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Geospatial information standards. A comparative study of approaches in the standardisation of geospatial information

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Abstract

Numerous functional and proposed geospatial standards are critically compared with respect to their purpose, their legal status and the data models supported. Special emphasis is laid upon the issue of interoperabilty, i.e. their inherent capacity to work in a distributed environment, thereby extending previous concepts of data exchange.

Keywords: Interoperability; Database schema; Modelling

1. Introduction

> Until definition and standards are adopted, the definition and development of GIS applications will remain an admixture of art, science and perspiration.

(Strand, 1995, p. 30).

Geographic information standards apply to the definition, description and management of geographic information and to geo-spatial services. The standardisation of geographic information

- increases the understanding and usage of geographic information.
- increases the availability, access, integration and sharing of geographic information.
- promotes the efficient, effective and economic use of digital geographic information and associated hardware and software systems.
- contributes to a unified approach to addressing global ecological and humanitarian problems.

Digital data from a wide variety of sources is being referenced to locations for use in a diversity of applications; consequently, there is an increasing need for geographic information standards. One plight in any standardisation effort is what to include and what to neglect. There is the dilemma of being generic enough without loosing necessary specialisation and detail. The requirements of various application fields are diverse, with respect to both the structure of data and operations. The consequence of this is adequately summarised by the adage “The nice thing about standards is that there are so many”. This article aims at clearing some of the paths into the jungle of models and concepts employed by some of the more ubiquitous geo-information standards. Section 2 is a history of standardisation efforts which illustrates, and perhaps even explains, the proliferation of standards in the realm of geo-spatial information. Most of the standards that will be dealt with here are too new to be judged in the light of real world experience. Therefore, the means to compare and discuss the different standards is to review their reference models and, if existent, the formalisations of their spatial sub-models or geometries. What is the content and structure of geographic information according to the discipline’s or national world view, and what are the processes supported for the analysis, presentation, representation and documentation of geographic information? Section 3 answers these questions with an introduction to the terminology of standards in the realm of geo-information.

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2. The evolution of standards

Since standardisation happens all over the world, there are many parallel developments and as more and more standardisation bodies become aware of each other, the current trend is more toward a unification than specialisation. Hence there are many fathers to the youngest generation of standards and no clear lineage can be developed. One common backbone in many modern standards is the geometry model employed. It can be traced back to the 1970s when the U.S. Census Bureau developed its minimal redundant topology (Mini-Topo, see Fig. 1) format (Corbett, 1979). It was quickly adapted by the military who made it a basis for the digital geographic information exchange standard (DIGEST) which for the sake of being the first codified standard of geo-information then in turn had a great influence on the standardisation efforts in most of the North Atlantic Treaty Organisation (NATO) nations in the 1980s. In spite of its large effect, the standardisation community is rather small and the influence of one standard onto the other is mainly through the same people sitting in the committees. It is probably no exaggeration to state that until recently more than 50% of the members were paid by defence related institutions. Civil business has been slow to pay more than lip service. One of the long-lasting contributions of DIGEST is its way of feature modelling. The type of feature and the associated attributes, are handled through designation of a code, as specified in DIGEST's feature attribute coding catalogue. Almost all other standards (SDTS, GDF, S-57, to name a few) adopted this approach; it seems to mirror the legends used in topographic maps, and as most governmental authorities charged with handling spatial information were staffed with people from national mapping agencies, the adoption was a simple one. A great chance was missed back then (1970's) to extend the notion of spatial information beyond the cartographic paradigm. This was also the time of centralised mainframe computers and the technological paradigm was (and is) that of a distribution format, e.g. for products such as the digital chart of the world (DCW).

Innovation had to come from outside, and again, it came from a small group of people, most particularly Kucera and Sondheim (Kucera et al., 1993) then working for the Ministry of Environment, Lands and Parks in British Columbia. They developed what became to be known as the spatial archive and interchange format (SAIF) which is to modern standards what Mini-Topo was to the older ones. Originally conceived as a system for the management of forests, it soon developed into a general purpose system from which its offsprings SQL3-MM and the open geodata interoperability specification (OGIS) emerge with a behaviourally based object-oriented modelling concept based on distributed component technology. It provides the means of achieving intraoperability within any particular information community and of facilitating interoperability with other communities. Other approaches fall somewhere in between Mini-Topo and the descendants of SAIF. The spatial data transfer standard (SDTS) models geo-data through graphics and associated attributes; in practice it is still basically a distribution format. ESRI's OLE for map objects and Intergraph's OLE for geographic data objects make use of desktop object technology and object modelling, as does SAIF itself. They support object oriented modelling and are open enough to act as an exchange hub but they lack the scope of OGIS or the emerging ISO 15046 family of standards for handling geo-information which ensure that they can be used in complementary and compatible ways.

3. Towards a common terminology

The following section lays the ground for the comparison of geo-information standards. Some terms and notions of conceptual modelling need to be clarified before we can descend into the intricacies of individual approaches. The domain reference model of Technical Committee 211 of the International Standards

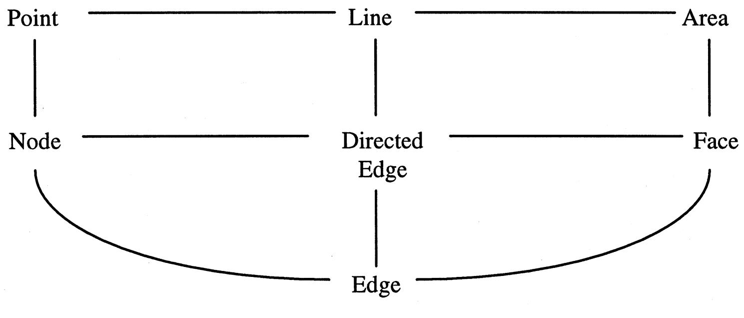

Fig. 1. Mini-Topo.

Organisation (ISO/TC211) will serve as a prototype, for the ISO committee tries hard (and successfully) to embrace the different perspectives.

3.1. High-level perspective

The prospective user of geographic information deals either with geographic features (vector model) or with raster cell data. In order to do so, metainformation, describing the organisation (and quality) of datasets is essential. This is depicted in Fig. 2. Relationships between geographic features (note: this does not apply to raster data) may be of three types; only the latter one, however, is of specific concern to *geographic* information:

- *Logical relationships* identify associations between features that may be defined to serve the purposes of specific applications.
- *Part_Of or decomposition relationships* define features that are components of other features; e.g. runways and control towers being components of airports.
- *Spatial relationships* are derived through the application of spatial operations using basic positional information as input.

Depending on the purpose of the standard, the reference model might be much more elaborate at some part or another (e.g. there might be specific section on temporal references, behaviour, portrayal or quality).

3.2. The mid-level perspective

The feature (or raster) view is not specific enough to define interfaces to all the different application areas. For that, the spatial sub-schema item in Fig. 2 needs to be detailed as there are many different (and often incompatible) ways to describe the underlying spatial properties. Fig. 3 describes the (mid-level) differentiation of the geographic data description item in Fig. 2. This figure shows the relationships between geometry and spatial attributes as well as between geometry and spatial relationships. Geometry provides a basis for spatial operations (which, so far, are neglected in most standards). Spatial operations, in turn, provide a basis for determining the values of spatial attributes of geographic features and for deriving spatial relationships between geographic features. Spatial attributes describe spatial properties of geographic features as relevant to a particular geometry. These include:

- position.
- shape.
- orientation.
- dimensionality.
- decomposability.
- self-similarity.
- scalability.

