13. Standardization

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This chapter contains a detailed presentation of the geomatics standards of the ISO/TC 211 *Geographic information/Geomatics* and the Open Geospatial Consortium (OGC) as of 2011. Section 13.1 is dedicated to interoperability which is a driving force for standardization along with many other interoperability enablers such as quality assurance, confidentiality, integrity, availability, authenticity, nonrepudiation, usability, verification, validation, and metadata which provide the trust and understanding of geospatial resources necessary ensure interoperability. The standards are categorized as de-jure and de-facto standards. The standardization organizations ISO, IEC and ITU are presented in Sect. 13.2 and the standardization procedure, from working draft, via committee draft, to international standard is outlined.

Section 13.3 describes the development of ISO/TC 211 from its predecessor, CEN/TC 287 *Geographic information*, to the present program of work. The most basic standards, the Reference models, are explained followed by a discussion about standards implementation strategies. A roadmap to the complete 19100 standards family concludes this section. Sections 13.4 and 13.5 address the ISO standards individually. Section 13.4 covers nongeometry standards; subsections address infrastructure, basic, imagery, catalogue, implementation, and webmapping standards, as well as location-based services, classification, and the qualification of personnel.

Section 13.5 covers geometry standards and explains the four most important publications in detail. Section 13.6 illustrates the manifold of links from ISO/TC 211 to other ISO committees and international organizations as internal and external liaison members respectively. Each of the liaison members is briefly portrayed. Section 13.7 is dedicated to the OGC which is an industry standardization body for implementation level standards. The structure and the standards development process are explained in detail. The standards are grouped into Interoperability Specifications (IS) and Abstract Specifications (AS); the latter served as a template for some early ISO 19100 standards. OGC standards are continuously being extended and many of them have been forwarded to become ISO standards. Each AS and IS is explained in detail. A glossary of ISO-terms with about 1000 entries is closely linked to this chapter.

13.1 Interoperability

Interoperability is achieved when varied persons, organizations, or systems can work together. This is important for geographic information because of the requirement to share information and processes in a broad field involving diverse information types about the globe with its diverse and complex features and processes engaging a wide spectrum of applications, people, and organizations. Data from around the world are defined and collected by humans of different cultures using a variety of sensors and methods; these data are used by a wide variety of processors operated by many types of organizations. There are three principles that must be met to realize interoperability.

1. The ability to find what you need when you need it;
2. Once located, the ability to access and obtain what is needed;
3. And after obtaining it, to be able to understand it and put it to good use.

Standards play a major role in providing interoperability but by no means are the only factor.

When performing geographic analysis we need to produce the information needed or find information produced by others, access and bring the information into a system, merge it with other information, and perform high-quality, coherent analysis that can be easily and accurately understood by others.

13.1.1 Infrastructure

Infrastructure is critical to interoperability; anyone who has tried to use a telephone during a local or regional emergency knows the value of an adequate infrastructure to communication interoperability. Telephone networks are built to handle an average number of calls per given timeframe plus an emergency reserve; however, during an emergency when almost every phone owner is trying to make a call, the network exceeds capacity and there is no dial tone available. Infrastructures are critical in the use of geographic information. A spatial data infrastructure (SDI) consists of the technology, the coordination between organizations and agencies, the policies, a supportive environment for the sharing and utilization of spatial data, and international standards for interoperability of resources [13.1]. A clearinghouse which collects and distributes spatial resources is an example of an activity supported by an SDI. Clearinghouses are repositories that collect, store, and disseminate resources or metadata about resources and can be physical or virtual [13.2]. A multiperspective description of an SDI is described in [13.3]. SDIs exist at the national, regional, and global level. Examples are the US National SDI [13.4], those of Latin America [13.5] and Asia/Pacific [13.6], the Infrastructure for Spatial Information in the European Community (INSPIRE) [13.7], and the Global SDI [13.8].

13.1.2 Training, Knowledge, and Human Resources

Interoperability is only possible if the information is provided, accessed, and used by knowledgeable people and organizations. As one of the tenets of interoperability is putting accessed information to good use, users of information in an interoperable exchange must have the necessary training and knowledge to understand and use it properly. Users must know, for example, which type of resources can be used for specific analysis. The military, for example, has found that data at a specific level of detail, accuracy, and currency, and an understanding of the reference system, are critical in specific mission planning and combat operations, and has established extensive training on official doctrine for the use of geospatial information. Geographic Information System (GIS) software vendors provide extensive training in the use of their products to ensure proper geographic analysis and application of their products. Many universities provide undergraduate degrees, multidisciplinary graduate education, and advanced research programs in the field of geospatial information science [13.9]. GIS may be applied in many fields. Efficient and proper application of GIS in these fields requires education and knowledge in information technology, databases, and in some cases web applications, geodesy and coordinate reference systems, remote sensing, statistics, and spatial theory as well as the subject where the GIS is applied: environmental protection, military, facility management, business analysis, etc.

13.1.3 Laws, Principles, and Best Practices

In many cases legal frameworks must be established to enable the sharing of geographic resources. Many nations restrict the access to and use of this information. Laws and agreements must be established to facilitate interoperability. Effective decision-making using geographic resources is enhanced following community or discipline established best practices [13.10]. Best practices ensure the proper and effective use of geospatial resources [13.11, 12].

13.1.4 Understanding and Working with Diversity (ETL)

Because there are a wide variety of standards, cultures, practices, languages, reference systems, models, etc. systems need to be designed to expect diversity in order to be interoperable. Extract, transform, and load (ETL) has long been a method of dealing with diversity prior to the existence of de jure geographic information standards, providing transformations between de facto standards; ETL is still relevant today, providing translations between the many de jure standards as well as between conceptual models and coordinate reference systems. Although ETL is sometimes referred to as interoperability without standards, it works best if it is performed on resources adhering to (different) standards; in that way, mapping between standards can be done once and transforms performed many times. Extraction is the process of obtaining or separating out data that is in diverse formats, unstructured, or in an alien or poorly structured or binary form so that it can be processed by a specific system. Examples are data from various sensors or Hypertext Markup Language (HTML) pages, or alien systems. Transformation is converting/restructuring the data so that it is compatible with the system in which it will be used. This can include sorting and filtering the data. Examples are transforming from one language to another, from one data model to another, or transforming geographic information to a common coordinate reference system (Chap. 8). Loading is the process of incorporating and integrating the new information into the target system.

13.1.5 Information Assurance

Interoperability does not work if the information cannot be trusted or is unfit for purpose. Information assurance (IA) is a formal concept/practice developed by the US defense and intelligence agencies to manage risks in the use, processing, storage, and exchange of information/data [13.13, 14]. These concepts are just as important in the transmission, storage, and utilization of, and decision-making using, geographic information. Information assurance includes the following items:

- *Quality*, which is defined in ISO 9000 as (the) "degree to which a set of inherent characteristics fulfils requirements." Information or any exchanged resources must be of sufficient quality to fulfill the requirement for which they were obtained for interoperability to be worthwhile. Producers need to ensure that their products are of suitable quality for their intended purposes and publish that quality information as metadata. Information about the quality as metadata allows users to select the geographic resources that are fit for their purposes, furthering interoperability.

- *Confidentiality*, which means preserving the restrictions on information access and use, protecting privacy and proprietary information to ensure that information is not disclosed to unauthorized entities. Interoperability may not be realized unless the parties in the exchange know that their information will be protected through copyright, secure handling procedures, and other means.
- *Integrity*, which means ensuring that data/information has not been changed, altered, or improperly modified in an exchange to ensure information nonrepudiation and authenticity.
- *Availability*, which means timely and reliable access to geographic resources to ensure the usability of the resource and confidence in the outcome of analysis performed using it.
- *Authenticity*, which means the property of being genuine, verifiable, and trusted to enable the geographic resource to be used with confidence.
- *Nonrepudiation*, which means ensuring that the sender of information is provided with proof of delivery and that the recipient is provided with proof of the sender's identity, so neither can deny having processed the information. Uses of geographic resources that are backed by the provider ensure confidence in the use of the resource.
- *Usability*, which is defined by ISO as *the extent to which a product can be used by specified users to achieve specified goals with effectiveness, efficiency, and satisfaction in a specified context of use*. With respect to geographic data quality, ISO 19157 [13.15] defines it as (the) *degree of adherence to a specific set of data quality requirements*.
- *Verification and validation*. Verification is ensuring that a resource is designed correctly to address specific requirements, while validation ensures compliance with that design. So, verification is done infrequently: at the time of resource design/development or when determining its fitness for use, whereas validation is done continually to ensure that the resource consistently meets the verified requirements. For example, verification of a system ensures that the geospatial data it uses and the processing performed can determine regional flood potential. The data input are then validated so that it meets the verified requirements.
- *Authoritative data*, which are officially recognized data that can be certified and are provided by a legal authority, or that adhere to a specification and doctrine for their use. Land cadastre is not legally binding unless derived from authoritative data [13.15, 16]. In many cases, the user does not need to know the detailed accuracy and timeliness information, as long as they use data authorized for a specific application.

13.1.6 Metadata

Metadata, defined as data about data, are a major interoperability enabler because they describe the information (to be) exchanged. Metadata are a primary interoperability enabler because they address all three of the principles of interoperability. Metadata in the form of a brief description of a resource that can be indexed for searching enable the resource to be discovered, and if the quality of the information of the resource is included in the metadata, potential users can determine whether the resource will fit their needs. Once a resource has been selected, metadata that provide information about cost along with access and use restrictions and provide information about the structure and format of the resource allow users to obtain the resource. Metadata that allow users to fully understand resources enable them to properly put it to good use (Chap. 12).

