example is a Time Domain in which a certain forbidden turn is effective (Attribute of a Relationship),
- Relationships, an example can be a forbidden turn which is described by a relation between two Road Elements and a Junction.

The conceptual data model, particularly, the feature category will be presented more precisely in the next section in consideration of OTN.

2.3.3.2 The Level Concept in GDF

In the GDF file structure, features (or elements) are organised into three levels (layers). Features in each level do not actually contain any geometry, but simply link to features in the level below from which you are supposed to take the geometry.

The three levels in GDF are:

- *Level 0 (Topology):* which describes the fundamental geometrical and topological entities to be used. The entities are nodes or dots (0-dimensional), edges or polylines (1-dimensional) and faces or polygons (2-dimensional) in a 2d or 3d coordinate space. Three different types of graph topology are possible:
  - Non-explicit topology. No topological relations between the basic geometric objects are defined. Topology can only be derived from the coordinates. Non-explicit topology always uses dots, polylines and polygons.
  - Connectivity (or network) topology. Topological relations between 0- and 1-dimensional basic geometric objects are fully defined. The graph is non-planar.
  - Full topology. Topological relations between 0-, 1- and 2-dimensional basic geometric objects are fully defined. The graph is planar.
- *Level 1 (Features):* which adds the possibility to describe real world geographic objects with their characterising properties. These are called simple features. The simple features use the underlying level 0 entities as their geometrical and topological representation. Simple features can be topological or non-topological. Every simple feature is either of point-, line- or area type. The simple features are represented by corresponding objects from level 0:
  - A topological point feature is represented by one node. An example of a topological point feature is a road junction.
  - A topological line feature is represented by one or more edges and always has a start- and end- bounding point feature (connectivity topology at simple feature level). An example of a topological line feature is a road element.
  - A topological area feature is represented by either one or more faces or the bounding edges. Examples of topological area features are address area and enclosed traffic area.
  - A non topological point feature is represented by exactly one dot (geographical position)
  - A non topological line feature is always represented by exactly one polyline.
  - A non topological area feature is always represented by exactly one polygon.
- *Level 2:* which gives the possibility to describe complex features which are aggregates of other features (simple and complex). Topology on level 2 can be defined since a complex feature can have a starting and ending complex feature (connectivity topology at complex feature level). Examples of level 2 features are road, intersection and roundabout. Non topological simple features can't be aggregated into complex features.

2.3.4 The GDF Data Model

The GDF standard specifies the conceptual and logical data model and the exchange format for geographic databases for ITS. The model identifies *features*, *attributes*, and *relationships.*

Feature is a data base representation of a real world geographic object. Examples of real world geographic objects are *roads* or *buildings*. Each Feature must belong to exactly one *feature class* and exactly one *feature theme.* Feature classes and feature themes are uniquely referenced by a *Name* and a *Code*.

Each *feature* is also of exactly one feature category. The features categories defined are *Point*, *Line*, *Area* and *Complex Features.* The difference between simple and complex features is that simple features are defined with the basic building blocks whereas complex features are defined with simple or other complex features. In other words, complex features form aggregates of other features. GDF features are defined by the feature catalogue:

- *Roads and ferries:* The road network is seen here primarily from the viewpoint of transportation and traffic. Ferry connections are placed together with road network elements in one theme. Examples are roads, junctions, intersections, etc.

- *Administrative areas:* For administrative purposes, the territory of a country may be divided into regions that have further subdivisions, forming a hierarchy of political units. Examples are cities, counties, countries, etc.

- *Named areas:* A named area is a clearly or fuzzy bounded area, covering a region having its own commonly used name to identify this particular region. Examples are postal areas, police district, The Alps, etc.

- *Land cover and use:* They provide contextual information about the coverage or usage of the earth's surface.

- *Structures:* Structures are used to describe significant constructions that are part of a transportation network. Examples are bridges, viaducts, tunnels, aqueducts, cuttings, galleries and retaining walls.

- *Railways:* Railways are similar to roads in that their constituent elements (such as *railway element* and *railway element junction*) together form a network.

- *Waterways:* The *waterway feature theme* contains the representation of water bodies. *Waterway features* are composed of *water bodies* and *water boundaries.*

- *Road furniture: Road furniture* comprises items of road inventory which are categorised by having a fixed location along a *road element* (either on the carriageway or the pavement) or *chainage referencing section.* Examples are *traffic lights*, *traffic sign* and *measurement device.*

- *Services: Service* is a generic term for an activity at a specific location. Examples are *hotel*, *restaurant*, *airport*, *bank*, etc.

- *Public transport:* The features included as *public transport* are: *route link*, *public transport junction*, *stop point*, *public transport point*, *stop area*, *route*, and *line.*

- *Chainage referencing features: chainage referencing section* and *reference point* are the two possible *chainage referencing features. chainage referencing section* shall be considered as a complex feature and is represented as an ordered set of reference points. A *reference point* shall be represented as a point feature.

- *General features: General features* are features that have properties, attributes or relationships that can apply to all *feature themes*. These features are defined separately to ease the representation of the common attributes and relationships.

Characteristics of features which are independent of other features are modelled as *attributes*. Attributes are of a certain attribute type identified by the name and the code. The value of an attribute instance is called an *attribute value*, which can either be a code, text, an ID or value. An attribute may be an aggregation of other attributes (*Composite Attribute*). A *Composite Attribute* consists of a number of sub-attributes. GDF attributes are defined by the attribute catalogue, e.g. *Street names*, *House numbering*, *Time domains*, *Official language*, and *Speed restrictions*.

Some information related to real world objects needs to be modelled in the form of a *relationship* between *features*, for example, "Is Capital of" is a relationship between"Berlin" and "Germany". All relationships are referenced by a particular relationship name. GDF topology is also defined by the relationship catalogue, for example, "stop point at a junction", "road element within administrative area".

2.4 XGDF

XGDF is still under development by an ISO working group in Japan. Up to the present there is little information about the status of the development. Fortunately, a couple of papers in Japanese, Korean, and Chinese have reported the development of XGDF. In this section an overview to the status will be provided.

2.4.1 Why is GDF not Enough?

The current role of the GDF standard as B2B map delivery mechanism will further exist. This role however has to adapt to the technology and market trends, and evolutions in the ITS arena such as:

- Emerging new application areas, e.g. ADAS (Advanced Driver Assistance Systems) and Pedestrian Navigation,

- New countries joining the ITS market,

- The evolving concepts of networked data exchange (on-line distribution, down-loads),

- Wireless applications and associated data descriptions such as XML and GML,

- On-the-fly merging of map data (dynamic map extensions, updating),

- Evolving database technology.

GDF has some weaknesses which shall be improved in the future, for example, there are few possibilities to report data quality measures. Positional accuracy can be reported at feature level, however, data quality elements like completeness, logical consistency, thematic accuracy, etc. can not be found in the specification. Besides, GDF files can not be edited easily, because GDF isn't based on XML and there are just few editors for processing GDF files.

2.4.2 Who is Developing XGDF?

XGDF is the working title of the next generation GDF to address the evolution of market requirements and related technologies that are under work in the ISO. Countries actively contributing to the work include Germany, Japan, PR Korea, Netherlands and USA.

Especially, the Chinese ITS community contributes to the development of XGDF through the active participation of Chinese experts, because China is in need of a map standard for ITS applications and GDF forms a good basis for Chinese map based standardisation activities, however, in its current form, GDF can not be applied in China because it is unable to model certain aspects of reality in China such as address system and administrative system.

Altogether, ISO/TC204 has 16 technical committees and works together with International Electrotechnical Commission (IEC) and International Telecommunication Union (ITU). In addition, ISO/TC204 and CEN/TC278 work together on the basis of Vienna agreement (see 2.1).

The scopes of the Working Group 3 (Transport Information and Control Systems (TICS) Database Technology) are as follows: (1) *Geographic Data File:* the definition of an application independent standard for interchange of TICS database. *Physical storage for TICS Database:* the standard for the data models used for the storage of Vehicle Navigation and Travellers Information Systems database compiled from geographic data file. (2) *Location Referencing Procedure:* this section of the standards specifies the location referencing procedures for the geographic database. (3) *Publishing Updates for Geographic Databases:* this section of the standard will specify the formats and procedures for publishing updates of geographic database used in TICS applications.

Sub-Working Groups include SWG 3.1 (Geographic Data File), SWG 3.2 (Physical Storage Format), SWG 3.3 (Update Publishing and Location Referencing), and SWG 3.4 (API). There are also some existing and planned standardisation projects, called Work Items (WI). The project XGDF has the reference number ISO/PWI 22953.