The strong position of surveyors in most of the standardisation committees is reflected by the prominence

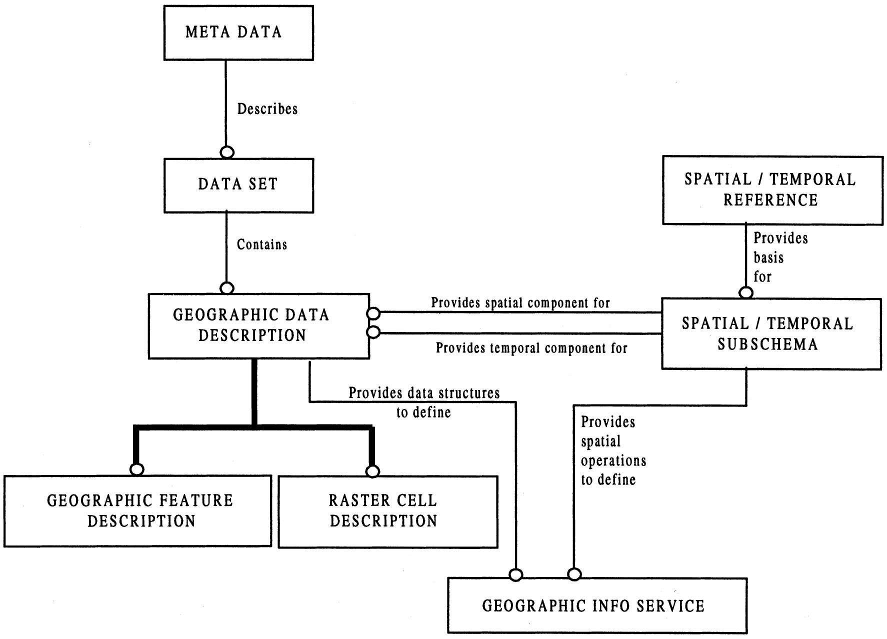

Fig. 2. General model of geographic information.

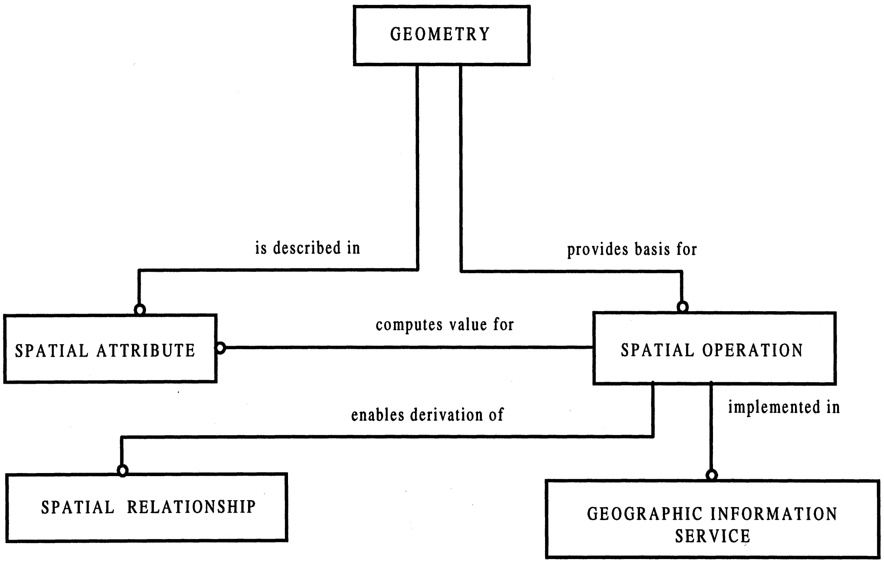

Fig. 3. Mid-level view of geographic data description.

of reference systems, both direct (geodetic, i.e. geographic, projection and grid referencing systems) and indirect. So far, temporal aspects have been largely neglected, so that geologists and archaeologists are likely to be disappointed by the outcome of current proposals.

3.3. The information technology perspective

The development of standards for geographic information must consider the adoption or adaptation of generic information technology standards whenever possible. It is only when this cannot be done that *geographic* information standards need to be developed. Beyond the needs of traditional applications of digital geographic information, there is a growing recognition among users of information technology that indexing data by location is a fundamental way to organise and to use digital data, exemplified by the spatial extensions to many of the major database management systems (Nieuwenhuijs, 1995). Hence the need to develop interoperable spatially-aware applications. *Interoperability* is a relatively new term in information technology (IT). It describes the development of *open systems* where data and operations can be shared between computers and users through information networks. To accomplish this, *standard* specifications of data and operations directed to data are needed. The meaning of a standard is at least two-fold. The specifications of data and operations make it possible for a potential user to identify the set of data that he needs, thereby providing information for the process of making a decision in information exploration stage. From a technical point of view, rules about naming and coding practices are needed if data are to be shared between computers and software of different kinds. Standardisation within the area of geographic information ought to be undertaken from an information technology perspective, so that it makes use of generic information technology standards.

3.4. Open systems

A current trend in information technology is to develop systems which further promote the sharing of data and related resources. One of the most significant factors underlying this trend is that no single vendor can provide everything that an organisation needs with respect to information systems and services. Another reason is that very large centralised databases are no longer practical. An answer to these problems are *open systems* whose development relies on concepts such as interoperability and portability. In an open system, an application is executable on any vendor's platform that is able to communicate in any vendor's network and the application is able to access any vendor's database. This principle requires systems to be able to communicate with one another and to exchange and use information including content, format and semantics. Portability implies the ability to transport (1) application source code between computer platforms and operating systems, (2) data between databases and (3) even people: users are supposed to be able to move among applications and transfer skills learned in one operating environment to another. The US National Institute of Standards and Technology (NIST, 1995) codified these ideas in a profile for a so-called open systems environment (OSE). In such an open system, flexibility is attained by adopting techniques and practices which don't prevent any of the above mentioned forms of portability due to differing performance characteristics and capabilities between systems.

The OSE approach has been adopted as a reference model in ISO/TC211 work as well (ISO, 1998). The framework is named GOSE or geographic open systems environment (see Fig. 4). To be specific, OSE encompasses a set of concepts that provide a basis for the specification of standards needed to implement open systems. Fundamental *entities* are application software, application platform and platform external environment. *Interfaces* are (shared) boundaries between entities, defined by functional characteristics and other characteristics. *Services* are capabilities provided by entities, falling into categories such as operating systems services, human/computer interface services, data management services, data interface services, graphics services and network services (NIST, 1995, p. 11).