13.1.7 Standards – De Jure, De Facto, Industry

A standard is a documented agreement between a producer and a consumer, i. e., a reference document to be used in contracts and international trade which specifies definitions of characteristics, technical design or content, precise criteria, rules, or guidelines. Standards ensure that material products, processes, and services are fit for purpose. Standards are typically focused on a specific community/user group and region. Examples are international standards (all regions), regional standards (for trading blocks such as the European Committee for Standardization), national standards (American National Standards Institute (ANSI), Deutsches Institut für Normung (DIN), etc.), community standards (Society of Automobile Engineers (SAE)), company standards developed for use within a single organization, and government standards focused on specific national and local government needs and applications. An example of international standards focused on a specific maritime community are those of the International Hydrographic Organization (IHO), which are focused on the safety and efficiency of maritime navigation such as *S-4 Chart Specification of the IHO and Regulations for International Charts* and *S-52 Specifications for Chart Content and Display Aspects of*

ECDIS (Chap. 23). Interaction amongst international organizations plays a major role in greater understanding of roles and functions and promotes technical cooperation which results in greater interoperability. For example, the technical cooperation between International Maritime Organization (IMO) which provides for regulatory carriage of nautical charts through its Safety of Lives at Sea (SOLAS) Convection greatly promotes the enhancement of hydrographic surveys and the dessimination of the data. Similar to a commercial product, to be successful, a standard must be well designed to fulfill its purpose, maintained and kept up to date, and well publicized.

As explained below, standards may be de facto or de jure. De facto standards, defined as *in fact, whether with legal right or not*, are product practices or standard techniques which have become dominant in a market. De facto standards can be unofficial or compulsory (de jure) standards that are dominant in a market when one or more standards exist for the same use. De facto standards exist because they were the first, best marketed, or the simplest path to interoperability. The QWERTY keyboard is an example of a de facto standard. Being designed to be inefficient so that keys would not jam (less frustrating) along with other factors to make the typewriter easy to use (single keys versus dial and key, inked ribbon, and roller bar for loading the paper) and used by the two most popular early manufacturers, it became dominant in the market and is still the de facto standard today, even though better designs have been proposed [13.17].

De jure standards, defined as *by law, legally accepted*, are standards mandated by an organization or nation and usually endorsed by a standards development organization, which are the subject of the sections on standards below.

13.2 Basics of Standards

Although everybody recognizes that standards have become essential in every corner of our life, they are usually considered a dry-as-dust topic that seems to block inspiration and flexibility. Standards are assumed to be a weak compromise between existing and proven solutions developed by dull administrative people.

13.2.1 Characteristics of Standards

In reality, standardization is a real challenge, often comparable to the most sophisticated development projects in the industry. Good standards are simple and unique; for example, Roman letters are in use after more than 2000 years, and they are still able to adapt to almost any language of the world. In contrast, Roman numerals were not that successful as a standard, because the theory behind them was not mature enough. As everybody knows, a numbering system without a zero has limited applications. But once developed, standards are by nature inflexible and there is reluctance to move from one to another.

All of us have gained some experience with standards during our lifetime. An example of a standard is A3 and A4 paper sizes used in most parts of the world, or the letter and legal paper size standards used in America. This kind of standard is helpful, and today, nobody would start arguing about the standard paper sizes.

Another group of examples are file formats. The Microsoft Word *.doc format is well known. Images are often stored or transferred in the tagged image file format (TIFF). We use them regularly, or rather we let our computer use them. These formats have been developed in conjunction with particular computer programs. The *.doc format belongs to the Microsoft Windows word processing system. TIFF was created by Aldus and adopted by Adobe.

A further example of a standard is the ISO 9000 series for quality management. These define a set of rules for investigating the efficiency of quality management in an organization. The ISO 9000 standards are more abstract than the other examples, but they are enormously important economically both for the companies being tested as well as for the accredited companies responsible for their certification.

These examples illustrate the vast and heterogeneous nature of standardization. Standards can be technical or management oriented, detailed or abstract, the result of an international consensus-building process or of a single company's development.

To move closer to the world of standardization, the subject can be viewed from various perspectives.

Linguistic Perspective and Types of Standards

In Medieval Europe, a standard was a flag or sculptured object with the distinctive ensign of a king raised on a pole to indicate the rallying point of an army. It was also used later for the authorized example of a unit of measure or weight [13.18].

- In modern English the word "standard" has a number of different meanings, even within the standardization business: An official standardization organization such as ISO publishes formal standards that have a certain level of relevance in the application domain. Often, this type is called a *de jure* standard. In the French and German languages, the corresponding terms are "la norme" and "die Norm".
- Companies develop industry standards for the purpose of operating their products. These standards are not officially branded unless they put them through the official standardization process. If the standard is well accepted by the user community, it becomes a so-called *de facto* standard.
- In sectors such as the information technology (IT) business and geomatics, consortia of companies agree on common specifications to ensure interoperability. These specifications are also *de facto* standards. However, in recognition of the companies' intention to develop common technical rules, they are called standards from the beginning.

Economic Perspective

The drive for industry to invest in standardization efforts is to benefit from the tremendous financial savings that ensue. A study in the year 2000 proved that the economic advantage of standards for the German industry is 15 billion Euros annually [13.19]. The reasons in detail are

- Standardization avoids the costs of adapting interfaces to a range of applications.
- Participation in the standardization process puts companies ahead of others not participating in the process.
- Standards enable a company to utilize a range of suppliers rather than becoming reliant on a limited number of sources.
- Standards support the legislation process. About 20% of the German standards (DIN) are referenced by laws and by-laws and take the burden of solving detailed technical questions away from the legislative body. In this sense, standardization simplifies the legislation process, as parliament does not have to deal with the subject in full detail. Abstract laws need only refer to the DIN standards that cover the details.

User's Perspective

If a technology is mature, then users expect standardized solutions that are simple, fast, and effective; for example, in 1996 a production company looking for a data exchange format that suited all practical needs for airborne imagery type data initiated the International Society for Photogrammetry and Remote Sensing (ISPRS) working group (ISPRS WG) dedicated to standardization. This user-driven case is a typical starting point for standardization.

After the initiative had started, discussions in the ISPRS WG and other committees revealed that a standard had to be designed in a much broader sense than originally intended.

A well-known format for referencing imagery to the Earth is GeoTIFF. It is a good solution for small-scale or georectified imagery but has some strong limitations. GeoTIFF is based on a well-defined set of TIFF tags. The original idea was simply to extend the set of TIFF tags to meet the requirements of airborne photogrammetry. However, it turned out that a simple definition of additional TIFF tags would only foster a temporary solution, as new sensor types continuously show up on the market. As programming time is expensive, one would not decide for interim solution. A desirable extension of the subject towards generic transformations and general sensor geometries is not possible without having developed an extended theoretical foundation and strategies to adapt the implementation to the latest solutions with minimum effort.

In fact, the modern solutions are model-driven, based on the ISO 19100 standards. The implementation will use the extensible markup language (XML).

System Manufacturer's Perspective

The best solution for a system manufacturer is a closed universe based on the manufacturer's system and without any interfaces to the outside world. Today, this is no longer realistic. Government agencies and other customers have forced manufacturers to open their systems and support standardized interfaces. In a continuously expanding market such as geomatics, it seems that sharing resources with industrial partners can favor the economic growth of a company.

If standardization is pushed towards an implemented solution, the companies not only have to pay for drafting the standard's documentation but also for programming the implementation. This can be expensive. To guarantee a return on investment, companies in the IT business (including geomatics) have opted for joint solutions. The best known example is the Open Geospatial Consortium (OGC).

Development Group's Perspective

A development group, usually called the standardization committee, has to draft a document that contains a solution for the standardization task. The document should also address future challenges, the details of which are often unknown when the development takes place. In this sense, standardization, particularly in the IT domain, is very closely related to the design of computer systems. A lot of money is invested according to the content of a specification, and the better the specification, the longer the investment will be enjoyed.

Choosing the right moment to launch a standard development is probably the most critical decision in the process. If it starts too early, newer industrial developments will overtake the standardization documents. If it starts too late, there might be little room left for standardization among the existing solutions that have established dominant positions.

As standardization generally takes place *after* industry has completed a number of developments, the standardization committee is always confronted with existing solutions, mostly with limited compatibility. Most software companies are not willing to invest in software adaptation, because modification of existing software towards compliance with a new standard is extremely expensive. This has accelerated the creation of industrial consortia in the IT domain, where common industry standards are often defined before the investment in software development starts. The development of a sufficiently generic standard in combination with the ability to define profiles for specific fields of application is a widely used strategy to integrate existing software into new standards. This strategy leads to compatibility at the abstract level but not necessarily at the implementation level. Often, extended compatibility can only be reached with future versions of the application software or with the advent of newer technologies. An example is the extensible markup language as today's *de facto* standard for encoding documents and database contents.

National Perspective

The principles of standardization are: do it once, do it right, and do it internationally. In the IT domain, any national approach is at best a preparation for or a benchmarking of an international solution. A typical example of this process is the history of the European approach to the standardization of geomatics through CEN/TC 287 *Geographic information* (CEN, Comité Européen de Normalisation). This committee became dormant after the ISO/TC 211 started its work, and its members' expertise and knowledge were integrated into the new worldwide committee. However, CEN/TC 287 was reestablished in 2003 to confirm the ISO/TC 211 standards as European legislation.

However, international standards do not mean that national or regional distinctions are overridden. An important subject is the linguistic adaptability of standards. As the English language dominates world business, in particular in the IT sector, it is often difficult to maintain the coherence of a standard-compliant system and a national user interface. Admittedly, this is often a matter of costs (Chaps. 1 and 4).

Differences in traditions are more difficult to solve. The first North American GIS were designed for medium-scale applications. From the beginning, they permitted integration of remote-sensing technology. European systems followed their cadastral tradition, which is more than two centuries old. America thinks in feet; Europe thinks in meters. This causes different viewpoints during the standardization development.

Hierarchy of Standards

Every standard has its typical level of detail that must be agreed upon before work starts. Usually, the IT domain recognizes three levels: abstract, implementation, and interface. Standards at the abstract level are independent of operating systems, applications, hardware, and encodings. Standards at the implementation level determine encoding. Standards at the interface level determine hardware or hardware-oriented software, often called firmware. As a general principle, ISO standards reside at the abstract level. Most industry standards are at the implementation level or the interface level.

Classification Perspective

Table 13.1 demonstrates an alternative approach to open up the subject of standardization. This approach defines a grouping of standards that covers far more than the formal standards addressed by the ISO. In fact, the intent is to be able to include any technical rules applicable in industry and administration. This grouping is hierarchically organized in two levels.