2.4.3 What can XGDF do?

XGDF should be developed in order to improve the weaknesses of GDF and provide a better data format for ITS applications. During the development of XGDF the WG3 has taken some existing standards in the ITS and GIS fields into consideration (see the next section). Precisely, XGDF should be further developed to ensure:

- More user friendly map display (e.g. 3D objects and surfaces),
- Additional feature classes,
- Explicit audible geographic names,
- On-line data delivery,
- Additional safety critical content (ADAS),

WG[1]	Work program		WG[2]	Work program	Leader
WG1	Architecture	England	WG13	System Architecture and Terminology	ISO
WG2	Quality and Reliability Requirements				
WG3	TICS Database Technology	Japan	WG7/8	Geographic Road Data Base; Road Traffic Data	ISO
WG4	Automatic Vehicle Identification	Norway	WG12	Automatic Vehicle and Equipment Identification	CEN
WG5	Fee and Toll Collection	Holland	WG1	Automatic Fee Collection and Access Control	CEN
WG7	General Fleet Management and Commercial, Freight	Canada	WG2	Freight and fleet Management System	ISO
WG8	Public Transport/Emergency	America	WG3	Public Transport	ISO
WG9	Integrated Transport Information, Management, and Control	Australia	WG5	TC-Traffic Control	ISO
WG10	Traveller Information Systems	England	WG4	TTI-Traffic and Traveller Information	CEN
WG11	Route Guidance and Navigation Systems	Germany	unknown	n/a	n/a
(WG12)	(Parking zone management)	(Deletion)	WG6	Parking Management	n/a
(WG13)	(Man machine interface)	(Deletion)	WG10	Man-machine Interface	n/a
WG14	Vehicle/Roadway Warning and Control Systems	Japan	n/a	n/a	n/a
WG15	Dedicated Short Range Communications for TICS Applications	Germany	WG9	Dedicated Short Range Communication	CEN
WG16	Wide Area Communications/Protocols and Interfaces	America	WG11	Subsystem-Intersystem Interfaces	ISO

Table 2.1: The ISO/TC204 WGs and the corresponding CEN/TC278 WGs

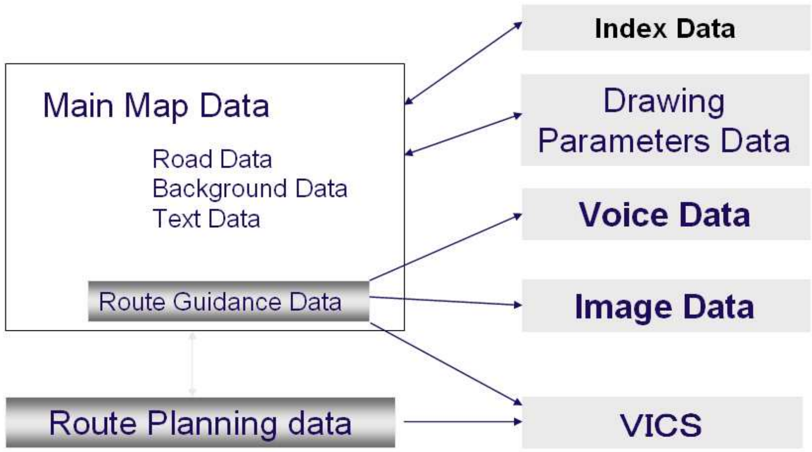


Figure 2.1: The composition of KIWI format

- Extended transportation networks and attribution, e.g. pedestrian routing,
- Client-server map access (Location Based Services),
- Compliance with state of art technology for data bases and handling (relates to relational database technology, object orientation, Relational database and SQL interfacing, etc.)
- Alignment with appropriate OpenGIS and ISO/TC211 standards,
- Advanced spatial temporal model, new concepts in spatial-temporal definition of geographic objects.

2.4.4 XGDF and Other Data Formats

As mentioned, the development of XGDF is being organised and performed by a Working Group in Japan. KIWI, a map data format for Car Navigation Database, is widely used in Japan. KIWI applies the experience of all Japanese system maker, is able to add every country's requirement, and is able to contain the temporal information of object as well. The composition of Kiwi format is shown in the figure 2.1.

In the development of XGDF some existing standards and data formats have been considered (see figure 2.2.)

In GDF no temporal schema is defined. XGDF uses the international standard ISO 19108, which is developed by ISO TC211 [6] and defines concepts for describing temporal characteristics of geographic information.

There are already some XML grammars related to XGDF such as:

- TranXML (Open Application Group OAGI)
- TransXML (NCHRP, AASHTO and Cambridge Systematics)
- XLS (XML application of OGC Location Services)

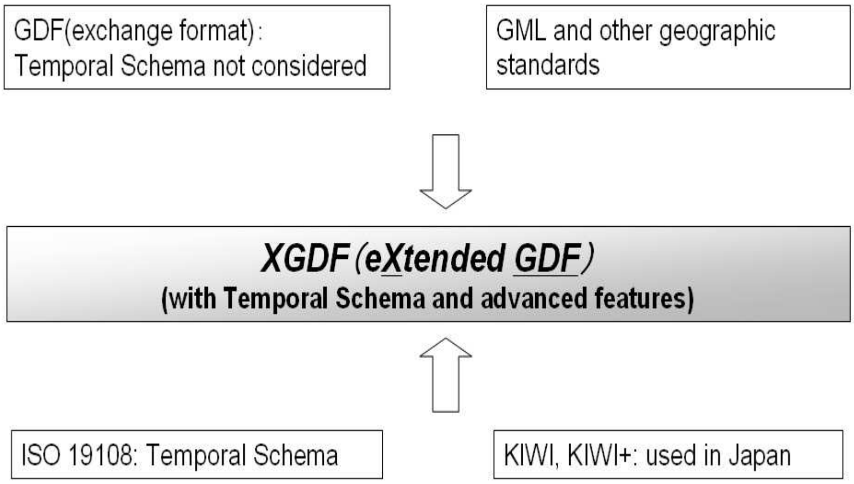


Figure 2.2: XGDF and other standards

- TourML (Tourism Markup Language)

In the XGDF project, an XML Schema will also be developed for GDF to enable application-independent interpretation of GDF data. XGDF aims to use XML to reduce the dependence on proprietary data formats and tries to provide open specifications that can be used directly for application development or customisation.

The data model in XGDF planned by ISO is shown in 2.3.

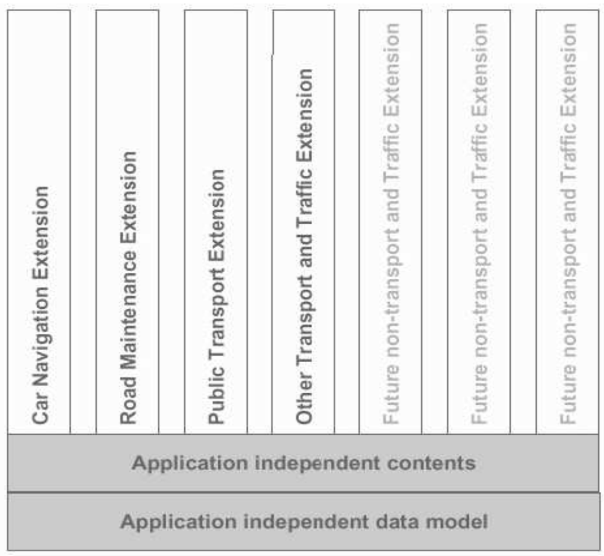


Figure 2.3: XGDF Data Model

Chapter 3

GIS Ontologies

3.1 Why ontologies in GIS?

Ontologies offer significant benefits to the design and use of geographic information, beyond the abilities of today's approaches. First, ontologies play an important role for information systems, because they define semantics independently of data representation and reflect the relevance of data without accessing them. Such a high-level description of the semantics of geographic information will provide new means for comparing and integrating spatial data. Second, ontologies can serve as the embodiment of a consensus reached by different GIS communities, thereby providing a crucial foundation for geographic knowledge interoperation. Third, schemas in GIS are not sharable or reusable in most cases: usually they are defined over a specific database, whereas ontologies are by nature reusable and sharable, because ontologies can provide a conceptual schema for any dataset regardless of its format, structure or size. Finally, the semantics embedded in ontologies define constraints imposed on the classes and relations used to design user interfaces and query languages, therefore, the use of ontologies in advanced GIS query languages will provide better access for domain-specific interactions.

3.2 Classification of Geographic Ontologies

In this paper we use the term low-level ontologies for fine ontologies that represent very detailed information and high-level ontologies for ontologies that represent more general information.

Ontologies are classified in four groups, according to their dependence on a specific task or point of view [2]:

- Top-level (or Upper) ontologies describe very general concepts, for example, a general concept of space.

- Domain ontologies describe the vocabulary related to a generic domain by specialising the concepts introduced in the top-level ontology.

- Task ontologies describe the vocabulary related to a generic task or activity by specialising the top-level ontologies.

- Application ontologies describe concepts that depend on both a particular domain and a task, and are usually a specialisation of them. In ontology based GIS these ontologies are created from the combination of high-level ontologies.

Sometimes domain and task ontologies are regarded as the same level, that is to say, Ontologies can be classified in three groups, too.

3.2.1 Top-Level Ontologies

A top-level ontology is limited to concepts that are meta, generic, abstract and philosophical, and therefore general enough to address (at a high level) a broad range of domain areas. Concepts specific to given domains will not be included; however, this standard will provide a structure and a set of general concepts upon which domain ontologies (e.g. geographic, etc.) could be constructed.

Researchers in geospatial ontology should study the following projects about Top-Level ontologies:

3.2.1.1 IEEE Standard Upper Ontology (SUO) Study Group

The SUO WG is developing a standard that will specify an upper ontology to support computer applications such as data interoperability, information search and retrieval, automated inferencing, and natural language processing. SUO is in effect a conservative extension of J. Sowa's upper level ontology and Russell-Norvig's upper level ontology achieved by the addition of a number of further concepts.

SUMO is written in Standard Upper Ontology Knowledge Interchange Format (SUO-KIF), which is a variation and simplification of the American National Standard KIF format. At present, SUMO consists of 1,000 concepts, including 4,000 assertions over 800 rules.

The IEEE Standard Upper Ontology is an effort to create a large, general-purpose, formal ontology. The ontology is an open standard that can be reused for both academic and commercial purposes without fee, and it will be designed to support additional domain-specific ontologies.

3.2.1.2 CYC

Cyc is an artificial intelligence project which attempts to assemble a comprehensive ontology and database of everyday common-sense knowledge, with the goal of enabling AI applications to perform human-like reasoning. Cyc ontology is one of the important parts of the CYC project (http://www.opencyc.org/). It was created based on the micro-theories. Each micro-theory captures the knowledge and reasoning required for some particular domains, such as space, time, causality, or agents.