A GIS application built upon this setting would consist of GIS application software running on an appli-

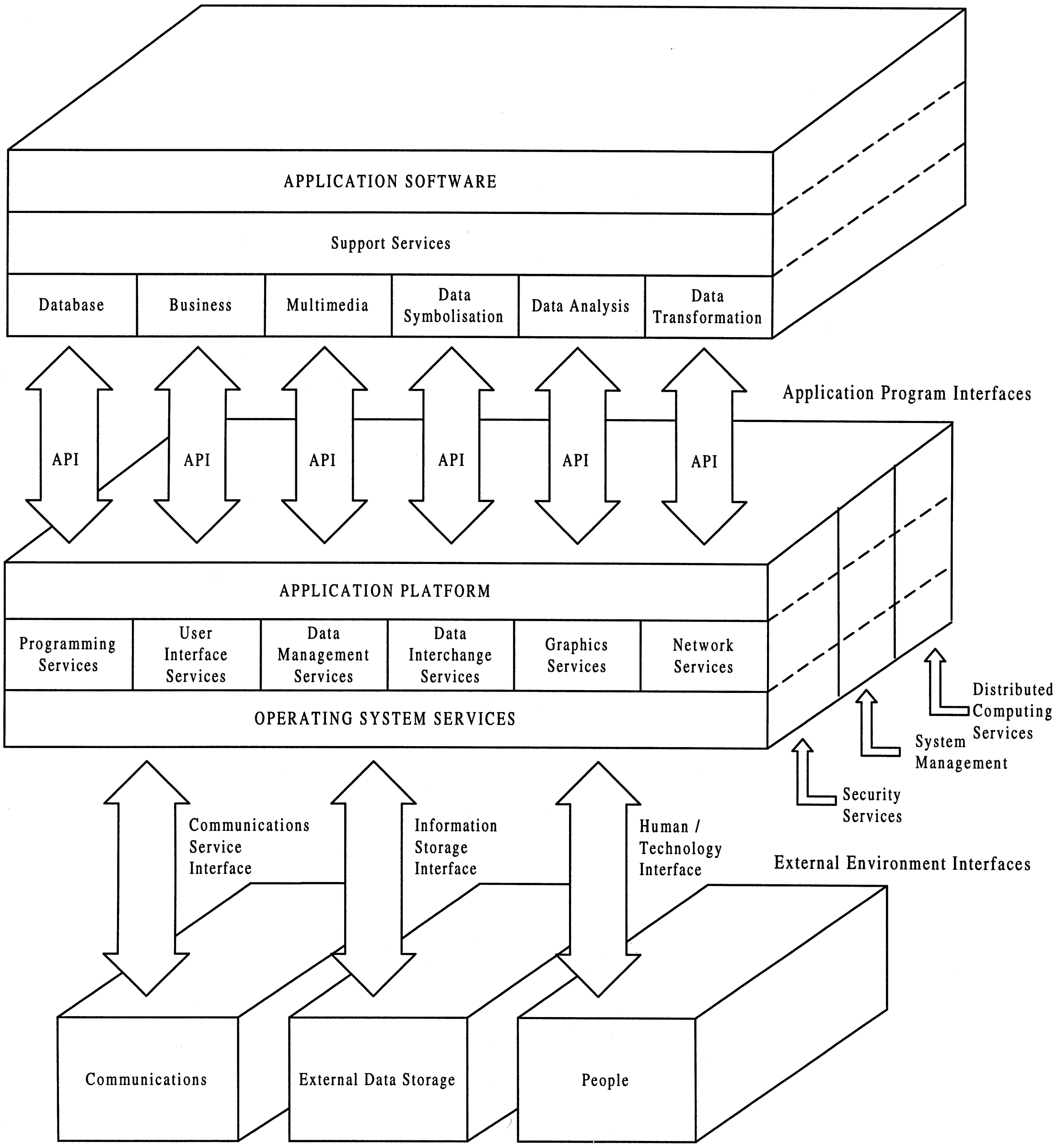

Fig. 4. Geographic open systems environment (GOSE) (ISO/TC211 N040).

cation platform interfacing with the external environment. The latter consists of users, information storage, and communications capabilities (as in the lower part of Fig. 4).

3.5. Profiles

The comprehensiveness and significant number of options available in many base standards make them difficult to implement. A profile, which can be a subset of a base standard, enables a partial implementation of the base standard. The concept of a profile is also used to define a set of integrated base standards or combination of subsets and base standards. OSE provides the principles and a classification scheme for OSE profiles which have been submitted for ratification as international standardised profiles (ISP). Base standards define fundamentals and generalised procedures. They provide an infrastructure that can be used by a variety of applications, each of which can make its own selection from the options offered by them.

Profiles defining conforming subsets or combinations of base standards are used to provide specific functions. Profiles identify the use of particular options available in the base standards and provide a basis for the development of uniform, internationally recognised conformance tests. As the applications of geographic information are ubiquitous, geographic information standards must be as generic as possible. The use of a part or the complete structured set of standards or even the multiple usage of one particular standard by a variety of disciplines and diversity of geo-processing applications is a substantial challenge for the realm of geographic information standards. The solution is adopted from information technology standards. The generic applicability of such standards is achieved by applying the concept of profiles.

4. Functional standards

In this section only those standards will be discussed that were developed for a particular user community and which have actually been passed by their respective bodies.

4.1. Digital geographic information exchange standard (DIGEST)

DIGEST was prepared and issued under the authority of the Digital Geographic Information Working Group (DGIWG) to promote the exchange of geographic information between the defence authorities of Belgium, Canada, Denmark, France, Germany, Italy, the Netherlands, Norway, Spain, the United Kingdom and the United States. DGIWG currently proposes to make DIGEST another ISO standard. DIGEST defines a set of rules and encoding conventions for the orderly exchange of spatially referenced raster, vector, and matrix data (DGIWG, 1997). Vector data may be transferred by either feature-oriented or relational exchange structures. DIGEST employs the U.S. Department of Defense's Vector Product Format (called Vector Relational Format (VRF)). At the conceptual level, it resembles the US spatial data transfer standard (see Section 5.2).

Data transfers are organised into a five-level hierarchy as follows:

- Volume level: the group of data being transferred.
- Data set level: individual cells within the group being transferred.
- Feature level: individual features within a given data set.
- Topological/spatial level: spatial (geometric) data.
- Attribute level: thematic (attribute) data.

DIGEST supports the exchange of raster, vector and matrix data sets. The standard accommodates all levels of topology and includes structures to support tiled data bases and the indexing of variable length data fields. Thematic data are transferred through a standardised catalogue of features and attributes. Standards for reporting spatial and aspatial aspects of data quality are included as well.

4.2. Geographic data file (GDF)

GDF may be regarded as the European preceding counterpart to OGIS. It started out as an initiative of members of the European automobile industry (Daimler Benz, Renault, Volvo) to develop a European digital road map (EDRM) for car navigation systems. GDF 1.0 was based on the UK national transfer format (NTF) which did not quite meet the specific requirements of the particular market niche. Version 2.0 adopted the DIGEST data model (see Fig. 5) and extended the scope to embrace intelligent vehicle highway systems (IVHS) and highway maintenance systems. The market pressure was high and so the consortium succeeded in passing the third edition of this standard within only a few years (CEN, 1995). Originally only a de facto standard, it has been endorsed both by Comité Européen de Normalisation CEN (technical committee 278) and ISO (technical committee 204). The latter will pass it as ISO/TR 14825.

GDF has a three level structure (see Fig. 6):

- Level 0: *topology*. This is a full topology description with nodes, edges and faces similar to DIGEST (see above).