13.2.2 International Standardization Organizations and Consortia

An individual trying to find the standard that is relevant to an application may encounter a large number of

Table 13.1 Classification of standards (after [13.20])

Top level	Bottom level	Explanation
Level of coverage	International Multinational, regional National Local	
Level of prescriptiveness	Recommended practice	Leads to an advisory document
	Information report	Informative document
	Standard	Normative document
Function	Design standards	Focus on user consistency in respect to product structure and appearance. Examples for design standards are zip codes and metadata. They still leave reasonable room for innovation
	Interface standards	Facilitate the interconnection of components or adjoining systems such as communication protocols and plug compatibilities
	Framework standards	These are the foundations of multiple products and services such as the metric system, data dictionaries, and a coordinate reference system
	Performance standards	These are results oriented and do not specify how to do it. Examples are braking distance or pavement service life
	Testing methods	They provide consistent and replicable methods for assuring quality and compliances. Examples are crash tests, conformance testing, and ISO 9000
	Terminology	It creates agreements on what words mean, accelerating contracting and minimizing confusion and conflict
Development process	De facto standards	They arise from market forces. De facto standards are most successful when dominant participants can *dictate* standards, but they also help speed the entry of smaller competitors, especially when standards are open and not proprietary
	Regulatory standards	They are created and enforced by public agencies through rule-making. These standards are best for public safety and health or for situations where economics require system-wide actions such as emission standards for automobiles
	Consensus standards	They are either voluntary agreements or set via standards developing organizations (SDOs) such as ISO

groups and organizations that claim to be competent in the standardization business. At the international level, ISO and OGC are well known to the geographic information community. However, other acronyms such as IEC and ITU (defined below) are less familiar. In addition, the standards community works with a lot of abbreviations, such as TC, SC, JTC, WG, and SIG (defined below), which makes them difficult to read and understand. Nevertheless, once the meaning of the abbreviations is known, they can simplify communication. This section reviews the important groups, explains their terminology, and describes their interrelations.

The groups can be subdivided into two categories: *international organizations* and *international consortia*.

International organizations base their decisions on consensus. By having a budget scheme that allocates the financial burden of the organization to all member countries according to their economic potential, international organizations are fairly independent of the interests of individual governments or industries. Most of the organizations have a long history – some of them are almost 150 years old – although today their work rate is sometimes considered to be too slow for industry needs.

Three international organizations dominate the field of standardization. They are sometimes called the standards developing organizations (SDO): the ISO is the International Organization for Standardization, the IEC is the International Electrotechnical Commission, and the ITU is the International Telecommunication Union.

The members of *international consortia* are drawn primarily from industry, often from government agencies, and universities are occasionally represented. The primary goal of international consortia is to bundle the interests of their members. One of their interests is the development of common standards to advance other developments. Though the standard development is done with the participation of all members, the strong influence of the larger companies cannot be neglected. Though the standards might not be built on a broad consensus, the results are generally technically feasible and foster progress on the subject. They are called industry or *de facto* standards.

The OGC could currently be considered the most important consortium in the geographic information community. Another example of a consortium is the World Wide Web Consortium (W3C). It organizes the work necessary for the development and evolution of a web technology into activities.

13.2.3 Formal International Standardization Organizations

Originally, the three organizations (ISO, IEC, and ITU) had their well-defined fields of activity. The IEC dealt with electrotechnical equipment, the ITU dealt with the radio transmission, and the ISO was responsible for all other subjects. However, today's sectors such as computer science have developed, and the borders between the subjects have become blurred. There are current demands to merge the work of all three organizations into one enterprise.

International Organization for Standardization (ISO)

The International Federation of the National Standardizing Associations (ISA) was founded in 1926, with its primary focus on mechanical engineering. The ISA ceased activities in 1942, owing to World War II. In 1947, the ISO was established as a new nongovernmental organization and continued the work. The ISO Central Secretariat is in Geneva, Switzerland.

People are sometimes confused by the mismatch between the name International Organization for Standardization and the three letters ISO. In fact, ISO is not an acronym, but rather a word derived from the Greek *isos*, meaning *equal*, which points to one of the goals of international standardization. This name is used around the world to denote the organization, thus avoiding the plethora of acronyms resulting from the translation of the full name into many different languages.

The work of ISO is based on three principles.

1. Consensus
   The views of all interested parties are taken into account. This is sometimes referred to as the democracy within the standardization development. In practice, influence in shaping a technical standard is largely restricted to the parties that can afford to pay for their experts to be involved. However, the final vote on a draft for an international standard depends on the agreement of 75% of the voting parties, independent of their activities during the development process.
2. Industry-wide
   The standards will always lead to global solutions that satisfy the needs of industries and customers worldwide. Due to diverse developments in different parts of the world, this principle often leads to a minimum consensus and to abstract-level standards. If worldwide consensus on a specific subject turns out to be impossible, the ISO would then withdraw its involvement.
3. Voluntary
   International standardization is market driven and therefore based on voluntary involvement of all interested parties. If a technical subject requires standardization, the interested parties would approach ISO, asking for guidance on the standardization process. ISO will guarantee compliance with the consensus principle and consistency with other international standards. The development will then receive recognition as an international ISO standard.

Members of ISO. ISO is the umbrella organization for national standardization activities. ISO members are primarily countries, which are usually represented by their respective national standards organizations. Examples of such national bodies are the American National Standards Institute (ANSI), the Standardisation Council of Canada (SCC), and the Deutsches Institut für Normung (DIN).

The national bodies are often unable to provide the complete range of expertise required for standard setting. Therefore, scientists and engineers usually exchange their knowledge within dedicated international organizations such as the International Cartographic Association (ICA) or the International Society for Photogrammetry and Remote Sensing (ISPRS). Companies express their interests through consortia such as the OGC. To incorporate this expertise, ISO has created another membership type called the external liaison organization.

In an effort to maintain consistent standards across committee borders and to avoid duplication of work, formal relations are established among ISO technical committees or subcommittees dealing with similar subjects. Theses relationships are called internal liaisons.

Technical Committees (TCs) and Subcommittees (SCs). The work of ISO is decentralized. While the ISO Central Secretariat is mainly concerned with the development of consistent standards according to the ISO regulations, the actual work is done in the technical committees (TC) and the subcommittees (SC). Every TC and SC has its own secretariat at a competent institution somewhere in the world; for example, the secretariat for ISO/TC 211 *Geographic information/Geomatics* is attached to the Norwegian Mapping Authority near Oslo.

The chairman has a powerful position within the TC, because he decides on the direction of the TC.

The number of members of a TC may range from 10 to 1000. In the case of TC 211, there are presently (2011) about 200 members, who meet about twice a year. In addition, today's communication technology allows almost daily exchange of notices and documents.

A technical committee is subdivided into working groups (WGs) that are usually responsible for the development of an individual standard or similar deliverable of the ISO. If the subject is very broad, the WG may be subdivided into two or more project teams that then become responsible for a single standard; for example, the standard ISO 19115 *Metadata* has been developed by a project team within the ISO/TC 211 WG 7 Information communities.

If a TC becomes very large, it has been found to be advisable to place the work of chairing the committee on more than one pair of shoulders. It is for this reason that the ISO established subcommittees (SCs). A TC may have many, one, or no SCs. It is a matter of power and politics whether a SC is established or not, because the chairman has essentially the same influence as the chairman of a TC.

The TCs and the SCs are standing committees, which enables them to provide the maintenance that a standard requires in a long-term perspective. In contrast, the project teams and working groups are dissolved once a standardization project has matured. The TC and the SC initiate a review of each standard after, at most, a 5 year interval. The outcome of this review may be confirmation, revision, or withdrawal of the standard.

The long-term cooperation of the TC members fosters personal contacts and often leads to new technical ideas. A TC is always open to new members and expertise and can be compared to a large family. At present, ISO has 218 technical committees and about 490 subcommittees (Fig. 13.1).

The ISO/TC 211 has no subcommittees (SC). Other technical committees such as ISO/TC 20 *Aircraft and space vehicles* have some subcommittees that function as another structural level. The technical committees that have been installed more recently tend to avoid subcommittees as this additional structural level.

Standardization Procedure in ISO. The idea for a new standard is always born outside ISO, and the ISO's role is to formalize a method to forward the idea to an internationally approved standard. The steward of the work is a technical committee or a subcommittee. The development process for a standard is subdivided into six consecutive stages.

1. *Proposal stage*. If an industry sector identifies the need for a new standard, then the industry representatives will ask their national standardization organization to send a new work item proposal (NWIP) to ISO. The ISO Central Secretariat assigns this new work item proposal to the most relevant technical committee (TC) or subcommittee (SC) and sends it out for a vote. Only if the majority of the P-members (participating members) of the TC or the SC vote in favor of the new work item proposal and at least five national bodies agree to actively participate in the working group will ISO advance the process. During this stage, the project team is formed and the members reach a consensus about the objectives of the planned standard.
2. *Preparatory stage*. The TC or SC sets up a working group and identifies a chairman referred to as the convener. The working group is asked to prepare a working draft (WD) as a first written summary of the future standard. Successive working drafts may be considered until the working group is satisfied that it has developed the best technical solution to the problem being addressed. At this point, the draft is forwarded to the working group's parent committee for the consensus-building phase. During this stage, the first version of the standard is developed.