The Upper Cyc Ontology currently consists of over 100,000 atomic terms, with 5000 concepts and 50,000 axioms.

3.2.2 Domain Ontologies

A domain ontology specifies concepts particular to a domain of interest and represents those concepts and their relationships from a domain–specific perspective. While the same concept may exist in multiple domains, the representations may widely vary due to the differing domain contexts and assumptions.

Every domain-specific ontology must use as a framework some upper level ontology which describes the most general, domain-independent categories of reality.

Three domain ontologies related to traffic and transportation networks will be introduced here.

3.2.2.1 SWEET

SWEET: The ontologies within the Semantic Web for Earth and Environmental Terminology (SWEET) [8] provide an ontology for Earth system science. The SWEET ontologies include several thousand terms, spanning a broad extent of Earth system science and related concepts (such as data characteristics) using the OWL language. For the SWEET ontologies incorporated an analogous keyword list used in the Earth Science Modelling Framework (ESMF) [8]: Earth Realm; Non-Living Element (Substance); Living Element; Physical Property; Units; Numerical Entity; Temporal Entity; Spatial Entity; Phenomena; Human Activities; and Data.

3.2.2.2 Towntology

The Towntology [3] is a project started in 2002, including two French laboratories named LIRIS and EDU located in Lyon, France. The main objectives of the project were to clarify and organise the terminology used by French urban planners in order to build an ontology about urban planning. The Towntology project aims at the construction of an urban ontology, i.e. to constitute a formalised vocabulary gathering for the domain of urban management and planning, the whole concepts, and their relations. The main objectives of this project are the construction of the basis of an urban ontology, i.e. to collect the terms used in this discipline into a semantic network. The geographic Ontologies defined by this project can be downloaded from [3].

3.2.2.3 SPIRIT

The Spatially Aware Information Retrieval on the Internet (SPIRIT) project [5] is a project funded as part of the Semantic Web European initiative which aims to provide an intelligent, web based, geographical search engine. At the heart of the SPIRIT system is a geographical ontology which provides support for the different components of the system. In addition to the geographical ontology, the SPIRIT prototype also maintains a domain-specific ontology, which is focused on tourism. The geographical ontology has been implemented using the Oracle Spatial database management system.

3.3 Some existing Geographic Ontologies

3.3.1 OGC Ontologies

Two OGC standards have been written in OWL, namely the Ontology for Geography Markup Language (GML) of the Open GIS Consortium (OGC) and the Ontology for Topic-2: Spatial Referencing by Coordinates (SRC) of the Open GIS Consortium .

3.3.2 OWL Ontologies based on Norms

Some ISO standards are written in ontologies using OWL. They are:

- Ontology for Conceptual Schema Language (ISO/CD TS 19103)
- Ontology for Geographic Information - Spatial Schema (ISO 19107:2003)
- Ontology for Geographic Information - Temporal Schema (ISO 19108:2002)
- Ontology for Geographic Information - Rules for Application Schema (ISO/FDIS 19109)
- Ontology for Geographic Information - Methodology for Feature Cataloguing (ISO/FDIS 19110)
- Ontology for Geographic Information - Spatial Referencing by Coordinates (ISO 19111:2003)
- Ontology for Geographic Information - Spatial Referencing by Geographic Identifier (ISO 19112:2003)
- Ontology for Geographic Information - Metadata (ISO 19115:2003)
- Ontology for Geographic Information - Metadata Application (ISO 19115:2003).

Chapter 4

From GDF to OTN

The background information about GDF has already been given in Section 2.3.1. We give now a more detailed presentation of the GDF data model before we come to OTN.

4.1 GDF

4.1.1 Structure of the GDF Data Model

In GDF, all objects are denoted by an ISO conform description which will subsequently be typeset in italics (e.g. *Feature*).

Each instance of a GDF objects has a number of characteristics called *Features* and represents a geographic object in the real world (e.g. "La Tour Eiffel"). Figure 4.1 shows the structure of features in GDF. Each feature belongs to exactly one *Feature Class* (e.g. "building"), which in turn is part of a *Feature Theme* (e.g. "area designation"). Additionally, it can have *Attributes* and *Semantic Relationships*, as well as a type called *Feature Category* which controls the geometric representation of the feature. This representation can either be a *Simple Feature* (point, line, polygon) or a *Complex Feature*.

Simple features are further divided into structured *Topological Feature* and unstructured *Non-Explicit-Topological Feature* types. Whereas the latter are always geometrically self-contained or independent, structured types can be connected to others in a part-of relationship. The representation of an intersection, i.e. a point feature, always has to be connected to its adjacent road segments, i.e. line features, and is, hence, a structured feature. The outlines of buildings, i.e. polygons, on the other hand, are sometimes not connected to any other feature and can therefore exist as unstructured features.

Every feature has a geometric representation which determines the position of the feature. For unstructured features there is a *"'Dot"'*, a *"'Polyline"'* and a *"'Polygon"'*. The structured features are the (*"'Nodes"'*), the (*"'Edges"'*) and the (*"'Faces"'*). In addition there are two different types of nodes, the *"'non isolated nodes"'* which are the ends of the edges, and the *"'isolated nodes"'* which lie inside a face.

A complex feature consists of a group of logically related structured features. A road, for example, is represented as a set of road segments.

GDF has three different levels of detail. Level 0 contains all unstructured features, level 1 all simply structured features and level 2 all complex features. Related features can be comprised

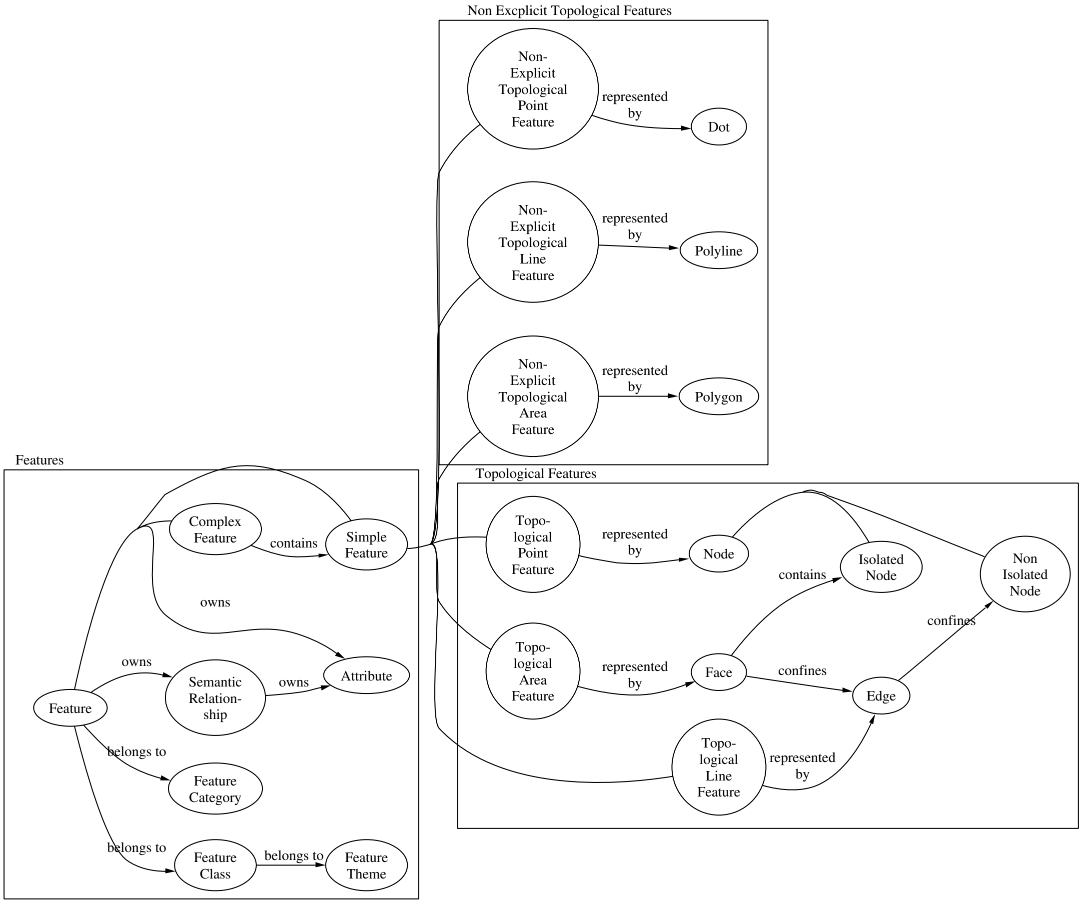


Figure 4.1: Structure and Attributes in GDF

in (*"'Layers"'*). Within a given layer, there are, however only either structured features or unstructured features allowed. With this mechanism you can comprise a given class of roads, motorways, for example, into one layer.

A feature can have attributes and relations. A attribute can be either a *"'simple attribute"'* or a *"'restrictive sub-attribute"'*. A composed attribute consists of a set of sub-attributes which describe the attribute in more detail. Such sub-attributes can be simple, composed or restrictive. The attribute "toll", for example, can have he sub-attributes "amount" and "currency".

Restrictive attributes are used only in connection with relations and other attributes. They themselves consists of a set of sub-attributes, which, however need not be restrictive. You can use them to restrict the validity of the corresponding attributes. The most important restrictive attribute is the *"'Validity Period"'*. A speed limit, for example, can have the validity period 10 pm until 6 am next morning.

A relation describes an attribute which correlates at least two features. It can also have sub-attributes and it can be restricted. A GDF relation is, for example, the location of a building along a road segment. It describes that the building can be reached via this road segment.