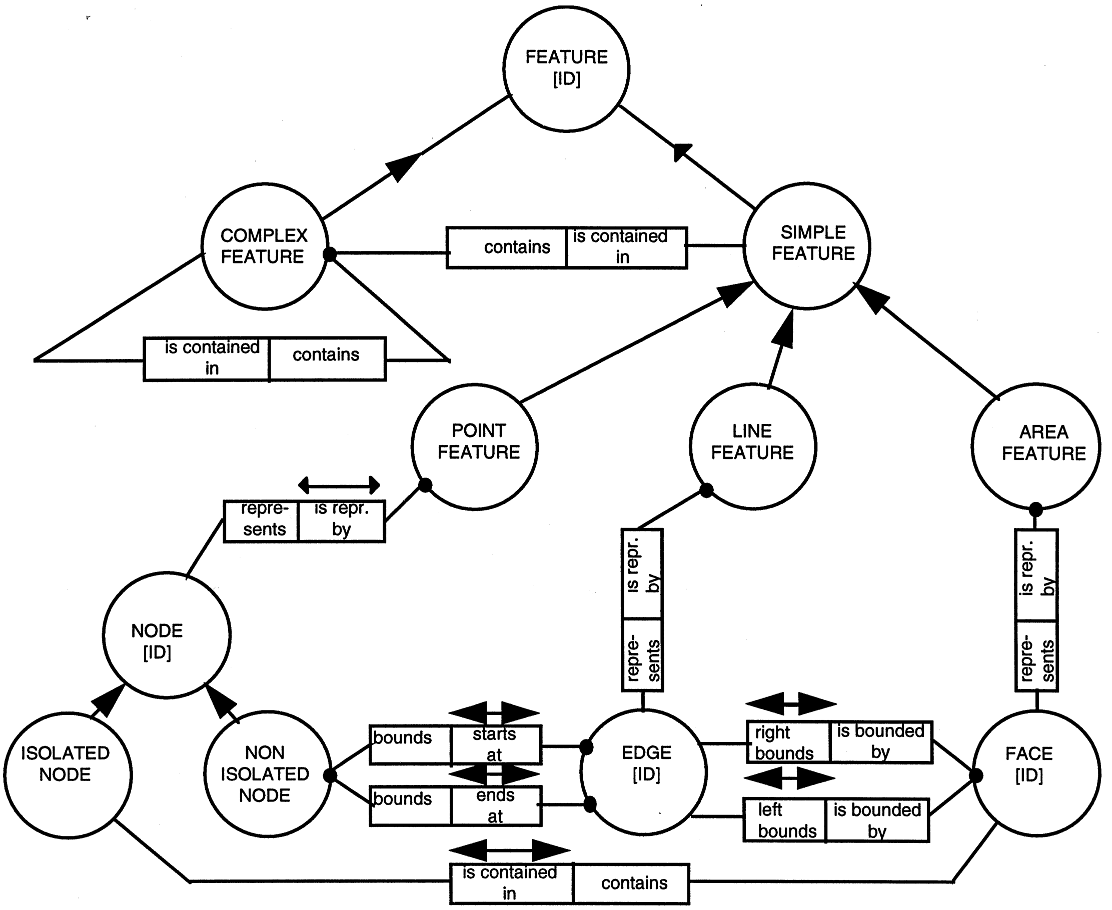

Fig. 5. GDF data model (from GDF documentation, 1995, p. 192).

- Level 1: *features*. Level 1 is the most used level of GDF. It contains simple features like road elements, rivers, boundaries, signposts, etc. Features can have attributes that are specific to the feature, i.e. one way, width of the road, number of lanes. Features can also have relations. Relations can be "forbidden turn from road element 1 to road element 2" or "road element 1 has priority over road element 2".
- Level 2: *complex features*. At this level the *simple features* are aggregated to a higher level feature. For instance, at level 1 all road elements of an intersection should be represented. At level 2, the intersection is represented by only a single point.

Level 2 is mostly used when a simplified description of the road network is sufficient. For instance, interurban route calculation does not require a high level of detail. Vehicle location by means of a GPS receiver, however, does need the detailed description of the road network. The pressure from U.S. and Japanese manufacturers to implement GDF as an ISO standard is indicative of the quality of this standard. In addition, the (almost) modular object-oriented structure allowed the European Council to mandate in its 4th Framework Programme that GDF is to be used in a range of other applications.

4.3. S-57

The International Hydrographic Organization's (IHO) S-57 transfer standard for digital hydrographic data describes the standard to be used for the exchange of digital hydrographic data between national hydrographic offices and for its distribution to manufacturers, mariners and other data users (IHO, 1992). For example, this standard is intended to be used for the supply of data for the electronic chart display and information system (ECDIS). Since S-57 is an international treaty it can be regarded as being somewhat higher than a 'mere' standard.

According to IHO/S-57, a database is organised as objects of different kinds. Real world entities are represented as database objects. An IHO/S-57 database object is an aggregation of attributes and an object

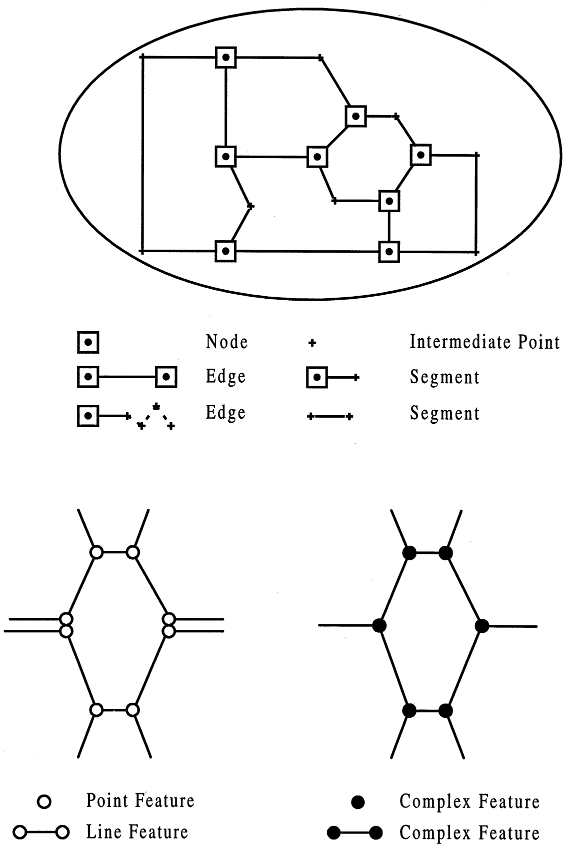

Fig. 6. GDF symbols in level-0, level-1, and level-2 representation.

identifier, as shown in Fig. 7. The location and other characteristics of a real world entity are represented as vector, raster or matrix (the latter two have not yet been specified in the current version of the standard). A vector object is either a node, an edge or a face. Other information relevant to an entity are metadata, cartographic data, geographical data and collection.

5. Generic and draft standards

5.1. Spatial archive and interchange format (SAIF)

As described previously in the history of geo-information standards, SAIF is the concoction of basically two people (according to a personal communication Henry Kucera submitted an only slightly altered version as his Masters thesis). It became a Canadian national standard in 1993; the current version is 3.1 (SAIF, 1994). SAIF is the first truly object-oriented specification of geo-spatial information. It has a base set of approximately 300 classes and allows multiple inheritance and many threads of data access at the same time. SAIF and SQL3-MM are likely to merge in their respective next versions.