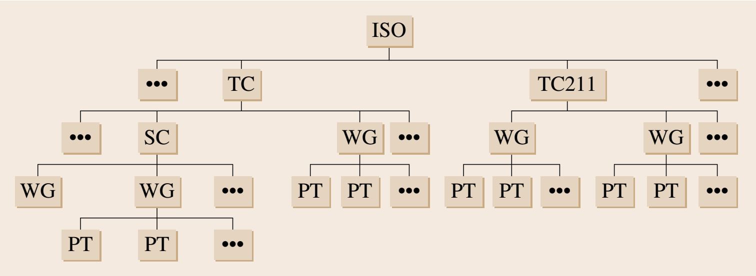

Fig. 13.1 Structure of ISO committees: TC, SC, WG, and project team (PT)

3. *Committee stage*. As soon as a first committee draft (CD) is available, the ISO Central Secretariat registers the document. It is distributed to all members of the TC or SC for comments. Within this stage, the document is reviewed carefully by independent experts who have not taken part in the internal discussions. During this stage, the standard reaches maturity.
4. *Enquiry stage*. In this stage, the document becomes a draft international standard (DIS). Over a period of 5 months, the ISO Central Secretariat circulates the document to all ISO member bodies for voting and comments. It is only approved for submission as a final draft international standard (FDIS) if a two-thirds majority of the P-members of the TC or SC are in favor, and not more than one-quarter of the total number of votes cast are negative. If the approval criteria are not met, the text is returned to the originating TC or SC for further study. During this stage, the standard is aligned with the existing standards of ISO and with other ongoing work.
5. *Approval stage*. The ISO Central Secretariat circulates the FDIS to all ISO member bodies and requests that a final yes/no vote be made within a period of 2 months. Technical comments that are received during this period are not considered, but will be registered for consideration during future revisions of the international standard. The text is approved as an international standard if a two-thirds majority of the P-members of the TC or SC are in favor and not more than one-quarter of the total number of the votes cast are negative. If these approval criteria are not achieved, the standard is referred back to the originating TC or SC for consideration in the light of the technical reasons submitted in support of the negative votes cast. During this stage, the standard has fulfilled all formal ISO requirements.
   In order to meet requirements for acceleration of the formal standardization procedure, the ISO Central Secretariat has started to weaken the rules and eventually publishes a positively voted DIS as an international standard, thus skipping the approval stage, if major comments are not anticipated.
6. *Publication stage*. Once an FDIS has been approved, only minor editorial changes are made to the final text. The ISO Central Secretariat publishes the international standard (IS).

When difficulties are encountered in achieving consensus, the standardization process may take up to 5 years. Many standards are completed just prior to this deadline in order to avoid all the efforts of the team being officially deleted. If the parties still require the standard after the 5 year deadline has passed, then the whole process has to start over again.

Deliverables of ISO**.** The ISO is commonly considered an organization that makes standards or, more precisely, leads to their development and finally publishes them as binding international standards (IS). However, this is only partially true. Firstly, until around 1970, ISO only published international recommendations. Secondly, ISO has defined a reservoir of tools with simpler development procedures than full international standards. These other tools may be taken into consideration if a full international standard is out of scope as a result of slowness, lack of consensus, or simply a different intention such as informative reporting.

The products of ISO are standard documents. They are generally called deliverables. The following list shows all deliverables

- ISO standard.
- ISO/PAS – ISO publicly available specification.
- ISO/TS – ISO technical specification.
- ISO/TR – ISO technical report.
- IWA – international workshop agreement.
- ISO guide.

ISO Standard. An ISO standard is normative. It is assumed that stages 1–3 of the standard development process are completed. In stage 4, the enquiry stage, the ISO Central Secretariat sends out the DIS to all ISO members for vote within a 5 month period. If two-thirds of the voting members (P-members) vote in favor and no more than one-quarter vote against, the DIS is approved. It moves onto stage 5, the approval stage. After integrating comments, the document is issued as a FDIS for a final vote with the same voting procedure as with the DIS, but with a period of only 2 months. If approved, it is published as an IS, with a review of the IS taking place at least every 5 years.

ISO/PAS – ISO Publicly Available Specification. An ISO publicly available specification (ISO/PAS) is also normative. After completion of stage 2 of the standard development, the preparatory stage, the working group must find consensus on the document. A simple majority of the P-members of the TC or SC is then necessary to create an ISO/PAS. An ISO/PAS must be reviewed after 3 years. After 6 years it must be advanced to an international standard or withdrawn.

None of the few examples of ISO/PAS documents is relevant to geographic information.

ISO/TS – ISO Technical Specification. An ISO technical specification (ISO/TS) is normative as well. After completion of stage 3 of the standard development, the committee stage, the document is handed to the TC or the SC. This document is called a committee draft (CD). The TC or SC sends out the CD for vote within a 3 month period. If two-thirds of the P-members vote in favor, the CD is approved as an ISO/TS. An ISO/TS must be reviewed after 3 years. After 6 years it must be advanced to an international standard or withdrawn.

An ISO/TS is a means to make a document official if there is insufficient support for an international standard or if other existing specifications will get the ISO brand.

An example for an ISO technical specification is the ISO/TS 19103 *Conceptual schema language*.

ISO/TR – ISO Technical Report. An ISO technical report (ISO/TR) is informative. At any stage after the approval of a NWIP the ISO Central Secretariat may decide to publish a document as an ISO/TR. The ISO/TR requires a simple majority of the P-members of the TC or SC for approval.

The ISO/TR are essentially of three types.

1. Type 1 for documents which had been intended to become standards but for which the required levels of agreement could not be attained.
2. Type 2 to describe either the directions of standardization in particular fields or in some instances to make an experimental standard available for trial use.
3. Type 3 is for information only.

In the future, the type 1 and type 2 ISO/TR will be published as an ISO/TS. The ISO/TR will be retained purely as informative documents, which were the ISO type 3 technical reports.

An example is the ISO/TR 19121 *Imagery and gridded data*. ISO/TR 19121 is a type 3 report that basically reviews the de facto standards in the field of imagery and gridded data.

IWA – International Workshop Agreement. An international workshop agreement (IWA) is normative. It is an ISO document that is prepared outside the formal structures of ISO such as the TCs. The market players, mostly industries, instead agree upon the IWA in an open workshop environment in fields where ISO has no experts or structures available. The IWA is one of ISO's strategies to accelerate its response to market requirements. The option exists to develop the IWA into a full international standard at a later stage.

ISO Guide. ISO guides provide guidance to technical committees for the preparation of standards, often on broad fields or topics.

Template of an ISO Standard. All ISO standards have the same appearance. They are based on the same document layout to simplify their creation and usage. ISO provides a template for a standard document, which is explained below.

ISO 19105 *Conformance and testing* was the first international standard published of the ISO 19100 family.

An ISO standard document consists of normative and informative pages. The cover sheet, the table of contents, the foreword, and the introduction are called the preliminary elements. The normative pages consist of the scope and the clauses and subclauses. The annexes may be defined as normative or informative.

Cover Sheet. The cover sheet contains the title of the document. All ISO 19100 standards have the introductory element "geographic information" and a main element such as "conformance and testing."

As French is the second language of ISO, all titles are also given in French, such as "*Information géographique – Conformité et essays*."

Table of Contents. Though the table of contents is an optional preliminary element, it is necessary if it makes the document easier to consult.

Foreword. The foreword makes reference to the ISO directives relevant for this standard and to the technical committee responsible for the maintenance.

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Introduction. The optional introduction is an informal description of the contents of the standard. It should enable a new reader to evaluate whether the standard is relevant for a given purpose or not.

Scope. The scope defines, without ambiguity, the subject of the document and the aspects covered, thereby indicating the limits of applicability.

The scope shall be succinct, so that it can be used as a summary for bibliographic purposes.

The scope has to be approved by the plenary of the technical committee or subcommittee in order to align the fields of work of all standards of the family.

Conformance. The conformance clause is only required in some standards in the information technology field. This clause shall enable a user to test a product for compliance with the ISO standard.

Normative References, Terms and Definitions, Symbols, and Abbreviated Terms. The normative references clause provides a list of the referenced documents cited in the document in such a way as to make them indispensable for the application of the document.

The terms and definitions clause refers to the terminology of the standard. In families of standards such as ISO 19100, it is recommended that one keep track of the terminology of all member standards of the family as a whole.

The symbols and abbreviated terms clause is completed as far as necessary for understanding the standard.

Basic Elements. The basic elements contain the provisions of the standard. They are ordered in clauses, subclauses, and paragraphs.

Annexes. Annexes are either normative or informative.

Normative annexes have the same relevance as a chapter in the main body of the standard. While drafting a standard document, it is often a matter of style how to distribute the basic clauses or the annexes. Often it supports readability to keep the basic clauses short and to keep major portions of the content in the annexes.

Informative annexes give additional information intended to assist in the understanding or use of the document.

A complete description of the types of clauses that can be used in an ISO standard can be found in [13.21].

International Electrotechnical Commission (IEC)

The IEC is the global organization that prepares and publishes international standards for all electrical, electronic, and related technologies. The IEC was founded in 1906. It is a nongovernmental organization with its central office in Geneva, Switzerland. At present (2011), the IEC has 60 member countries and 21 associated member countries.

IEC and ISO follow almost identical standardization procedures, with standards built on consensus among the interested parties, worldwide solutions, and voluntary initiatives. In general, the IEC uses the same terms for the six stages leading to an international standard: proposal stage, preparatory stage, committee stage, enquiry stage, approval stage, and publication stage.

ISO/IEC Joint Technical Committee 1 (JTC1)

The ISO and the IEC were founded by the mechanical engineering and electrical engineering communities, respectively. Although the separation of the two organizations might have been logical at one time, the era of computers required joint efforts involving both organizations. In 1987, the joint technical committee 1 (JTC1) was created to provide a single, comprehensive standardization committee that addressed international information technology standardization.

Recently, a second joint technical committee was created: JTC2, entitled Joint Project Committee – Energy efficiency and renewable energy sources – Common terminology.

International Telecommunication Union (ITU)

Founded in 1866, the ITU administers the worldwide use of radio frequencies and satellite orbits. It is the oldest of the three large standards developing organizations. As the ITU is an international organization within the United Nations (UN) system, it represents all countries in the world, presently numbering 193. The Secretary General is located in Geneva, Switzerland.

The ITU is subdivided into three sectors: the radiocommunication sector (ITU-R), the telecommunication standardization sector (ITU-T), and the telecommunication development sector (ITU-D).

The activities of the telecommunication standardization sector mainly lead to standardization for network hardware and network protocols. The work is distributed to a number of study groups. The ITU has recently introduced an *alternate approval procedure* that enables a standardization procedure as fast as 9 months between the start with a stable technical document and the final ballot. The deliverables are recommended standards for international use. As the UN is a treaty organization, the recommended standards immediately become national laws in many countries.

Access to Standard Documents

All deliverables and additional publications can be bought from the ISO, the IEC, and the ITU. The deliverables of the ISO/IEC JTC1 are available through the ISO and the IEC channels.

All standards and other deliverables are available in paper. A growing number of documents can also be ordered as CD-ROM or downloaded as a portable document format (PDF) file. The online accessed files are watermarked. The shipping of paper documents and CD-ROMs takes a few days only.

The details of the ordering procedure are published on the homepages of the three standards developing organizations. The sections are called ISO Store, IEC Webstore, and ITU publications, respectively.