4.1.2 Themes in GDF

The features are categorised in 12 themes. (Figure 4.2):

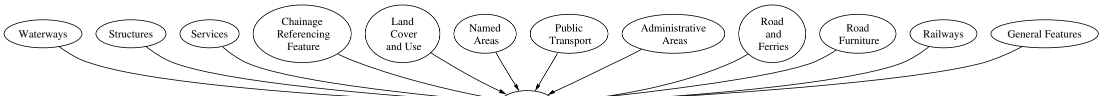


Figure 4.2: Themes in GDF

Waterway: The describe all kinds of water areas, from channels up to seas.

Structures: Auxiliary buildings like bridges or tunnels are modelled in this theme.

Services: , e.g. schools, petrol stations, pharmacies or airport terminals.

Chainage Referencing Features: is theme for modelling general networks, i.e. graphs with nodes and edges.

Land Cover And Use: They describe the structure of areas, for example islands, forests, industrial areas and even buildings.

Named Areas: Areas which logically belong together can be modelled with these features. Examples are market places or school districts.

Public Transport: for modelling public transport systems.

Administrative Areas: This describes the partitioning of a country in regions (counties, Borroughs etc.)

Road and Ferries: This is the most important theme of the data model. It contains features of roads and ferries.

Road Furniture: They represent features like road signs or traffic lights.

Railways: for modelling railway systems

General Features: for top level features which can be used together with the other themes.

4.1.3 General Attributes

Several features can have the same attributes. The next section gives an overview over these common attributes.

Many features have more than one name. In this case one distinguishes the *"'Official Name"'* and *"'Alternate Names"'*. The alternate names need not be officially valid, but they may be commonly used. The "'Karlsplatz/Stachus"' in Munich, for example has the official name "'Karlsplatz"' and the alternate name "Stachus"'.

A name is a complex attribute and consists in general of a *"'Prefix"'* and a *"'Name Body"'*. The prefix usually indicates the type of the feature. (In "'Hotel Vierjahreszeiten"' is "'Hotel"' the prefix and indicates that the object is a hotel.) The name body consists of *"'Official Name*

Text"' and *"'Alternate Name Text"'* components. There may be further composed attributes: *"'Name Component"'* with components *"'Name Offset"'* and *"'Name Length"'* to identify the name body. With *"'Name Component Type"'* one can describe the data type of the name, for example string or number.

Some features may have a reference pointer to data of other features. The reference pointer can be referenced with *"'External Identifier"'*. The composed attribute *"'Multimedia File Attachment"'* can be used to refer to an external resource.

The feature *"'Display Class"'* which has values between "'First Class"' and "'Tenth Class"' can be used to prioritise features into important and less important features. This information can be used to control the level of detail in graphical representations.

"'Opening Periods"' and *"'Validation Periods"'* are described as composed attributes consisting of a list of start times and durations.

The attribute *"'Positional Accuracy"'* determines how precise the position of a feature is determined. Its value is given in meters. 0 means that the attribute is unknown.

Many features are defined relative to a road segment. The attribute *"'Street Side"' (SI)* determines at which side of the read the feature lies. The road side is always determined by the order of the end points of the read segment. A ring road must therefore artificially split into at least two segments.

Some features require a *"'Toll"'* for their users. This is a composed attribute *"'Toll Charge"'* and *"'Currency"'*. So far means of transport and number of passengers are not distinguished.

4.1.4 *"'Road and Ferries"'*

Roads and ferries belong to a common theme in GDF, because they both are considered as a means for transporting cars. They can be described in two levels of detail. Level 1 contains the precise geographic description. A road consisting of two lanes separated by a green area, for example, are modelled as separate road segments. At level 2 the two road segments would be joined into one road segment and the green area between them would be dropped completely. Figure4.3 shows an example for such a level architecture.

The Level 1 elements in the data model are *"'Address Area"'*, *"'Address Area Boundary Element"'*, *"'Enclosed Traffic Area"'*, *"'Ferry Connection"'*, *"'Junction"'* and *"'Road Element"'*. The complex Level 2 elements are *"'Aggregated Way"'*, *"'Ferry"'*, *"'Interchange"'*, *"'Intersection"'*, *"'Road"'* and *"'Roundabout"'*.

A *"'Road Element"'* is a line segment and describes the part of a road between two adjacent intersections. It begins and ends at a *"'Junction"'*. Start and end point determine the direction of the road element. The aggregated set of road elements is a *"'Road"'*. Road and ferry connections have the same structure in the data model.

Larger areas which allow cars to move freely around, for example parking places or camping grounds, are described by the feature *"'Enclosed Traffic Area"'*. They are connected via *"'Junctions"'* with the road network.

Most addresses consist of a street name and a house number. Some places or areas, however, have their own name which is not related with a street name. For this purpose GDF provides the feature *"'Address Area"'*. An address area is determined by *"'Address Area Boundary Elements"'* which represent the connection to the road network. An address area must have at least one address area boundary element which is connected to a road element.

A set of road elements can also be composed to a *"'Roundabout"'* or to a *"'Intersection"'*. Motorway junctions or motorway accesses, for example, can be modelled as intersections con-

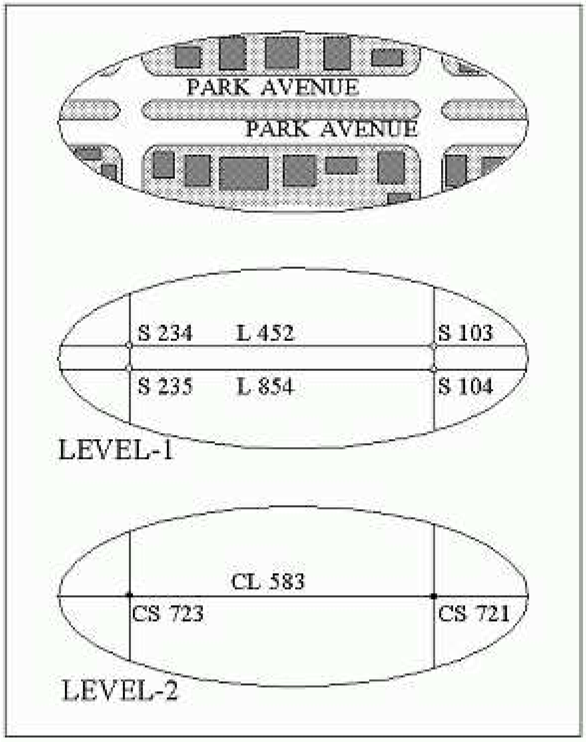


Figure 4.3: Example of a Level Architecture (Figure 5.17 from [4])

sisting of road elements. Other components of road networks which belong together in one way or another can be modelled as *"'Aggregated Ways"'*.

Restricting attributes of the Road Network
Besides the general attributes many features of the road network have more specific attributes. An example is *"'Vehicle Type"'* (VT), which specifies the vehicle class that is allowed to use a road. Possible values are "'Pedestrian"', "'Bicycle"', "'Passenger Car"' and "'Taxi"'. These value can also be negated, thus excluding the vehicles from this class to use the road. The driving direction can be restricted with *"'Validity Direction"'*. It is even possible to assign restricting attributes to a particular lane of a road with the attribute *"'Lane Dependant Validity"' (LD).*

Road and their Basic Attributes
The attribute *"'House Number Range"'* can be used to assign house numbers can to road elements. The specification of the numbering scheme is very flexible. One can define *"'First House Number"'* and *"'Last House Number"'* for each road side. The attribute *"'House Number Structure"'* can have values "'Regular with even numbers"', "'Regular with odd numbers"' and "'Irregular"'. IN the last case one can list the house numbers explicitely.

"'Length of a Road Element"' gives the projected two dimensional length of the road element, whereas *"'Measured Length"'* gives the actual three dimensional length of the road element. *"'Width"'* determines the with of the road element in centimetres.

The type of the road element can be specified with the attribute *"'Form of Way"'*. Possible values are "'Part of a Motorway"' "'Part of a Multiple Carriageway which is not a motorway"'"'Part of a Single Carriageway"', "'Part of a Roundabout Circle"' or "'Part of a Pedestrian Zone"'.

The attribute *"'Average Vehicle Speed"'* gives the average speed of the cars at a road element.

The direction of a road element, which is determined by the sequence of the end points, can be different to the direction of the traffic flow. The attribute *"'Direction of Traffic Flow"'* can have the values "'Traffic is allowed in both directions"', "'Traffic is closed in positive direction, and open in negative direction"', "'Traffic is closed in negative direction, and open in positive direction"', "'Traffic is closed in both directions"'.

Restrictions of the Usability

With *"'Maximum Height Allowed"'*, *"'Maximum Width Allowed"'* and *"'Maximum Length Allowed"'* one can specify the allowed height, width and length of the vehicles in centimetre. *"'Maximum Total Weight Allowed"'* and *"'Maximum Total Weight per Axle Allowed"'* restricts the maximum weight allowed in tenth of a ton.

Another attribute is *"'Construction Status"'* which can have the values "'Under Construction - Open"', "'Under Construction - Closed"' and "'Planned"'.

Accidents at particular road elements can be registered with the composed attribute *"'Accident"'* consisting of *"'Accident Date"'* and *"'Accident Identifier"'*. The accident identifier is a number whose meaning is not yet fixed by the GDF standard.

Additional Attributes of Roads

There is the attribute *"'Ownership"'* with values "'Public owned"' or "'Privately owned"'.