The design roots of SAIF are in the information sciences. SAIF is designed to facilitate interoperability, particularly in the context of data interchange. According to SAIF's modelling paradigm, data model concepts are mathematical constructs (tuples, lists, sets, etc.). The SAIF standard schema consists of spatial and temporal constructs that are created from mathematical constructs. The user schema consists of constructs corresponding to real world entities and is created from spatial, temporal and mathematical constructs. One of the major drawbacks of the current version is that SAIF lacks definitions of operations (this is however, addressed by the two succeeding specifications SQL3-MM and OGIS).

SAIF data modelling techniques encompass association techniques (generalisation, aggregation and simple association) and construction of new types. Geographic object types, for example, road, forest stand and oil spill, are defined in the SAIF standard schema. The position of the specified phenomena is represented by a spatial or spatio-temporal object. This provision for temporal objects is one of the major advantages of SAIF over other functional standards. The information content of a specific application is represented by a set of relevant types derived from the data model and standard schema classes. Table 1 shows constructs of the standard schema.

5.2. Spatial data transfer standard (SDTS)

Compared to the other standards described here, SDTS has a limited scope (SDTS, 1992). It is designed as a language for communicating spatial information. It is a *transfer* standard that embraces the philosophy of self-contained transfers, i.e. spatial data, attribute, geo-referencing, data quality report, data dictionary and other supporting metadata are all included in the transfer. Work on the standard began in 1980 and this is reflected in its restriction to a mere exchange format. Nevertheless, SDTS provides all the means to ensure that the full semantic depth is preserved in the data exchange, provided that the target system's data model supports the semantics. Codified as US Federal Information Processing Standard (FIPS, 1995) 173 SDTS is implemented through the use of profiles. Four profiles exist or can be expected soon:

- *Topological vector profile* (TVP): the TVP is the first completed profile and was developed to support geographic vector data with geometry and topology. It includes the SDTS defined spatial objects representing vector data with full topology that comprise a

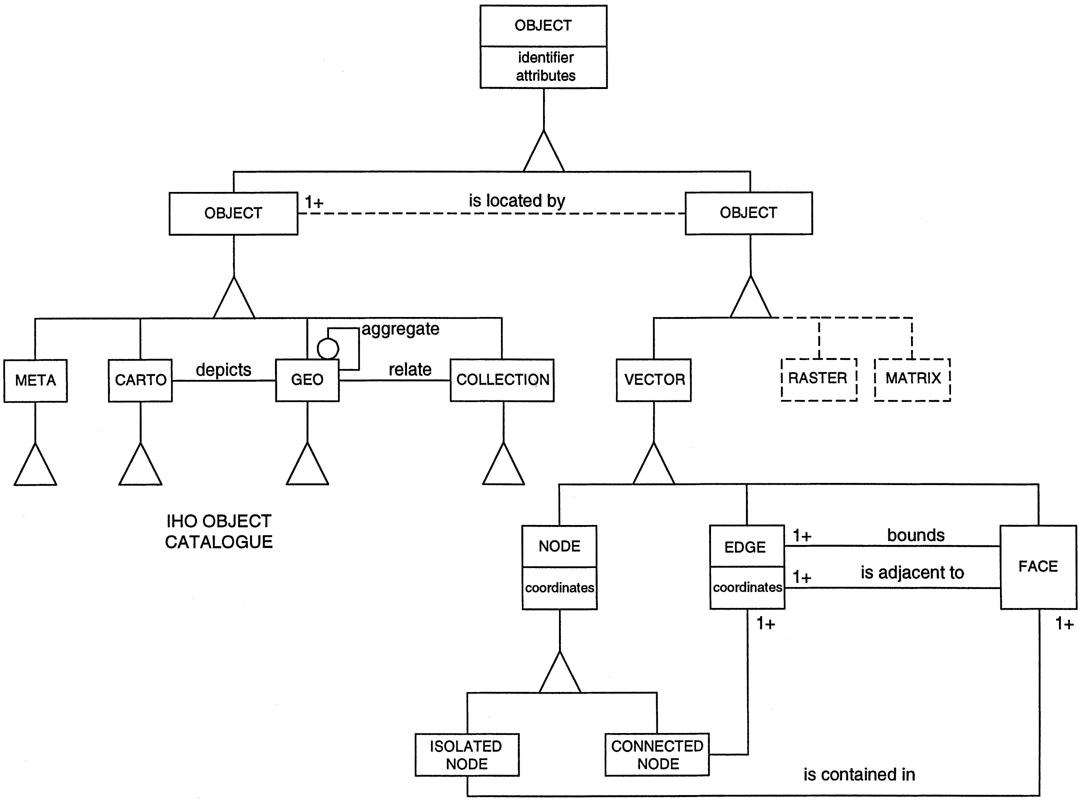

Fig. 7. IHO/S-57 data model.

two-dimensional manifold. Data sets may contain point, line, polygon and composite features.

- *Raster profile* (RP): the RP (so far only in draft form) was developed to support two-dimensional spatial data sets in which features or images are represented in raster or gridded form. This profile can accommodate image data, digital terrain models, gridded GIS layers and other gridded data. This profile does not permit vector objects, raster objects higher than two dimensions or irregular grids.
- *Transportation network profile* (TNP): the TNP contains specifications for an SDTS profile for use with geographic vector data with network topology. Data sets are represented by vector objects which comprise a network (sometimes non-planar) or planar graph. Excluded are raster data and geometry-only vector data.

Table 1
SAIF standard schema constructs

SAIF standard schema constructs	Examples
Geometric classes	geometric aggregate, point classes, vector line classes, vector area classes, vector volume classes, cellular structures (grids)
Time classes	time aggregate, date classes, interval classes, duration
Text or symbol classes	text aggregate, aligned text, symbol
Relationship classes	spatial, temporal, derived, controlled by, connected to
Metadata classes	global metadata, identification, profile, locational definitions, metadata, supporting classes for referencing and quality
Supporting classes	coordinate classes, external reference, classes supporting definition of structures, matrix, …
Enumeration classes	supporting in nature, definitions of domains
Class structure definitions	type, tuple, enumeration, etc. definitions

- *Point profile*: the point profile is also been referred to as the geodetic profile or the high precision point profile. A draft version of the point profile was prepared in mid 1996 by the National Oceanic and Atmospheric Administration–National Geophysical Data Center (NOAA–NGDC) and the US Geological Survey. This profile is designed to support a major release of geodetic control point data from NOAA's national geodetic survey (NGS), as well as point-only data from other agencies.

Additional profiles are being considered for CAD data, non-topological vector data and DIGEST-VPF relational vector data.

5.3. CEN/TC287

This proposed standard is currently the most difficult to assess. The technical committee was instituted when centralised mainframe computers and simple data exchange were considered to be state-of-the-art. It was about to pass an outdated draft when ISO/TC211 was established, and many members feared that all their labour would be obsolete. Rather than dying a long death, the committee seems now to be invigorated and constantly adapts (and improves) the internal drafts. The main distinction of the CEN/TC287 reference model is the lack of feature entities (they can be approximated by the novel concept of a *spatial view*) and the Babylonian language employed, i.e. the English version of the document is only comprehensible to someone with a good knowledge of French (CEN, 1996).

There is a proliferation of spatial sub-schemas with one basic (and all encompassing) one called G0 (see Figs. 8 and 9) and eight others for:

(G1) full planar graphs.
(G2) planar graph linear networks.
(G3) non-planar graph linear networks.
(G4) non-planar graph linear network with sur faces.
(G5) spaghetti.
(G6) bounded triangulated irregular networks.
(G7) raster images.
(G8) grids.