13.2.4 ISO 9000 Family of Standards

In nontechnical areas, ISO is often considered as a synonym for ISO 9000 quality management systems. The ISO 9000 family of standards sets rules for the efficient structure of the internal workflow of an enterprise. These standards can apply to any type and size of company or institution. Being certified according to ISO 9000 has become an important factor in competition for markets.

Being ISO 9000 certified does not necessarily reflect on the quality of a company's products. It only proves that the internal workflows and their links to customers and suppliers were near optimal when the audit took place. The major challenge to a company remains its success in the market, and is dependent on many factors including expertise of the personnel, sufficient capital, or good service.

Numbering of the ISO 9000 Family of Standards

There are several individual standards in the ISO 9000 family, and adding to the confusion, the numbering system was changed in the year 2000. Therefore, the formalities are explained first, followed by the concepts of the standard.

The version of ISO 9000 that is presently valid was published in the year 2000. The previous version was published in 1994. The version of an ISO standard is shown by the year set after the standard number, for example, ISO 9000:2005.

ISO 9000:2005 *Quality management systems – fundamentals and vocabulary* is a basic document for the whole ISO 9000 family of standards.

ISO 9001:2008 *Quality management systems – requirements* provides a comprehensive list of regulatory requirements needed to assess the ability of a company to meet customer satisfaction. This standard is the only one of the ISO 9000 family against which third-party certification can be carried out.

ISO 9004:2009 *Managing for the sustained success of an organization – a quality management approach* provides advice and hints for continuous improvement of management quality within a company or institution.

ISO 19011 *Guidelines on quality and/or environmental management systems auditing* provides a guideline to the verification of a system's ability to achieve defined quality objectives. It might be used internally or for auditing suppliers.

Many other ISO standards deal with aspects of quality management. Examples include project management, measuring equipment, manuals, economics, training, and the automotive industry. Further details can be found in the bibliography and on the ISO Internet homepage.

A major change from the 1994 edition of the ISO 9000 standards to the 2000 edition is the reduction of the number of individual standards. The present ISO 9001:2008 includes the old ISO 9001:1994, the old ISO 9002:1994, and the old ISO 9003:1994. Figure 13.2 explains the relation of the standard numbers of the two editions [13.22–26].

ISO Technical Committee 176

The standardization body responsible for the development of the ISO 9000 family of standards is ISO/TC 176 *Quality management and quality assurance*. At present, the secretariat is in the USA. In addition to its responsibility for the ISO 9000 family, ISO/TC 176 has been entrusted by the ISO/Technical Management Board with the function of consultant to all ISO technical com-

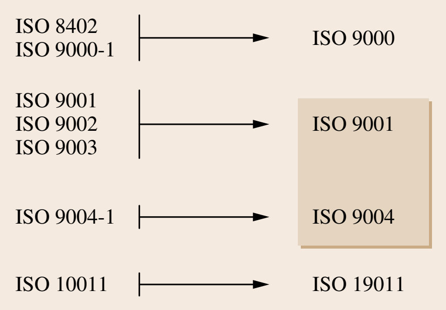


Fig. 13.2 Relation of ISO 9000 standards 1994 edition to ISO 9000 standards 2000 edition and later. The *left-hand* side lists the standards of the 1994 edition, and the *right-hand* side lists the standards of the 2000 edition. The *arrows* indicate which standards were combined to reduce the overall number of related standards

mittees in the application of quality management and quality assurance. This is to ensure the integrity of the generic quality system standards and to prevent proliferation of sector-specific ISO quality systems standards that may lead to fragmentation of the quality systems of companies in multiple assessments and thus to increased costs. The technical management board is the central technical planning and steering committee of ISO.

Concepts of the Quality Management System

The implementation of a quality management system at company or institution level is described in detail in the ISO 9000 family of standards.

- Stage 1: Identify what others expect from the company or institution.
  - Customers and end users
  - Employees
  - Suppliers
  - Shareholders
  - Society
- Stage 2: Determine the processes that are needed to supply products to the customers.
  - Customer-related processes
  - Design and/or development
  - Purchasing
  - Product and service operations
  - Control of measuring and monitoring devices
- Stage 3: Plan to close the gaps.
  - Identify actions
  - Allocate resources
  - Assign responsibilities
  - Establish a schedule
- Stage 4: Carry out the plan.
  - Implement the identified actions
  - Track the progress against the schedule
- Stage 5: Conformance = certification and/or registration

At this stage, a company or institution may engage an accredited registration/certification body to perform an audit and certify that the quality management system in place complies with the requirements of ISO 9001:2008. The reasons for a paid independent audit are generally

- requirement of a contract with a customer,
- market position,
- regulatory requirements,
- risk management,
- internal goals.

Unless an audit is performed, the results may only be used internally.

The concept of the ISO 9000 family of standards provides a long-term perspective on improvements to the effectiveness and suitability of quality management systems. ISO 9004:2009 provides the methodology for this continuous effort.

13.2.5 Cultural and Linguistic Adaptability

The language used in a standard is an essential user requirement, as “Web users stay twice as long and are three times as likely to buy from sites presented in their native language” [13.27] (Gartner Group).

Technically speaking, interoperability means the ability of heterogeneous datasets to function jointly and to give access to their resources in a reciprocal way. Semantic interoperability includes multilingual interoperability. Semantic interoperability is defined as the ability of a user to fully understand the data received in a data exchange in order to be able to make full use of those data if needed.

ISO/TC 211 has recognized this important user requirement by adopting the principles of cultural and linguistic adaptability (CLA), which has been defined as follows by the ISO/IEC JTC 1 [13.28, 29]:

Cultural and Linguistic Adaptability is the ability of a product, while keeping its portability and interoperability properties,

- to be internationalized, that is, be adapted to the special characteristics of natural languages and the commonly accepted rules for their use, or of cultures in a given geographic region;
- to fully take into account the needs of any category of users.

The term *internationalization* is defined as the process of producing an application platform or application that is easily capable of being localized for (almost) any cultural environment. Examples of characteristics of natural languages are: national characters and associated elements (such as hyphens, dashes, and punctuation marks), writing systems, correct transformation of characters, dates and measures, sorting and searching rules, coding of national entities (such as country and currency codes), presentation of telephone numbers and keyboard layouts. Related terms are localization, jurisdiction, and multilinguism [13.30].

Cultural and linguistic adaptability should therefore be viewed in a wider sense than only translating an ISO standard to a specific human language.

Table 13.2 Example for cultural and linguistic equivalencies of the word "potato" (after [13.31])

Identifier (World Customs Organization)	Country code (ISO 3166-1)	Cultural and linguistic equivalencies (three-letter code from ISO 639-2)
HS: 0701	484 (Mexico)	(esp): papa
HS: 0701	724 (Spain)	(esp): patata
HS: 0701	124 (Canada)	(eng): potato (fra): pomme de terre

In the field of metadata, the following strategies are suggested to address cultural and linguistic adaptability requirements. ISO/TC 211 has primarily implemented the methods in ISO 19115 *Metadata* and ISO 19135 *Procedures for item registration*.

1. The use of an identifier as a pivot between linguistic equivalencies
   An identifier is defined as a sequence of characters, capable of uniquely identifying that with which it is associated, within a specified context. A name should not be used as an identifier because it is not linguistically neutral [13.32].
   The standard ISO 19135 *Procedures for item registration* will ease the use of identifiers by establishing registers. The following example (Table 13.2) shows the identifier HS:0701 that is used as a pivot between linguistic equivalencies in the Spanish, English, and French languages. The Spanish language includes cultural equivalencies between Spain and Mexico.
2. The use of code lists instead of free-text lists of permissible values
   Code lists shall be used instead of free-text lists wherever possible.
   The example from ISO 19115 illustrates the use of code lists. The metadata element *maintenance frequency code* serves as the pivot between human-language equivalencies (Table 13.3).
3. Handling human languages adequately in free-text fields.

13.2.6 Requirements for Future Developments of Standards

Standards exist to make life easier, safer, and less costly. Industry has speeded up its innovation cycle, but the development of standards still follows procedures defined 50 or 100 years ago. Today, many standard users are concerned about the present shape of the universe of international standardization.

A good standard is the sum of its many individual parts, some of which may be difficult to achieve. The most important properties are

- a standard has to be ready when it is needed,
- a standard has to be relevant to the market,
- a standard has to add value to a business and help save money,
- an international standard has to be applicable worldwide,
- a standard has to be compatible with other standards in the subject area,

Table 13.3 Code list for maintenance frequency code

Name	Domain code	Definition
MD_Maintenance FrequencyCode	MaintFreqCd	Frequency with which modifications and deletions are made to the data after it is first produced
continual	001	Data are repeatedly and frequently updated
daily	002	Data are updated each day
weekly	003	Data are updated on a weekly basis
fortnightly	004	Data are updated every **2** weeks
monthly	005	Data are updated each month
quarterly	006	Data are updated every **3** months
biannually	007	Data are updated twice each year
annually	008	Data are updated every year
asNeeded	009	Data are updated as deemed necessary
irregular	010	Data are updated in intervals that are uneven in duration
notPlanned	011	There are no plans to update the data
unknown	998	Frequency of maintenance for the data is not known

- the standards relevant to the subject have to be consistent.

To ensure that the international standardization process fulfills its intended purpose, some members of the user community are demanding fundamental changes of the structure and the procedures of the standards organizations [13.33].

- The three big standards developing organizations (ISO, IEC, and ITU) should avoid overlapping work and pool resources such as administration, publishing, and marketing.
- The development of new standards must be completed within a maximum of 3 years in order to keep pace with industry's innovation cycle. The technical experts of the industry should have a stronger influence in the working groups, replacing the old-fashioned rule of allowing only official representatives.
- The standardization terminology contains an overwhelming number of structural units, document types, document resources, membership statuses, etc. These terms need to be simplified and harmonized to enable users to understand standardization abbreviations more easily.

The standardization of geographic information is heavily influenced by the existing structures and procedures of ISO. Any further work on the geographic information standards should take into consideration the ongoing discussions about fundamental changes of ISO, IEC, and ITU. A few years ago, the maximum time allowed for the development of an ISO standard was reduced from 7 to 5 years.