Road blockages can be specified by the composed attribute *"'Blocked Passage"'*. Its components are *"'Blocked Passage Location"'* with values "'Physically blocked at Start Junction"', "'Physically blocked at End Junction"' or "'Physically blocked between Start and End Junction"'. The attribute *"'Blocked Passage Type"'* with values "'Removable"' or "'Permanently fixed"' determines whether the blockage is removable. If the value is "'Removable"' one can specify with the attribute *"'Removable Blockage"'*, who can use the road element anyway. Possible values are "'Accessible for Emergency Vehicles only"', "'Accessible via Keyed Access"' or "'Guarded"'.

The number of lanes can be specified with *"'Number of Lanes"'* for the precise number of lanes, or *"'Minimum number of Lanes"'* and *"'Maximum number of Lanes"'* for the minimal and maximal number of lanes. The value "'Present"' or "'Not present"' of the attribute *"'Emergency Vehicle Lane"'* determines whether a separate lane is available.

The same two values for the attribute *"'Passing Restrictions"'* can be used to specify whether overtaking is allowed or not.

The type of division between different lanes can be described with the composed attribute *"'Divider"'*. The component *"'Divided Road Element"'* with values "'Divided"' or "'Not Divided"' says whether the lanes are divided or not. If they are divided, one can specify the way they are divided with *"'Divider Type"'*. The value "'Legal Divider"' means that there is just a lane marking. "'Physical divider; Crossable"' indicates, for example, tramway rails dividing the lanes. The other alternative is "'Physical divider; Not Crossable"'. The width of the division is stated with *"'Divider Width"'*.

For radio data services like TMC (traffic message channel) or RDS it is necessary to indicate road elements or other parts of road networks with a service specific identifier, usually a short number. This can be done with the attributes *"'Location Reference Type"'* and *"'Location Reference Code"'*.

Railways
Whereas roads are modelled in great detail, the modelling of rails is quite coarse. Analogous to *"'Road Element"'* there is the feature *"'Railway Element"'*. A railway element is part of a rail which is delimited by *"'Railway Junctions"'*. Railway stations, however, cannot be used to delimit a railway element.

4.1.5 Public Transport Systems

In GDF there is a clear distinction between geographical items like roads or rails, and the transport systems which use these items. Public transport systems are modelled completely separate from the underlying physical objects, such that there is no connection to roads or rails. The network of a public transport system is described by *"'Route Links"'* which connect *"'Public Transport Junctions"'*. A route link can contain *"'Public Transport Points"'*, but their precise position at a route link is not determined. Several route links can be combined to a *"'Route"'*, which itself can be part of a *"'Line"'*. For example the underground line U5 in Munich consists of two *"'Routes"'*, which describe the traffic in the two opposite directions. It is possible that a line consists of more than two routes. This may, for example, be necessary for a bus line which takes different routes at different times of the day. A route may contain different *"'Stop Points"'*, for example bus stations. They can be located with physical coordinates. Stop points with the same location, for example bus terminals, can be combined into a *"'Stop Area"'*.

Further information, like time tables or possibilities to change lines cannot be modelled in GDF. It is only possible to attach services to stop points. There is, however, no direct connection between these services and the transport network.

4.1.6 Structures

Structures are additional physical parts of a transport network. Examples are noise barriers, bridges or subways. Structures can have the usually general attributes. The extra attribute *"'Structure Type"'* determines the type of the structure. Possible values are "'Bridge"', "'Viaduct"', "'Aqueduct"', "'Tunnel"', "'Cutting"', "'Gallery"', "'Retaining Wall"' or "'Embankment"'. The attribute *"'Structure Category"'* with values "'over"' or "'under" distinguishes bridges and subways.

4.1.7 Land Cover and Use

The features of this theme provide information about the texture and usage of areas. As Fig. 4.4 shows, *"'Land Cover and Use"'* is subdivided into *"'Building"'*, *"'Artificial Surface"'*, *"'Agricultural Area"'*, *"'Forest and Semi-Natural Area"'*, *"'Wetland"'*, *"'Island"'* etc.. A few of these sub themes have extra attributes. *"'Green Urban Area"'*, for example, has the attribute *"'Park Type"'* with values "'City Park"', "'Regional Park"', "'Country Park"', "'State/Provincial Park"' oder "'National Park"'. *"'Beach Dune and Sand Plain"'* has an attribute *"'Sand Area Type"'* with values "'Beach/Dune"', "'Desert"' or "'Other"'.

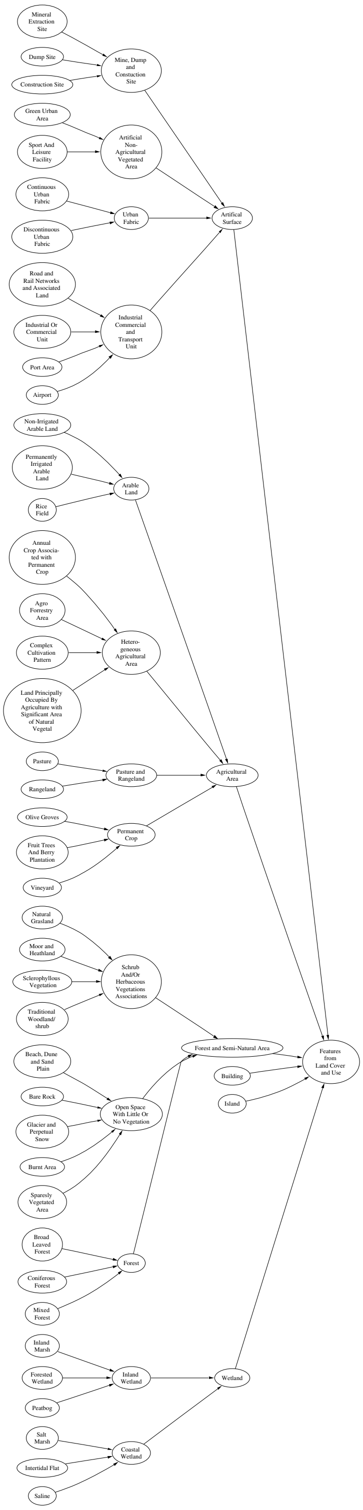


Figure 4.4: Land Cover and Use in GDF

The type of a building, for example tower, skyscraper etc. can be specified with *"'Building Class Name"'*. A building can contain many different kinds of services, from shops like pharmacies up to, say a university. All this is covered in the theme *"'Service"'*. A list of such services can be associated to a building.

4.1.8 Services

A *"'Service"'* in GDF is a service which is offered at a particular location. This can be a business, but it can also be, for example, a parking place, because this offers the service to park a car. The modelling of services in the broad senses is such a wide area that only those parts which are directly related to buildings or roads are contained in GDF. These include airports, hotels, restaurants, train stations, banks, pharmacies, camping grounds, car dealers, cinemas, town halls, shopping malls etc. So far there is only a rudimentary structuring of services in GDF with only very few additional attributes. All this needs to be refined considerably.

4.1.9 Dates

GDF has a quite expressive language for specifying dates. This ranges from concrete calendar dates over expressions like "'every first working day in the month"', "'from sunrise to sunset"', till "'at some time"'. A date consists in general of a *"'Starting Date"'* and a *"'Duration"'*. Both parts consist of a string which is subdivided into different parts. Every part begins with a control character followed by a number. "'y"' stands for year, "'M"' for month, "'w"' for week, "'d"' for day, "'h"' for hour, "'m"' for minute and "'s"' for second. The string "'y2004M10d30h12"', for example, denotes as *"'Starting Date"'* 30.10.2004 at 12 o'clock. The string "'d1h8m30"' means as *"'Starting Date"'* 8:30 AM every first day in a month. The string "'y1s12"' as *"'Duration"'* means a duration of 1 year and 12 seconds.

There are more control characters available. "'t"' is followed by the day in a week. "'1"' means Sunday and "'7"' means Saturday. With "'f"' (first) and "'l"' (last) one can combine the day with the month. "'f21"', for example, means the second (2) Sunday (1) in a month. "'l21"', on the other hand, means the second (2) but last Sunday (1) in a month.

The control character "'z"' introduces "'Fuzzy-Times"'. There are, however, only a few predefined fuzzy times. "'z4"' as *"'Starting Date"'*, for example, means beginning of the holidays. "'z6"' means beginning of winter time. "'z54"' as *"'Duration"'* means the duration of the holidays and "'z55"' as *"'Duration"'* means the duration of the winter.

Dates can be combined in GDF with the logical operators "'*"' (and) , "'+"' (or) and "'-"' (not). The opening time of a shop, from 9 AM until 5:30 PM during the working days, and from 10 AM until 2:00 PM at Saturdays, can be represented by the following string "'(h9){h8m30} * (t2){d5} + (t7h10){h4}"'. The date in round brackets is the starting time and the date in curly brackets is the duration.

4.1.10 Permanent Data Storage

GDF data are stored in a compact way as text files with fixed record length of 81 or 82 characters. The first two characters of a line specify the type of the data record, or are blanks if it is continuation of a data record. "'05"' is used for attributes and "'07"' for features. Particular features have particular codes. "'4110"', for example is a road element and "'4120"' a junction. The header of a file can contain new definitions of features and attributes with corresponding identifiers. The meaning of the remaining characters in a data record depends on the type of the attribute or feature.

4.2 OTN

The main purpose of GDF is to serve as a standard for storing geographical data. The elements of the GDF standard, however, also represent an ontology of notions in the domain of traffic networks. Therefore we extracted the ontology part of GDF, did some extensions and represented it as a formal ontology in the OWL ontology framework. The result is the *Ontology of Traffic Networks* (OTN). This is now a general purpose ontology which can be used for all kinds of things besides data storage. For example, we used it for specifying how the elements of a traffic network are to be displayed in Scalable Vector Graphics (SVG). We used the Protégé system (http://protege.stanford.edu/) for developing OTN.