Less would here probably have been more. All aspects of a modern (geo-spatial) standard such as object-orientation, support for distributed processing, a layered architecture with a services model, process-orientation, etc. are now being added to the already bulky proposal. Whether this will be successful remains to be seen.

5.4. ISO/TC211

The ISO geoinformation reference model (ISO, 1997) has been used in the beginning as a reference for the comparison of other standards. This is no coincidence as the ISO committee sees itself as a provider of templates for other (functional) standards to work on. This is explicitly the purpose of work item 6, where the committee attempts to implement other standards as a profile of ISO 15046.

Together with the Open GIS Consortium (OGC), this group is the most recently established one and they have many common features (e.g. committee members, underlying philosophy, etc.). OGC is more ad-hoc and its corporate members want to see results fast. With its attempt to broaden the scope beyond the American continent, however, the differences to ISO in scope and character begin to blur. On the scale between a pure standard in the foot steps of CEN and the "we codify what the customer wants, not the scientist" attitude of OGC the ISO committee seems to have found a nice balance. Compared with the information management oriented CEN model the ISO model is technology-oriented. Furthermore, the aim and scope of the ISO model is much broader. Both models emphasise information definition, description and access. The ISO model also points out universal usage, integration of information, geo-processing functionality, information management and geospatial services. The CEN model still is clearly exchange-oriented while the ISO model aims at a more integrated approach following the open systems philosophy. At the schema level, all three are quite similar and it does not take much effort to represent one schema in terms of another one or to unify them all into one. Fig. 10 shows the only peculiarity of the ISO spatial subschema where a topological complex is a subset of a geometric complex.

5.5. Open geodata interoperability specification (OGIS)

The public domain GIS GRASS, developed by the US Army, had nurtured a paradigm of code sharing and crude interoperability (long before this phrase became topical). The Open GRASS Foundation was founded in 1992 with the goal to attract major industry interest and hence money to create an interoperable application environment consisting of a configurable user workbench supplying the specific tools and data necessary to solve a problem. Only when (Tcl/Tk-based) GRASS was abandoned in 1994 and the far more radical idea of a shared data space and a generic data model supporting a variety of analytical and cartographic applications was born, the big vendors began to endorse the concept of an open geodata interoperability specification, resulting in several name changes from Open GIS Foundation to the Open GIS Consortium (OGC, 1996).

The two main components of the architectural framework of the OGIS are the OGIS geodata model

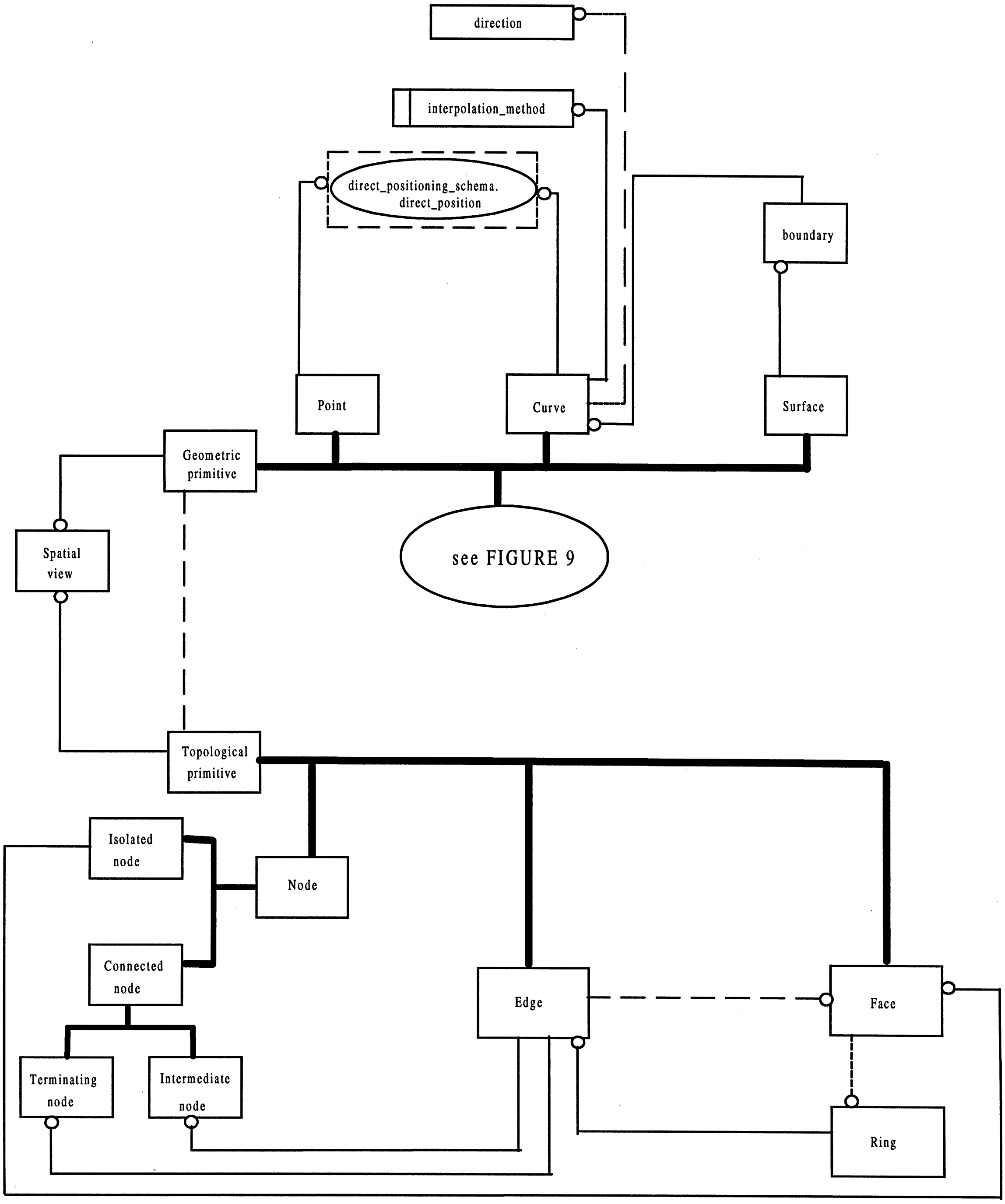

Fig. 8. Basic spatial schema according to CEN/TC287.

(OGM) and the OGIS reference model. The OGM is the core component of the framework. It consists of a hierarchical class library of geographic information data types (herein being a successor of SAIF) which comprise the shared data environment and unified data programming interface for applications. The OGM is also intended to be the interface to other geographic information standards.