13.3 Geomatics Standards

The reader will be familiar with GIS and will think in terms of the GIS with which he or she has gained experience. Some might think in terms of digital maps that are available on the Internet and others in terms of their areas of responsibility: property cadastre, environmental applications, or fleet management systems. Another important applications might be disaster management, where a GIS can help save lives if rescuers receive an almost immediate and detailed picture of the environment of the disaster location.

This section deals with the standardization of geomatics. Worldwide standardization of geomatics is not simple, because an enormous number of entirely different applications are served by GIS techniques. For instance, applications can range from city maps delivered on a CD to global climate monitoring. Geomatics applications run on a single workstation or access thousands of computers connected in a network. Overall, a GIS consists of a number of rather independent modules serving data capture, data storage, or data exchange, to mention a few.

The reader might think that some kind of a typical GIS should become an international standard. This would make the work easier, because all *standard GIS* would have a similar shape in terms of their core components. Most users demand standardized data exchange formats, because problems with data transfer are well known.

ISO standards are developed with a long-term perspective. Most of them are written at an abstract level to guarantee long-term stability. In contrast, developments in the geomatics domain continue to make fast progress. Some of the ISO standards for geomatics are implementation oriented, even though this is not the first priority of the ISO/TC 211 work.

13.3.1 History of Geomatics Standards

Standardization of computer graphics began in the 1970s, but standardization of geographic information did not begin until approximately 1990. Both efforts originated in Europe.

First Generation

The first ISO standard in computer graphics was ISO/IEC 7942 *GKS Graphical Kernel System*. The development began with a workshop at Chateau Seillac in France in 1976, and the standard was published in 1985. GKS is a generic standard for two-dimensional vector graphics, independent of operating systems, programming languages, and output devices. Language bindings for four important programming languages then followed. GKS has been used in a number of systems and can be considered successful. However, even at the time GKS was published, some of its elements still performed too slowly for larger volumes of mapping data.

During the following years, GKS was extended to include the third dimension. Because of differing philosophies on the development ISO resulted

Table 13.4 ISO/IEC JTC1 subcommittees relevant for computer graphics and geographic information technology

ISO/IEC JTC1/SC24 *Computer graphics, image processing, and environmental data representation*	GKS, GKS-3D, PHIGS, CGM, CGI, PNG (portable network graphics), VRML (virtual-reality modeling language), BIIF (Basic Image Interchange Format)
ISO/IEC JTC1/SC32 *Data management and interchange*	SQL/MM (Structured Query Language/Multimedia)
ISO/IEC JTC1/SC34 *Document description and processing languages*	SGML (Standard Generalized Markup Language) HTML (Hypertext Markup Language)

in two incompatible new standards being published. The European solution, ISO 8805 GKS-3D, was upwardly compatible with ISO/IEC 7942 GKS, while the US-supported solution, ISO/IEC 9592 *PHIGS Programmer's Hierarchical Interactive Graphic System*, was an independent development. GKS-3D and PHIGS share a common core of concepts but they differ in the handling of display lists. GKS-3D supports a linear segment storage concept, while PHIGS supports a hierarchical store.

To complete this picture, two other first-generation standards must be mentioned: ISO/IEC 8632 *CGM computer graphics metafile* and ISO/IEC 9636 *CGI computer graphics interface*. Both of these standards share the same concepts such as primitives and attributes that are currently used in many areas. CGM was used directly as output, but with the advancement of technology, Postscript, Printer Command Language (PCL), and now Scalable Vector Graphics (SVG) would be the currently preferred expression language. This is also the reason why the CGI-level interface is now internal to boards.

These standards are no longer used for new developments, because some legitimate uses that would commonly be thought of as computer graphics are not addressed. Amongst these are

- *Image processing applications*. The successful processing of images was not commonplace before the wide availability of raster devices.
- *Window management*. Graphics standards were developed at a time when the full physical resources on each display would be available to a single application, whereas today, window management systems are based on dynamic partitioning of a set of resources among tasks.
- *High-quality typesetting*. The quality of text facilities available on modern systems far exceeds those expected to be widely available in the original timeframe of the standard's development. Consequently, the text facilities are neither simple enough for convenient use by a novice, nor sufficiently sophisticated for control of high-quality typesetters [13.34].

Graphic Format Standards

The working groups on the computer graphics standards are affiliated to the ISO/IEC JTC1, the Joint Technical Committee 1 of ISO and IEC. ISO/IEC JTC1 addresses international information technology standardization that is on the borderline between the traditional ISO and IEC fields of work. ISO/IEC JTC1 is subdivided into a number of SCs whose work has resulted in a large number of standards, most of which are well known, but which are rarely related to the work of ISO and IEC. Table 13.4 lists the SCs that are relevant for computer graphics and geographic information technology and some of the standards they have developed.

For further details about ISO/IEC JTC1 see Sect. 13.6.1.

Beginning of the Standardization of Geographic Information/Geomatics

Europe has long-established traditions in the development of standards for cadastre, cartography, and environmental protection. Following these traditions, the first project to standardize geographic information started in Europe in 1991. Led by the Association Française de Normalisation (AFNOR), the national standards body of France, the European standardization organization CEN created its Technical Committee 287 *Geographic information*. The work of CEN/TC 287 resulted in eight European prestandards. The successful conceptual developments were integrated into the larger body of ISO a few years later. The work of CEN/TC 287 originally contained a full range of nearly 20 standards. Facing the upcoming establishment of ISO/TC 211 in 1994, and to avoid duplicate work, CEN/TC 287 ceased its activities and went into a dormant state until 2003.

Table 13.5 identifies the eight European prestandards and the two CEN reports for geographic

Table 13.5 Prestandards and other deliverables of CEN/TC 287 before the dormant phase

ENV 12009	Reference model
ENV 12160	Data description – spatial schema
ENV 12656	Data description – quality
ENV 12657	Data description – metadata
ENV 12658	Data description – transfer
ENV 12661	Referencing systems – geographic identifiers
ENV 12762	Referencing systems – direct position
prENV 13376	Rules for application schema
CR 13425	Overview
CR 13436	Vocabulary

ENV = European prestandard,
prENV = draft European prestandard,
CR = CEN Report

information before 1994. Their titles read as an abstract of the standards later developed by ISO/TC 211 *Geographic information/Geomatics*. Many CEN documents were used as draft standards of ISO, and many of the CEN experts continued their work in ISO/TC 211.

Some of the above-mentioned prestandards had evolved into CEN standards before they were downgraded to CEN prestandards in order to avoid competition with the ISO/TC 211 results.

The demise of CEN/TC 287 is not typical of CEN technical committees. Since the unification of the continent, the importance of European standards in other subject areas has grown, and standardization is now a priority.

The European Union is in the process of developing a spatial data infrastructure (SDI) named the Infrastructure for Spatial Information in Europe (INSPIRE), which is a project of the Environment Directorate-General (DG), the Eurostat DG (statistics), and the Joint Research Centre, the DG for research. A Directorate-General is a central administration level that is directly subordinate to the government of the European Union, the European Commission.

The INSPIRE project led to a revival of the CEN/TC 287 activities with the goal of developing a European profile of the ISO 19100 standards for geomatics. The formal background for this project is the new edition of a cooperative agreement between ISO and CEN known as the 2001 *Vienna agreement*. This agreement enables close formal cooperation between the two standardization organizations in order to avoid duplicate work.

Table 13.6 lists the profile of the ISO geomatics standards that have been approved by CEN/TC 287 since its revitalization. This profile is focused on the standards required for building the INSPIRE project. Typically, the European version of the ISO standards follows 1 or 2 years after the publication of the ISO standards.

13.3.2 ISO/TC 211

History and Work of ISO/TC 211

The driving forces behind the establishment of ISO/TC 211 were the North Atlantic Treaty Organization (NATO) Defence Geospatial Information Working Group (DGIWG) and the national standards efforts in the USA and Canada. The other two organizations that contributed experiences in the standardization of geographic information were the International Hydrographic Organization (IHO) and CEN/TC 278 *Road transport and traffic telematics*. CEN/TC 287 *Geographic information* had an established program of work that essentially became the plan for the ISO/TC 211 base standards. It was the DGIWG that originally proposed the formation of ISO/TC 211, and because it was procedurally easier to have a nation make the proposal, Canada made the proposal in 1994.

Both the original CEN work and the DGIWG work were closer to the implementation level than the current ISO/TC 211 standards. Over time, the ISO standards have become more abstract base standards that require profiles and implementation specifications in order to be put to use.

With the establishment of ISO/TC 211, a joint worldwide effort to standardize geomatics began. In particular, ISO/TC 211 integrated the European and North American experiences with other regions of the world including Asia, Australia, and South Africa, which have since joined the committee.

Scope. The objective of the work of ISO/TC 211 is to establish a set of standards for geographic information/geomatics. The standards would specify an infrastructure and the required services for handling geographic data, including management, acquisition, processing, analysis, access, presentation, and transfer. Where possible, the standards would link to other appropriate standards for information technology and provide a framework for the development of sector-specific applications [13.35].

Structure. An ISO technical committee consists of the chairman, the members, the working groups, some advisory groups, and eventually some subcommittees.