4.2.1 Basic Structure of OTN

OTN is more or less a direct encoding of GDF in OWL. OWL has some technical requirements which required some adjustments. For example, names in OWL cannot have whitespace characters. Therefore whitespace characters in GDF names had to be replaced by "'_"'. All class names begin with uppercase letters, whereas all attribute names begin with lowercase letters. For example, the *"'validity_Period"'* is the name of an attribute and *"'Validity_Period"'* is the name of the underlying data type.
As in GDF, there are five different basic classes (see Fig. 4.5):

Feature contains all GDF features as OTN classes;

Geometric defines the geometric forms of features;

Composite_Attributes represent classes consisting of composed attributes;

Relationship describes the non-geometric relationships between features;

Transfer_Point is a class which describes how to get from one object to another (e.g. train stations).

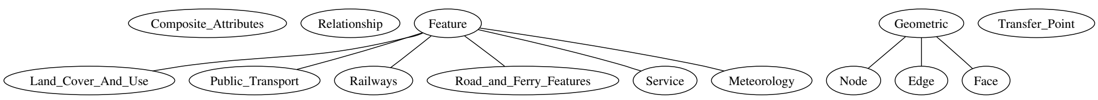


Figure 4.5: Basic Classes in OTN

A feature in OTN corresponds to a feature in GDF. It belongs to a class and to a theme. It contains attributes as well as relations to other features and it has a geometric representation.

OWL provides subclasses and inheritance. This is exploited for representing membership to a class or a theme not with pointers as in GDF, but with the subclass relationship. The class *"'Feature"'* is the top class of all features. It is subdivided into the themes, which in turn are top classes of all the feature classes. OTN also distinguishes simple and composite attributes. The value of a simple attribute is just a literal of the OWL data type *"'owl:DatatypeProperty"'*.

Composite attributes refer to a further resource of type *"'owl:ObjectProperty"'*. All composite attributes themselves are comprised in a class "'Composite_Attributes"'.

The relationships between features are in GDF represented by "'Relation Records"'. In OWL it is more natural to represent them also as attributes, because all attributes in the underlying Description Logic are relations anyway. There are a few exceptions where relationships are also represented as subclasses of a top class *"'Relationship"'*.

The geometric shape of objects is in GDF represented as attributes with corresponding values. This is no longer necessary in OTN because in OWL one has multiple inheritance. Therefore objects with geometric shape can be modelled as a corresponding subclass of a class *"'Geometric"'*. The corresponding geometric classes are *"'Node"'*, *"'Edge"'* and *"'Face"'*.

4.2.2 Change of Location and Means of Transport at a *"'Transfer_Point"'*

A number of features in OTN has the attribute *"'is_Accessible_At"'*, which specifies via which other feature pedestrians can reach this feature. For example, you can walk into a public means of transport, a building, a service or an area. All these ways to access a feature are included in the class *"'Transfer_Point"'*. Not every access which is possible in the OTN model actually makes sense. If you drive a car, for example, you can not walk into a building without having the car parked first. If took a taxi, however, this is possible. Such cases cannot be distinguished in OTN and must therefore be checked in the application system.

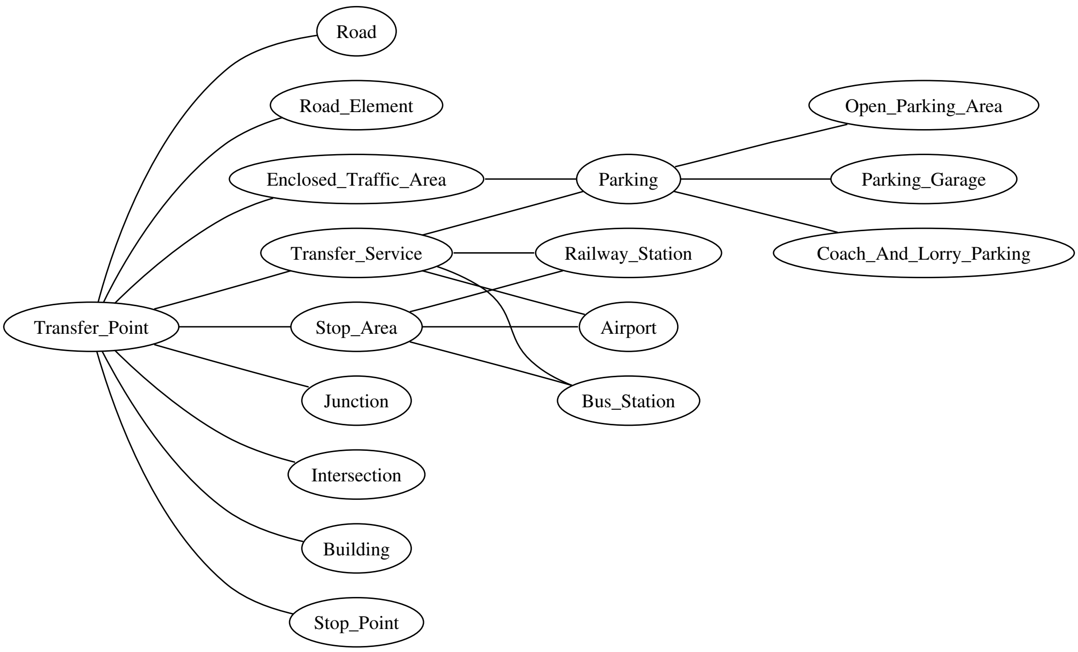


Figure 4.6: Change of Location and Means of Transport at a *"'Transfer_Point"'*

One can access the road network via *"'Junctions"'*, *"'Intersections"'*, (*"'Roads"'* or *"'Road_Elements"'* or *"'Enclosed_Traffic_Areas"'*). Access via a *"'Building"'* or a *"'Stop_Point"'* or *"'Stop_Area"'*) is allowed as well.

The change of a means of transport is described with a *”‘Transfer_Service”’*. It has for example a subclass *”‘Parking”’* with further subclasses *”‘Open_Parking_Area”’*, *”‘Parking_Garage”’* and *”‘Coach_And_Lorry_Parking”’*. Since these features represent areas on which cars can drive, they are also subclasses of *”‘Enclosed_Traffic_Area”’*. Other changes of means of transport can be described using the classes *”‘Railway_Station”’*, *”‘Airport”’* or *”‘Bus_Station”’*. They are also subclasses of *”‘Transfer_Service”’* and *”‘Stop_Area”’*.

4.2.3 Geometric Objects

Every *”‘node”’* has the attributes *”‘x”’*, *”‘y”’* and possibly *”‘z”’*. They define the geographic coordinates of this node. An edge represents a line segment. It has the attributes *”‘starts_at”’* and *”‘ends_at”’* which are nodes. The line segment need not be straight.

A road element, for example is represented as an edge between two junctions. If the road element is not a straight line, one can add an attribute *”‘intermediate_coordinates”’*. Its value describes a polygon as a list of relative coordinate changes.

Example:
The edge from node A(10,5) to node B(20,30) via the points (12,0) and (18,20) is represented as follows:

```
<Edge rdf:ID="A_nach_B">
 <starts_at>
  <Node rdf:ID="A">
   <x>10</x>
   <y>5</y>
  </Node>
 </starts_at>
 <ends_at>
  <Node rdf:ID="B">
   <x>20</x>
   <y>30</y>
  </Node>
 </ends_at>
 <intermediate_coordinates>2 -5 6 20 </intermediate_coordinates>
</Edge>
```

4.2.4 General Attributes of Features

All features have the attribute *”‘alternate_Name”’* to give them arbitrarily many names. In contrast to GDF there is, however in OTN no distinction between official and unofficial name. Names in OTN are just strings. Name prefixes are not distinguished explicitly.

The attribute *”‘external_Identifier”’* can be used to refer to features which are contained in another data source. In contrast to *”‘external_Identifier”’* one can use *”‘external_Link”’* to refer with an URL to an external resource on the internet.

Features can have identifiers which are relevant for services like TMC, RDS etc. These identifiers can be defined with *”‘location_Reference”’* attributes. They consist of *”‘location_Reference_Type”’* and *”‘location_Reference_Code”’*. Possible values for *”‘location_Reference_Type”’* are ”‘RDS”’, ”‘TMC”’, ”‘VICS”’ and ”‘OTHER”’.

The primary application of GDF is to describe road networks. Therefore these are modelled in much more detail than other networks. In OTN we added further concepts for describing public transport systems, in particular busses, trains and air planes.

4.2.5 The Road Network

The class of *"‘Road_and_Ferry_Features"’* is subdivided into the classes which are known from GDF: *"‘Address_Area_Boundary_Element"’*, *"‘Address_Area"’*, *"‘Aggregated_Way"’*, *"‘Enclosed_Traffic_Area"’*, *"‘Interchange"’*, *"‘Intersection"’*, *"‘Junction"’*, *"‘Road"’*, *"‘Road_Element"’*, *"‘Roundabout"’*, *"‘Ferry"’* and *"‘Ferry_Connection"’*. New is the class *"‘Enclosed_Traffic_Area_Boundary"’*, which describes the boundary of traffic areas. Figure 4.7 describes the relationship between these classes.