The OGM is announced to include sophisticated definitions of spatial objects, fields and functions. The OGIS reference model (see Fig. 11) describes a consistent open development environment characterised by a

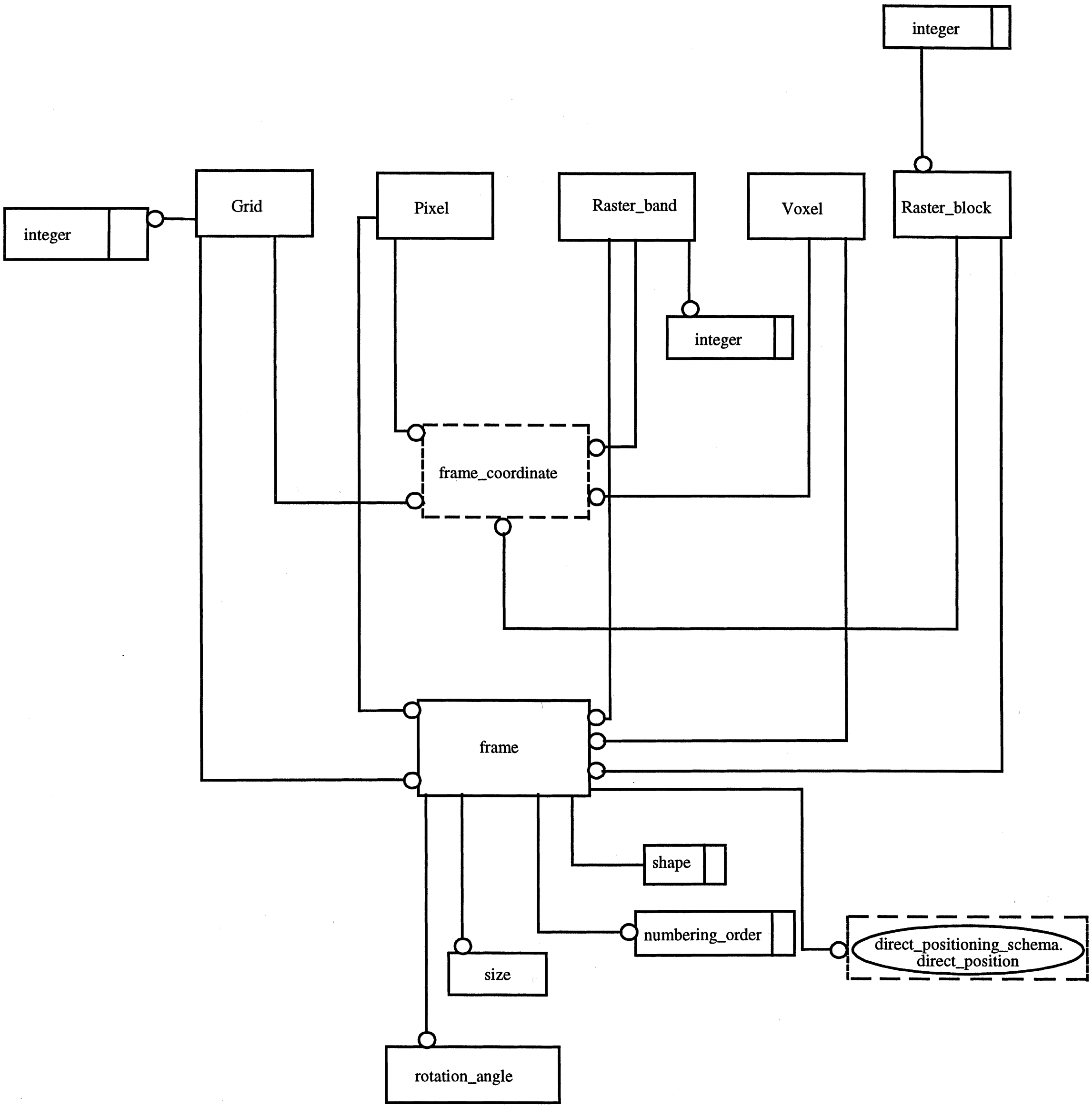

Fig. 9. Raster part of CEN/TC287 basic spatial schema.

reusable object code base and a set of services. The design approach for the OGM determines the set of services that must be supported in the reference model. As a result, it requires directories of services and databases, which will support complex query processing. It also specifies standard methods for requesting and delivering geospatial transformations and processing tasks. The reference model will also facilitate transformations between 'private' data and model constructs, as well as coordinate conversion and raster/vector conversion. It also manages visualisation and display and it supports data acquisition. On paper and hearing it from members of the technical committee (personal communication) this all seems very promising but the drawback so far has been the secrecy about details. Aside from a few dozen insiders, nobody knows yet what the internal interfaces between, say the OGIS feature world and the geometry schema, will look like.

6. Other standards with a spatial component

6.1. SQL3-MM spatial

ISO Joint Technical Committee 1 SC21 handles the standardisation of general data base query languages

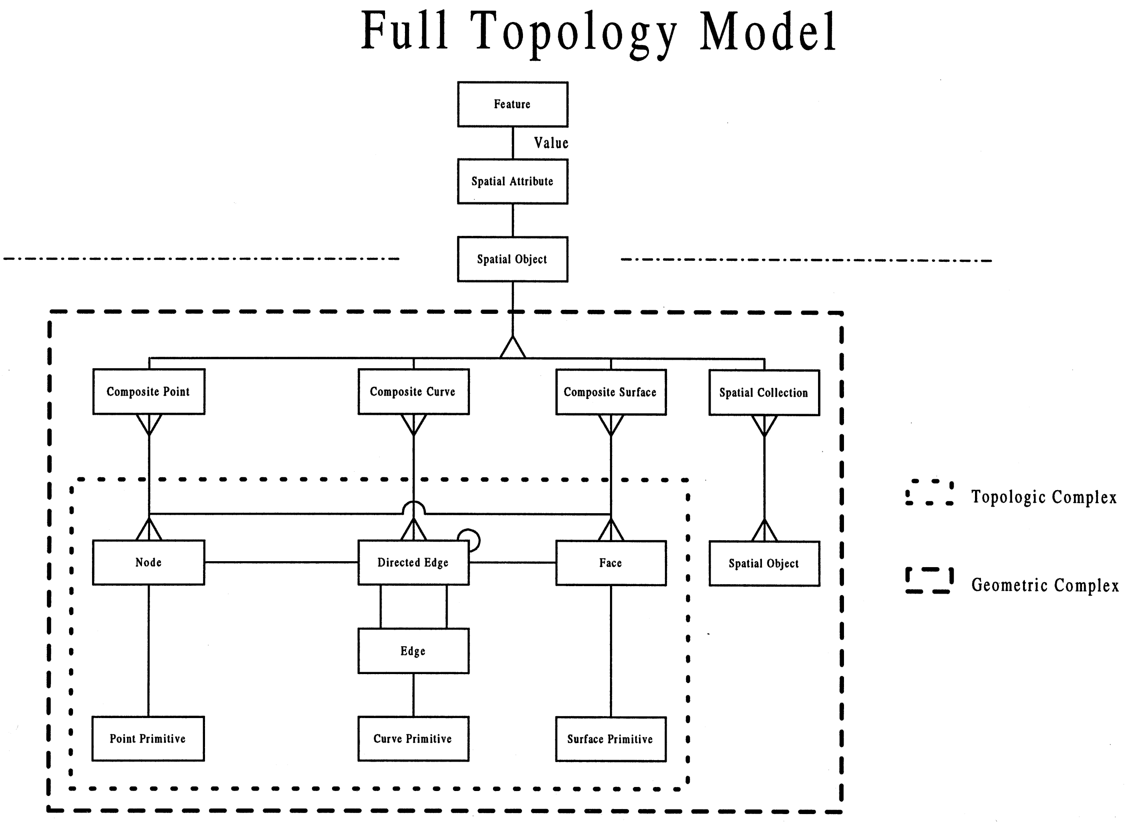

Fig. 10. Spatial complex in draft ISO/TC211.