Table 13.6 Standards and other deliverables of CEN/TC 287, 2003–2011 (EN = CEN-standard)

EN ISO 6709:2009	*Standard representation of geographic point location by coordinates* (ISO 6709:2008)
CEN/TR 15449:2006	*Standards, specifications, technical reports, and guidelines, required to implement spatial data infrastructure*
EN ISO 19101:2005	*Reference model* (ISO 19101:2002)
EN ISO 19105:2005	*Conformance and testing* (ISO 19105:2000)
EN ISO 19106:2006	*Profiles* (ISO 19106:2004)
EN ISO 19107:2005	*Spatial schema* (ISO 19107:2003)
EN ISO 19108:2005	*Temporal schema* (ISO 19108:2002)
EN ISO 19109:2006	*Rules for application schema* (ISO 19109:2005)
EN ISO 19110:2006	*Methodology for feature cataloguing* (ISO 19110:2005)
EN ISO 19111:2007	*Spatial referencing by coordinates* (ISO 19111:2007)
EN ISO 19112:2005	*Spatial referencing by geographic identifiers* (ISO 19112:2003)
EN ISO 19113:2005	*Quality principles* (ISO 19113:2002)
EN ISO 19114:2005	*Quality evaluation procedures* (ISO 19114:2003)
EN ISO 19115:2005	*Metadata* (ISO 19115:2003)
EN ISO 19115-2:2010	*Metadata – Part 2: Extensions for imagery and gridded data* (ISO 19115-2:2009)
EN ISO 19116:2006	*Positioning services* (ISO 19116:2004)
EN ISO 19117:2006	*Portrayal* (ISO 19117:2005)
EN ISO 19118:2006	*Encoding* (ISO 19118:2005)
EN ISO 19119:2006	*Services* (ISO 19119:2005)
EN ISO 19123:2007	*Schema for coverage geometry and functions* (ISO 19123:2005)
EN ISO 19125-1:2006	*Simple feature access – Part 1: Common architecture* (ISO 19125-1:2004)
EN ISO 19125-2:2006	*Simple feature access – Part 2: SQL option* (ISO 19125-2:2004)
EN ISO 19126:2009	*Feature concept dictionaries and registers* (ISO 19126:2009)
EN ISO 19128:2008	*Web Map Server interface* (ISO 19128:2005)
EN ISO 19131:2008	*Data product specifications* (ISO 19131:2007)
EN ISO 19132:2008	*Location-based services – Reference model* (ISO 19132:2007)
EN ISO 19133:2007	*Location-based services – Tracking and navigation* (ISO 19133:2005)
EN ISO 19134:2008	*Location-based services – Multimodal routing and navigation* (ISO 19134:2007)
EN ISO 19135:2007	*Procedures for item registration* (ISO 19135:2005)
EN ISO 19136:2009	*Geography Markup Language (GML)* (ISO 19136:2007)
EN ISO 19137:2008	*Core profile of the spatial schema* (ISO 19137:2007)
EN ISO/TS 19139:2009	*Metadata – XML schema implementation* (ISO/TS 19139:2007)
EN ISO 19141:2009	*Schema for moving features* (ISO 19141:2008)
EN ISO 19142:2010	*Web Feature Service* (ISO 19142:2010)
EN ISO 19146:2010	*Cross-domain vocabularies* (ISO 19146:2010)

The chairman, elected by the members of ISO/TC 211, is Olaf Østensen from the Norwegian Mapping Authority.

The members are the national members and liaison members. The *national members* are represented by the authorized standardization organizations of the respective member country, also called the *national body*. Normally the national bodies are *participating members* (P-members) with full voting rights, while others are *observing members* (O-members) with observer (nonvoting) status only. The liaison organizations are domain specific, worldwide or regional organizations that can contribute expertise to the standardization process. Examples of non-ISO organizations (referred to as *external liaison members*) are the Open Geospatial Consortium and the International Hydrographic Organization. *Internal liaison members* are other ISO or IEC committees, such as ISO/TC 204 *Intelligent transport systems*, that also have interests in geographic information.

Representatives from liaison organizations are invited to take part in the discussions and can receive all information on the standardization project, but are not granted voting status.

The working groups (WGs) form part of the ISO/TC 211 hierarchical structure, and as the name implies, they are the place where the standards are actually drafted. Until 2001, ISO/TC 211 had WGs 1–5; after the work of WGs 1, 2, 3 and 5 finished in 2001, WG 4 remained and WGs 6, 7, 9, and 10 were created. The WGs combine a number of individual standardization projects related to a common topic, such as WG 4 Geospatial services.

The technical committee creates advisory groups for special purposes such as the advisory groups on strategy and on outreach. Such groups analyze the current and future requirements for geomatics standardization and draft proposals to the technical committees on how to proceed. The advisory groups do not belong to the working groups; they are directly responsible to the technical committee and support the chairman. The technical committee has also created four maintenance groups that care for issues of the committee as a whole. The Programme Maintenance Group (PMG) evaluates every new standardization project for its consistency with the already developed family of geomatics standards. The Terminology Maintenance Group (TMG) maintains an often-updated spreadsheet of all terms and symbols to prevent ambiguous definitions within the ISO 19100 family of standards. The Harmonized Model Maintenance Group (HMMG) is working on the integration of all partly incompatible models of the ISO 19100 standards. The XML Maintenance Group (XML MG) supports the project teams in using the XML consistently when drafting the standards documents.

ISO/TC 211 has no subcommittees (as of April 2011).

Statistics. The work of ISO/TC 211 can be described in the following numbers (April 2011).

- ISO deliverables
  - Total of about 60 standardization projects
  - About 45 international standards (IS) completed.
  - About 10 standardization projects in the stages of draft international standard (DIS) or final draft international standard (FDIS).
  - 2 technical reports (TR).
  - 1 review summary (RS).
  - About 5 standardization projects withdrawn.
  - Presently about 30 projects active.
  - 1st international standard: ISO 19105:2000 *Conformance and testing*.
  - 1st technical report: ISO/TR 19121:2000 *Imagery and gridded data*.
- Members
  - 32 P-members;
  - 31 O-members;
  - 31 external liaison members:
  - 15 internal liaison members;
  - 3 relations to CEN technical committees (Europe);
  - 2 advisory groups and 7 other groups;
  - About 600 individuals involved since 1994.
- Meetings
  - 31 plenary meetings until April 2011.

Program of Work. In 1994, ISO/TC 211 started with only 20 standardization projects. These formed a suite of base standards for geographic information and thus made the technical committee a coherent and powerful group. Some experts consider these abstract base standards as the original obligation of ISO/TC 211. The base standards included the reference model, feature definition, spatial and temporal schema, coordinate reference system, portrayal, encoding, quality, and metadata, to mention the most important ones. The majority of the base standards have reached a final stage of development.

ISO/TC 211 is presently undergoing significant changes in order to meet the challenges of the future (Fig. 13.3).

1. Since the completion of the base standards, interest has been focused on their implementation in real-world systems. Admittedly, implementation issues are outside the scope of ISO, but they are the only way of proving the viability of the original abstract development. It has been recognized that the field of geographic information is so heterogeneous that the base standards are not always able to fully meet the requirement for a generic and consistent approach that is expected from an ISO suite of standards. Their implementation produces the necessary feedback to optimize the base standards. The cooperation of the OGC is of particular importance for the implementation issues, because some of their implementation-type standards, such as the GML, have become ISO standards.
2. Emerging technologies have started to widen the original scope of ISO/TC 211. The industry now expects a tremendous growth in the mar-

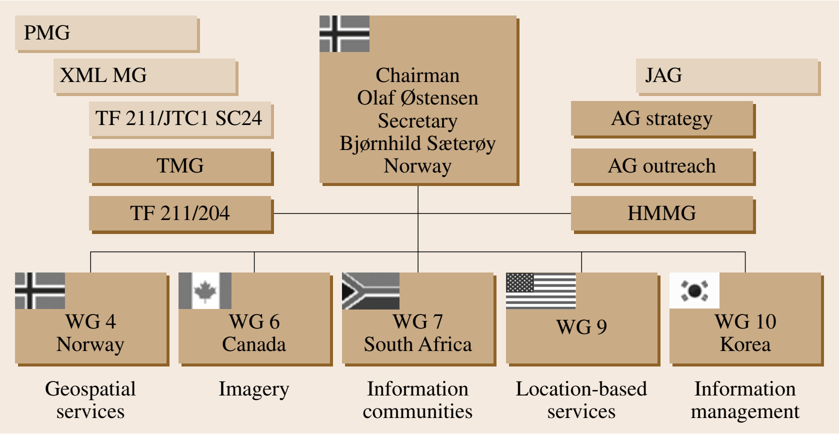


Fig. 13.3 Structure of ISO/TC 211 (status 2011) (after [13.35]). TF 211/JTC1 SC24 = Task Force ISO/TC 211 – ISO/IEC JTC1 SC24; TF 211/204 = Task Force (ISO/TC 211 – ISO/TC 204); JAG = ISO/TC 211/OGC joint advisory group; AG strategy = advisory group on strategy; AG outreach = advisory group on outreach; WG *x* = working group *x*

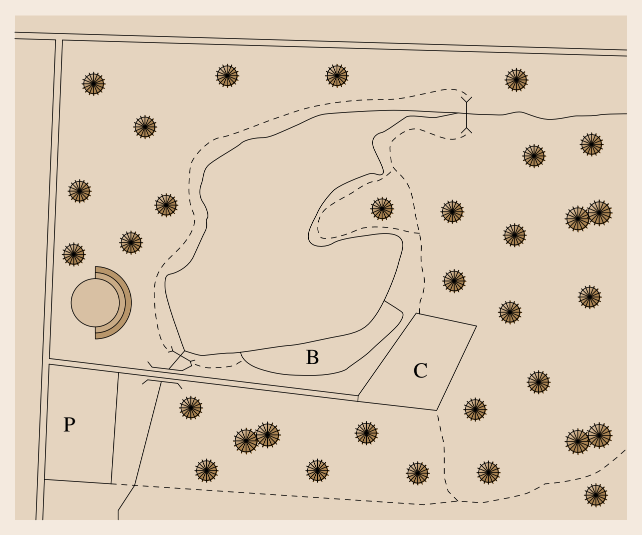


Fig. 13.4 Example of a tourism GIS (B = beach, C = campground, P = parking)

ket for location-based mobile services as well as four-dimensional data and prediction modeling in the near future and is pushing for standardization at the boundaries of geographic information, general databases, and mobile positioning systems.

3. The base standards only focused on vector geometries, as the field of gridded data – digital images, coverages, and elevation models – seemed too large and unknown to be included in the first attempt at geomatics standards. The projects on imagery standards started in 2001.

The new direction of ISO/TC 211 is formally reflected in the reorganization of the WGs. The only remaining original group is WG 4 Geospatial services. The titles of the new WGs are WG 6 Imagery, WG 7 Information communities, WG 9 Information management, and WG 10 Ubiquitous public access.

So far, the majority of the standards of the ISO 19100 family have been published as international standards. However, most of the standardization projects of ISO/TC 211 will be completed in the near future. Therefore, all standardization projects are addressed as ISO standards in this chapter.

Example of an ISO-Compliant GIS

This section provides a basic understanding of the interrelation between the standards of the ISO 19100 family. This understanding is communicated via a small tourism information GIS. This GIS is decomposed from the programmer's perspective in order to relate every component to an individual ISO 19100 standard and to explain which details are standardized and which details are outside the scope of ISO 19100.