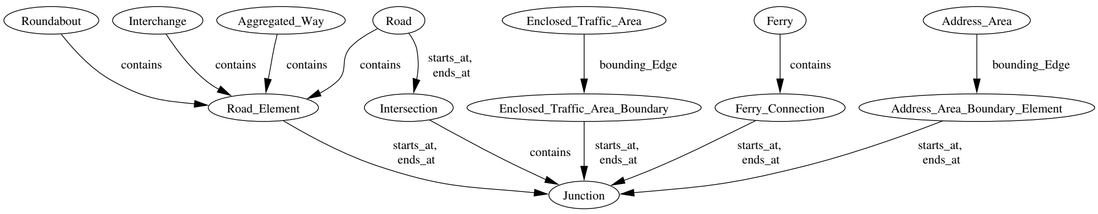


Figure 4.7: The Road and Ferry Network in OTN

Irregular Addresses

Addresses can be specified with house numbers and postal codes. The modelling of house numbers is for road elements is almost exactly in the same way as in GDF (see Paragraph 4.1.4). There is a slight technical difference. Since Protégé does not yet support ordered lists, they are represented as comma separated strings.

The type of traffic areas can be specified with the attribute *"‘enclosed_Traffic_Area_Type"’*. Possible values are "‘Parking_Place"’, "‘Parking_Building"’, "‘Unstructured_Traffic_Square"’ and "‘Another_Type"’.

Ferry Connections

The type of a *"‘Ferry_Connection"’* is determined by the attribute *"‘ferry_Type"’*. It can be of type *"‘Ship"’*, *"‘Hovercraft"’* or *"‘Train"’*. The attribute *"‘length"’* gives the length of the connection in meters.

The maximal weight, width, height and length are specified with the composed attributes *"‘maximum_Total_Weight_Allowed"’*, *"‘maximum_Width_Allowed"’*, *"‘maximum_Length_Allowed"’* and *"‘maximum_Height_Allowed"’*. They consist of the actual values in tenth of a ton or centimetres respectively, together with the *"‘validity_Period"’*. So far OTN supports only simple dates and no fuzzy times. A time period is given by a *"‘starting_Date"’* and a *"‘time_Duration"’*. OTN uses the same syntax for dates and durations as GDF, but stores the starting date and the duration separately. Only the Boolean connective "‘or"’ is supported so far.

Timetables

One of the most important extensions in OTN is the modelling of timetables, which contain the operative schedule of public transport, such as ferries, trains, etc. While GDF only allows for specifying the hours of operation (from - until), this part has been substantially extended for OTN to cater for the requirements of routing tasks. As the following example shows, all necessary details defining a connection can be represented.

Each connection, such as a ferry connection or a railway segment between two stations can own a *timetable*, which contains at least one *Timetable*. Each one is valid within a certain *validity_ Period*, i.e. during this time, the service is operational. From *starting_Date* on, for a period of *time_ duration* the service operates every *loop_Time*. The starting node is denoted by a reference in *starts_ at*, the duration of travel is defined in *travel_ Time*. Optionally, *waiting_ Time* specifies the idle period before departure, for example for boarding or disembarking a ferry.

The following timetable defines a service operating hourly from 6:30 to 18:30, from node *A* to node *B*, which has a travel time of 30 minutes and a waiting time of 20 minutes before departure:

```
<Timetable rdf:ID="Timetable_A-B">
  <starts_at rdf:resource="#A"/>
  <waiting_Time>m20</waiting_Time>
  <loop_Time>h1</loop_Time>
  <travel_Time>m30</travel_Time>
  <validity_Period>
    <Validity_Period rdf:ID='validity_Timetable_A-B'>
      <time_duration>h12</time_duration>
      <starting_Date>h6m30</starting_Date>
    </Validity_Period>
  </validity_Period>
</Timetable>
```

Junctions

The class *"‘Junction"’* describes normal road junctions as well as other types of junctions. The attribute *"‘junction_Type"’* with values "‘Mini-Roundabout"’, "‘Railway_Crossing"’ or "‘Border_Crossing"’ determines the type of junction.

Accidents can also be attached to components of the transport network. The composed attribute *"‘accident"’* consists of an identification number (*"‘accident_Id"’*) and a date (*"‘accident_Date"’*).

Roads and their Basic Attributes

A *"‘Road"’* has the standard attributes together with the extra attribute *"‘official_Name"’*. An official name can also be assigned to a *"‘Road_Element"’*. Road elements can have *"‘route_Numbers"’*, *"‘postal_Codes"’* and a *"‘house_Number_Range"’*. The length and width of the road elements are given by *"‘length"’* and *"‘width"’*.

The attribute *"‘form_of_Way"’* describes the type of the road. Possible values are "‘Motorway"’, "‘Multiple_Carriageway_which_is_not_a_motorway"’, "‘Single_Carriageway"’, "‘Roundabout_Circle"’, "‘Traffic_Square"’, "‘Encloses_Traffic_Area"’, "‘Slip_Road"’, "‘Service_Road"’, "‘Entrance_or_exit_to_a_car_park"’, "‘Entrance_or_exit_to_Service"’, "‘Pedestrian_Zone"’ and "‘Walkway_not_passable_for_Vehicles"’.

Since a road element may be used in different ways at different times, one can restrict its usage with *"'validity_Period"'*. For example, one can specify that a road element is used between 8 AM until 8 PM as a pedestrian zone, and otherwise as a normal street.

The average speed of vehicles can be attached as the attribute *"'average_Vehicle_Speed"'*. It consists of *"'speed"'* in kilometres per hour, the lane *"'lane_Dependant_Validity"'*, a *"'validity_period"'*, and a *"'vehicle_Type"'*, for example "'All_Vehicles"', "'Passenger_Cars"', "'not_Passenger_Cars"', "'Pedestrian"', "'not_Pedestrian"' etc.

Restricted Usability

Both road elements and ferry connections contain restrictions about the allowed width, height, length and weight:
"'maximum_Width_Allowed"', *"'maximum_Height_Allowed"'*, *"'maximum_Length_Allowed"'* and *"'maximum_Total_Weight_Allowed"'*.

The composite attribute *"'construction_Status"'* consists of *"'construction_Stage"'*, *"'lane_Dependant_Validity"'* and *"'validity_Period"'*. They describe the status of the road element. The value of *"'construction_Stage"'* ranges from "'Planned"' over "'Under_Construction-Closed"' until "'Under_Construction-Open"'. The latter one is used for indicating road works where some lanes are still open.

Further Attributes of Roads

With *"'special_Restriction"'* one can state that a road element is publicly accessible at a particular time (*"'public_Accessible"'*). A temporary blockage is described by the lane, the validity period and the *"'blocked_Passage_Type"'*), which can be "'permanently_fixed"' or "'removable"'. The location of the blockage *"'blocked_Passage_Location"'*, can be "'at_Start_Junction"', "'at_End_Junction"' or 'between_Start_and_End_Junction"'.

The attributes *"'toll"'* with components *"'toll_Charge"'* and *"'currency"'* can be used to describe toll roads. New in OTN is the possibility to distinguish the toll for different vehicle types.

The composite attributes *"'minimum_Number_of_Lanes"'*, *"'maximum_Number_of_Lanes"'* and *"'number_of_Lanes"'* specify the number of lanes at a *"'street_Side"'* and for a *"'validity_Period"'*.

The maximal gradient of a road in degrees can be given with *"'road_Gradient"'*. If it is a mountain pass road one can state with *"'height_Of_Pass"'* the maximal height in meters.

"'has_Emergency_Vehicle_Lane"' indicates the availability of a special lane for emergency vehicles. *"'emergency_Vehicle_Lane"'* is then the particular lane.

The probability for traffic jams can be stated with the composite attribute *"'traffic_Jam_Sensitivity"'*. It has the components *"'traffic_Jam_Probability"'* with values "'No"', "'Low"', "'Medium"', "'High"' and "'Very High" and the date and duration for traffic jams.

For indicating the state and condition of a road there is the composite attribute *"'road_Surface"'*. It consists of the information whether the road is paved, the *"'road_Surface_Condition"'*, which can be "'Good"' or "'Pure"' and the *"'road_Surface_Type"'*, which can be "'Rigid"' "'Flexible"', "'Blocks"' , "'Gravel"' or "'Dirt"'.

The way the two sides of a road are separated can be expressed with the composite attribute *"'divider"'*. The Boolean component *"'divided"'* says whether the sides are divided. The structure of the division is *"'divider_Type"'*, which can be "'Physical_divider;Not_Crossable"', "'Physical_divider;Crossable"' or "'Legal_Divider"'. The width of the division is stated with *"'divider_Width"'* (in meters). One can add temporal restrictions to the division.

As in GDF, there is only a rudimentary modelling of railway networks in OTN. The theme *"'Railways"'* consists only of *"'Railway_Element"'* and *"'Railway_Element_Junction"'* with no further attributes.

4.2.6 Public Transport Systems

We have extended the modelling of public transport systems, i.e. the theme *"'Public_Transport"'* considerably in OTN. In particular it is possible to describe the exact path of a means of transportation between two stop points. There is a class *"'Line"'*, whose instances can be used by different *"'public_Transport_Modes"'* ("'Bus"', "'Light_Rail"', "'Underground"', "'Urban_Rail"', "'Rail"' or "'Airplane"'). A *"'Line"' "'contains"'* a set of *"'Routes"'*, which themselves contain a set of *"'Route_Sections"'*. They can be further subdivided into *"'Route_Links"'* which *"'starts_at"'* and *"'ends_at"'* at a *"'Stop_Point"'*. Stop points of different routes can be combined into *"'Stop_Areas"'*.

A *"'Stop_Point"'* is a subclass of *"'Public_Transport_Junction"'* which can also terminate a *"'Route_Link"'*. With these mechanisms the stop points can be precisely located at a route, which is not possible in GDF.