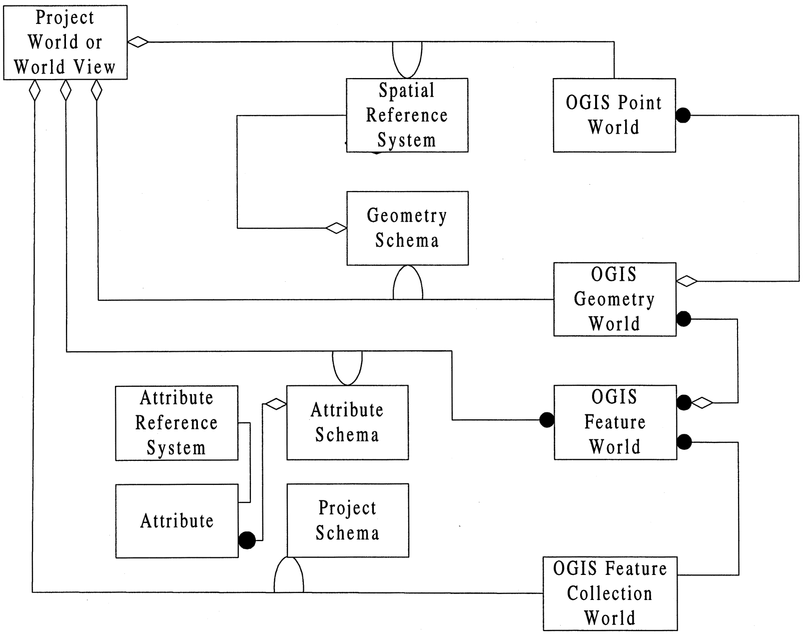

Fig. 11. Object types in open GIS feature collection.

and has been responsible for, in particular, the codification of the structured query language, SQL. Several extensions are now in the works for a new third version of this standard, one of which deals with multimedia applications. Working group 3 of this committee chose 'geo-spatial' as one of these areas of applications (Ashworth, 1996). The close relationship between the SAIF and SQL3-MM standards has been mentioned previously. In SQL3-MM, spatial objects are logical aggregates of geometric and spatial referencing objects. For spatial objects, operators are defined that return other spatial objects that constitute both their interior and boundary. Set operators are defined that return unions, intersections, and differences. Classification operators return information regarding dimension, number of components, etc. Spatial operators can be defined as composite boolean on the topological components of the spatial objects only. An overview to the spatial data types, the closest equivalent to a spatial sub-schema, is given in Table 2.

6.2. GRIdded binary (GRIB) and binary universal form for the representation of meteorological data (BUFR)

GRIB (Stackpole, 1992) is the world meteorological organisation's (WMO) standard for gridded data and BUFR (Stackpole, 1988) is their standard for discrete point data. Both are general purpose *exchange* formats. They are geo-spatial in as such as each grid cell or point ID has an implicit reference to a particular area on the earth's surface, the locational boundaries being described in latitude/longitude values. All other parameters are non-spatial.

6.3. Epicentre

Epicentre is a tool created by the Petroleum Open Software Corporation (POSC) for the exploration and productive use of oil fields (E&P). It uses the latest paradigms in software engineering (e.g. object-orientation, use of sophisticated schema languages, interoperability) to support the integrated E&P business processes oriented to the entire life cycle of a reservoir asset. The epicentre data model defines objects and their characteristics relevant to petroleum E&P, and establishes relationships between these objects (POSC, 1997). Implementing the data model enables various disciplines within the E&P industry (users, data base administrators, software developers) to share the same set of data regardless of application or computing platform. Epicentre V2.2 was released in 1997 and is available to the general public.

Technically, it resembles SAIF and SQL-MM. All three share the information science background, but epicentre puts less emphasis on temporal aspects than the other two. The provision of 3-dimensional geometries, on the other hand, is probably more sophisticated than in any other standard. Although there are references to geodetic reference systems, the geo-spatial character is weak. There is no elaborate system of spatial sub-schemas as in CEN/TC287, ISO/TC211 or the OGM. The processes supported apply to business processes rather than geo-spatial ones. Nevertheless, epicentre is a full-blown de-facto standard with emphasis on systems integration based on a fused data model to support all parties involved in the E&P business.

Table 2
SQL3-MM spatial data types

Data type	Purpose, examples
Supporting data types	domains, coordinates
Geometric abstract data types	point types, line types, area types, volume types, cellular structures, property value types (sparse frame handling)
Time abstract data types	dates, interval, duration, time aggregate
Metadata abstract data types	temporal referencing, height referencing, tiling, bounding box, general location, positional accuracy, quality, metadata
Temporal abstract data types	concepts and functions to deal with temporal topology (temporallyDisjoint, temporallyIntersect, atStart, atEnd, etc.)
Spatial abstract data types	structures and functions required to describe, manage and query spatially and temporally referenced information: raster, graph abstract data types
Spatio-temporal abstract data types	useful when describing classes of objects for which the locational and temporal aspects of an object are both of significance (SpatialTemporalObject, SpatialTemporalComposite MultiTemporalRasterComposite)

Table 3
Representations (data structures) supported by selection of geoinformation standards

DIGEST (GDF)	SAIF and SQL3-MM	IHO/S-57	CEN	ISO 15046 (OGIS)
Raster	no particular representation; but 41 geometric classes that cover most conceivable representations	raster	raster image	raster
Matrix		matrix	grid	matrix
TIN		spaghetti	bounded TIN	spaghetti
Spaghetti		chain-node	spaghetti	planar graph
Planar graph 3D		planar graph	non-planar network with surfaces	planar graph 3D
Node-arc-area		full topology	non-planar network	point set
Planar network			planar network	
Full planar graph			full planar graph	
			basic	

7. Conclusion

A summary of the spatial sub-models supported by the discussed standards is given in Table 3. It shows, as indicated in the beginning, the merging of concepts, at least with respect to the geometries involved. There is a general tendency to evolve from a mere data exchange at the interface level to systems integration with common semantics.

A number of organisations from around the world have played lead roles in the pursuit of interoperability. These include the Canadian Geomatics Standards Board (SAIF and DIGEST), the Digital Geographic Information Working Group (DIGEST and the FACC), the International Organisation for Standardisation (ISO/TC211, Geoinformation and ISO/IEC JTC1 SC21 WG3, SQL3-MM) and the Open GIS Consortium (proponents of OGIS). Of these, perhaps the Open GIS Consortium is the most prominent today. It has direct support from industry, government and the defence community. There is a lot of pseudo information about OGIS that does not specify any details but helps greatly in educating the public. Publicity-wise, OGC has already won, it remains to be seen whether the products based on OGIS will be able to fulfil the high expectations.

As of March 1998, there are some strong hints towards a merger of the spatial sub-models for ISO 15046, SQL(-MM), OGIS and DIGEST. Recent meetings among the core participants of the North American member organisations (ISO, 1998) tried to synchronise the development of the four specifications and the ISO/TC211 committee agreed to adapt its schedule to allow for the development of a coherent standard. There will still be room for different flavours such as the SQL's emphasis on database-oriented aspects, or OGC's stress on implementation issues, but we may expect a rather unified view of geospatial geometries to be standardised by the turn of the century. Unfortunately, even ISO/TC211 has abandoned its behavioural perspective of geospatial information, resulting in a perpetuation of the current chaos prohibiting interoperability of geospatial analyses.

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