Example
Figure 4.8 shows a part of a route. It contains three route sections: from "'Stop_Point 1"' via "'Stop_Point 2"', to "'Stop_Point 3"' and from there to "'Stop_Point 4"'. The route meets between "'Stop_Point 2"' and "'Stop_Point 3"' the "'Public_Transport_Junction 1"', which may also be part of another line. The route section is therefore subdivided into two route links. After "'Stop_Point 3"' there is again a junction which leads to "'Stop_Point 4"' or "'Stop_Point 5"'.

Direction along a Route
Elements in GDF can be ordered, which can, for example, be exploited to specify a direction. This is not so easily possible in OWL. Therefore we must model directions explicitely.

A *"'first_Stop_Point"'* states the beginning of a route. Starting with this point one can follow the route sections to the next stop points, which automatically defines a direction. If the route forms a ring one must choose one stop point as a *"'first_Stop_Point"'*.

4.2.7 Land Coverage and Use

This is modelled in sufficient detail in GDF. The only differences of the corresponding OTN model is that the attribute *"'park_Type"'* has an additional value "'Cemetery"', and a new attribute *"'is_Accessible_at"'* which describes the access to an area.

4.2.8 Services

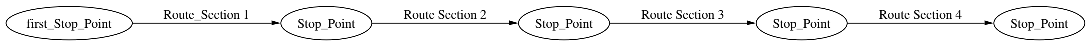
OTN supports particular queries to a OTN database, for example

- find the way to the closest pharmacy, or
- give me all restaurants around location X.

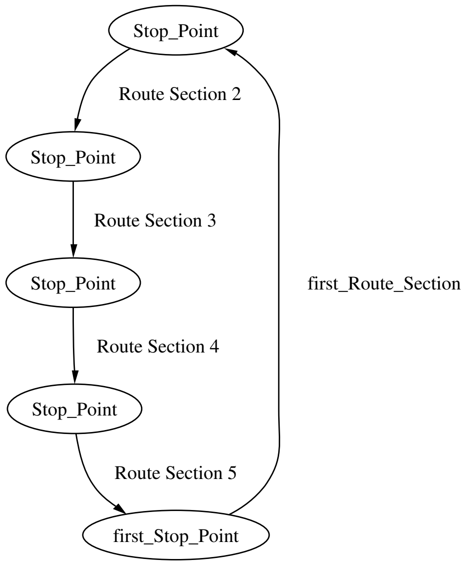
Figure 4.8: Example of a Public Transport Network

Pharmacies and restaurants could be encoded in GDF as *services*, but there are mainly suggestions for GDF services, not standards. The only standard service is *”‘Entry_Point”’*. *”‘Entry_Point”’*, however, is not an OTN service, but encoded as an attribute *”‘is_Accessible_at”’*. We formalised instead a quite large variety of services in OTN. Many of them are the suggestions for GDF services, but OTN contains a few more. Figure 4.10 gives an overview over the OTN services.

The most important service is *”‘Transfer_Service”’*, which has been explained already in Section 4.2.2. Examples for *”‘Transfer_Services”’* are *”‘Parking”’* with the attributes *”‘parking_Facilities_Available”’* for storing the maximum number of parking slots, *”‘free_Parking”’* and *”‘park_And_Ride”’*.



(a) Linear Line



(b) Line in Form of a ring

Figure 4.9: Direction of a Route in OTN

4.2.9 Meteorology

We added to OTN the possibility to formalise weather information. The top class for this is *"'Meteorology"'*, with subclasses *"'Temperature"'* and *"'Weather"'*. Both are also subclasses of *"'Face"'* such that one can restrict weather information to particular areas. There are the attributes *"'degree"'* (for temperature) and *"'weatherType"'* with values "'snow"', "'sleet"', "'hail"', "'dew"', "'rain"', "'shiver"' and "'storm"'.

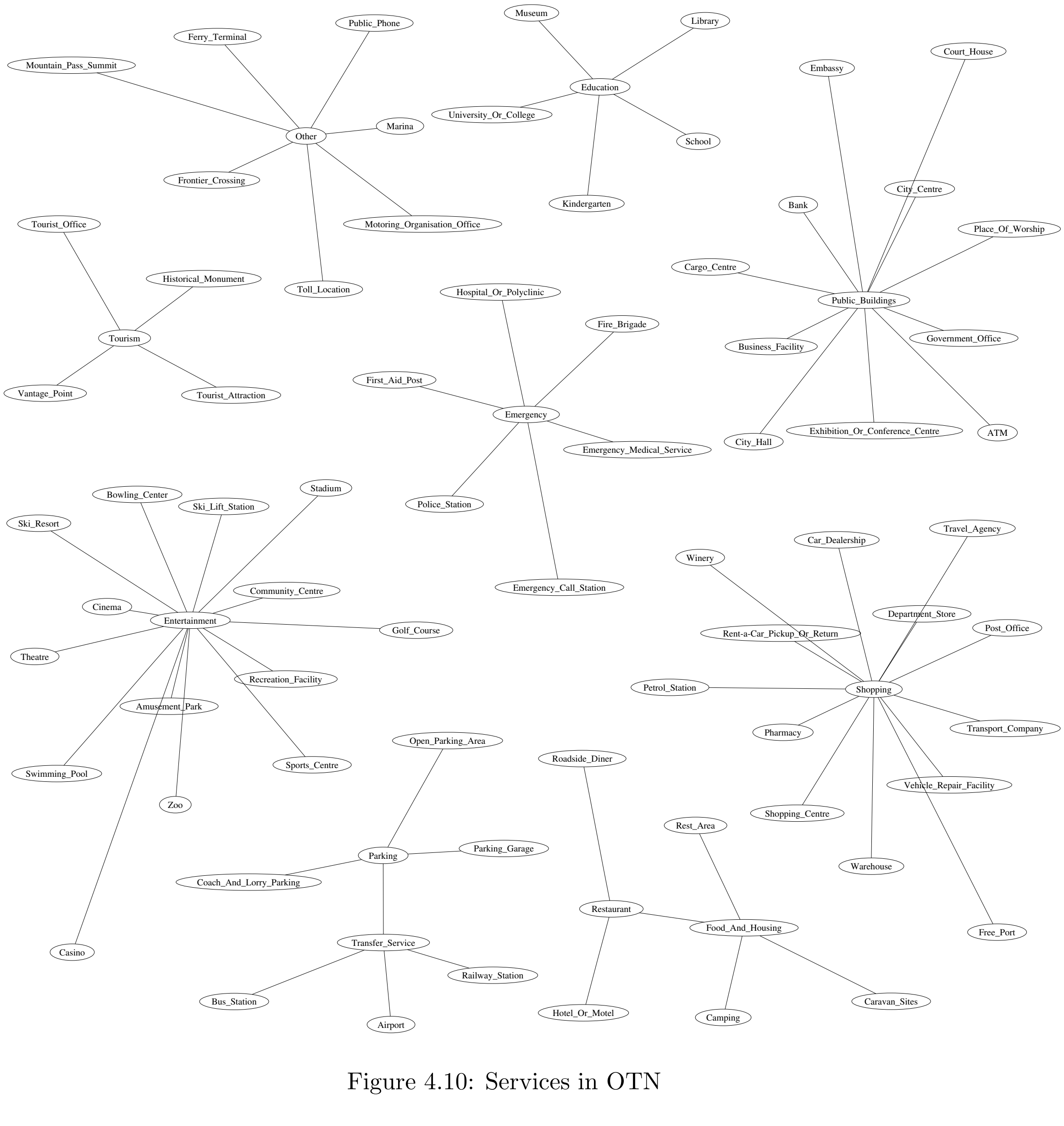


Figure 4.10: Services in OTN

Chapter 5

Summary

This deliverable starts with an overview over standardisation efforts in the area of transportation networks. The standardisation efforts concern mainly the development of standardised data formats for geographical data. From the data structures one can extract formal ontologies for transportation networks. This has partly been done for the GML standard. We did a similar work for the GDF standard and the result, OTN, is presented in this paper. The advantage of ontologies which follow the data standards are that one can use them together with the data, which we demonstrated in deliverable A1-D5. This can only be an intermediate step to an ontology of transportation networks, which is independent of the data standards. Nevertheless, we are convinced that OTN and similar ontologies are still useful as mediators between such an abstract ontology and the data stored in the various standardised formats.

Acknowledgement

This research has been co-funded by the European Commission and by the Swiss Federal Office for Education and Science within the 6th Framework Programme project REWERSE number 506779 (cf. `http://rewerse.net`).

Bibliography

[1] 278, C. Offical web site of cen/tc 278: Road transport and traffic telematics, 2005. http://www.nen.nl/cen278/.

[2] Guarino, N. Semantic matching: Formal ontological distinctions for information organization, extraction, and integration. In *SCIE* (1997), pp. 139–170.

[3] http://lisi.insa-lyon.fr/ townto. Towntology, 2005. http://lisi.insa-lyon.fr/ townto/.

[4] ISO. Geographic data files 3.0 (gdf) documentation, 1995. http://www.ertico.com/links/gdf/gdfdoc/gdfdocon.htm.

[5] Jones, C. B., Purves, R., Ruas, A., Sanderson, M., Sester, M., van Kreveld, M., and Weibel, R. Spatial information retrieval and geographical ontologies an overview of the spirit project. In *SIGIR '02: Proceedings of the 25th annual international ACM SIGIR conference on Research and development in information retrieval* (New York, NY, USA, 2002), ACM Press, pp. 387–388.

[6] Michinori HATAYAMA, S. K. Realization of temporal schema in kiwi+ format, simple topology and spatial temporal - open database schema.

[7] Noblett, C. M. Iso/tc 204:intelligent transport systems. Information about TC 204.

[8] Semantic web for earth and environmental terminology, 2005. http://sweet.jpl.nasa.gov/index.html.