Characterization of the Example GIS. The example is a tourism GIS, as shown on the map in Fig. 13.4. It contains topographic data such as the lake, the woods, and the roads. It also contains thematic data such as the delineated trails as hiking trails and the opening hours of the theater. The map is a partial representation of the data and their structure. The map shows only the graphics. The other data might be shown by another type of map or by an interactive program on the computer screen.

The following paragraphs summarize other information that belongs to the GIS *alphanumerically*. These data are typical for this kind of GIS.

A company called Tourism-GIS-Association may be responsible for any aspect related to the example GIS.

The GIS data, such as the topographic base map and the information center for the local community, have different origins; for instance, the geometry, including information content, may have been copied from a topographical base map. The state mapping authority provided additional information about the last revision date and the geometric accuracy of the data. The local community may have supplied the delineation of some of the trails as official hiking trails and the opening times of the campground and the theater.

From the programmer's point of view, the GIS may be decomposed into the components of data capture, data storage, and data display. In the tourism GIS, the data capture has been completed by introducing the various components from other resources as mentioned above. We can assume that no extra data were surveyed in the field for use in the GIS.

A database will be used for data storage. The data are not simply lines as shown on the map, but rather are grouped into so-called objects, such as the theater. Additional data, such as the opening hours, can be linked to this object. Another object is the lake, including its shoreline. The objects themselves consist of points, curves, and surfaces and are defined by their coordinates. The mosaic of all objects with the graphic type surface is equal to the complete area covered by the GIS.

A data editing component of the tourism GIS could include a user-accessible function to compute, for example, the approximate lengths of the hiking trails. The user may have to click on the graphics of the trail to cause the system to display the trail's length.

The functionality of the data display component is the shown map. In a general sense, the display is controlled by a reference table that relates every type of object to a graphic representation, such as two parallel lines for roads.

Relation to the ISO 19100 Standards. The ISO 19100 family of standards does not form a complete and hierarchical model for the whole universe of geographic information. The standards are more a collection of independent abstract standards for creating and managing GIS. Most standards are only loosely linked.

In the terminology of the ISO 19100 standards, the tourism GIS is an application schema. ISO 19101 *Reference model* defines the components of an application schema, as shown in Fig. 13.5.

Data Capture. ISO does not standardize the data capture procedures for a GIS. The ISO 19100 standards only provide guidelines and metadata elements to describe the origin and quality of the data. The relevant standards are ISO 19157 *Data quality* and ISO 19115 *Metadata*.

The following paragraph provides a detailed relation of the tourism GIS to the quality concept of the ISO 19100 standards. Let us assume that we have to write a *quality evaluation report* about our GIS. This report is a standardized procedure of ISO 19114. It might report values of the *data quality elements* such as

- completeness: 100% coverage,
- logical consistency: no errors found,
- positional accuracy: ±5 m,
- temporal accuracy: last map revision 3 years ago; community information supplied last spring,
- thematic accuracy: topographic base map does not supply shelters and other similar elements for tourist purposes.

It might also report values of the data quality overview elements, including

- purpose: tourism GIS will enable an online information source of tourist details and it will also promote tourism in the area,
- usage: dataset was assembled for the tourism GIS,
- lineage: dataset was created under the supervision of the Tourism-GIS-Association.

ISO 19157 *Data quality* provides advice on different levels of detail for the quality check.

Let us assume we have only checked the purpose, usage, and lineage, and that we will write the results in a report. ISO 19115 *Metadata* provides the formal names of all the necessary data elements. Accordingly, the evaluationMethodType of the report will be *indirect* in this case.

Conceptually, ISO 19115 covers the complete list of metadata elements of all ISO 19100 standards. An amendment to ISO 19115, ISO 19115-2 *Metadata – Part 2: Extensions for imagery and gridded data*, integrates further elements related to imagery. The detailed explanation of every element within its thematic context is placed in each individual standard of the ISO 19100 family.

Data Storage. In the terminology of the ISO 19100 standards, the tourism GIS is referred to as a *dataset*.

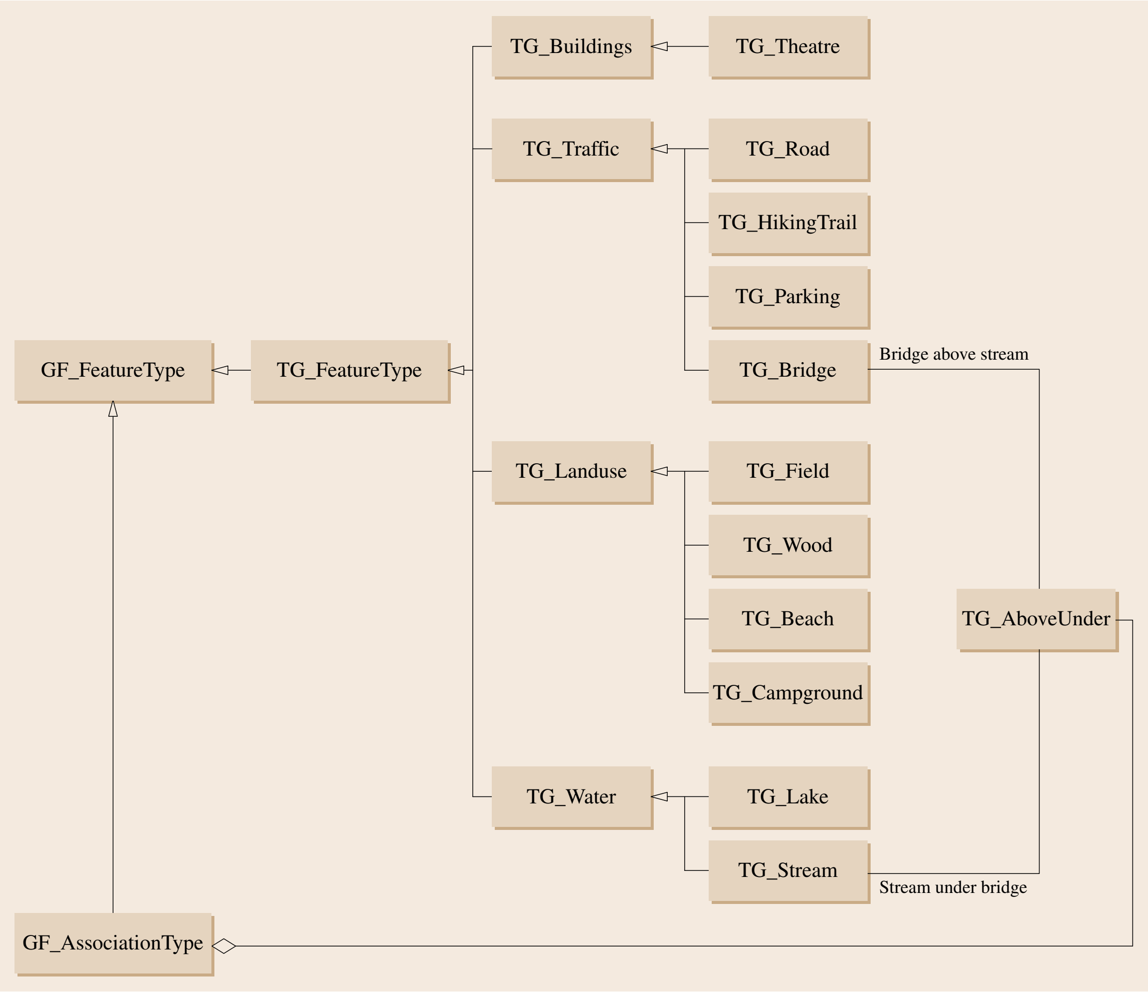


Fig. 13.5 Data model of the tourism GIS shown as a UML class diagram. All classes of the tourism GIS start with the two characters "TG" to indicate their relation to the tourism GIS. (UML is addressed in Sect. 13.4.1)

The elements of the dataset were called *objects* in the beginning of this section. However, although the term "object" is familiar in the context of object-oriented languages, in the domain of geographic information the term "feature" is more widely used to denote an element of a dataset. The term "feature" has also been adopted by the ISO 19100 standards.

ISO 19109 *Rules for application schema* contains all the definitions related to features [13.36]. The core of ISO 19109 is the General Feature Model (GFM). It states that a feature may have attributes and operations. Attributes identify whether a feature is a point, a curve, or a surface, and operations identify whether the feature changes according to external influences, such as the theater being closed in winter. Features may be logically grouped into larger units; for example, woods and fields both belong to land use. A single element in the dataset, such as one of the hiking trails, is called an instance of the feature *hiking trails*. Some features have special relationships that become important once a map is drawn or networking algorithms are applied to the dataset. An example for this case is the bridge crossing the streams. The bridge will always go over the stream at a different elevation above the water surface. This relationship is an association between features.

It is obvious that the possible features of a GIS have to be agreed upon before population of the database starts. The result of this design process is basically a list-

Table 13.7 Feature catalogue of a tourism GIS

GF_FeatureType high level	GF_FeatureType low level	GF_Operation	GF_AttributeType	GF_AssociationType
Buildings	Theater	Closed in winter	GM_Point	
Traffic	Road		GM_LineString	
Traffic	Hiking trail		GM_LineString	
Traffic	Parking		GM_Polygon	
Traffic	Bridge		GM_Point	Bridge over stream
Land use	Field		GM_Polygon	
Land use	Wood		GM_Polygon	
Land use	Beach		GM_Polygon	
Land use	Campground	Closed in winter	GM_Polygon	
Water	Lake		GM_PolynomialSpline	
Water	Stream		GM_PolynomialSpline	Stream under bridge

ing of all allowed features together with their attributes, operations, and associations. The listing is called a feature catalogue. The complete result is called a *data model* (Fig. 13.5).

The ISO does not standardize feature catalogues and data models. The only guidance provided is the ISO 19110 *Methodology for feature cataloguing*. This standard provides the general rules and a catalogue template to support a complete and consistent listing [13.37].

The following list is a simplified feature catalogue for the tourism GIS (Table 13.7).

It was stated earlier that the attributes of a feature could be of type point, line, or area. In fact, this was an oversimplification. The ISO 19100 standards provide a great variety of geometry classes and rules for how they are related to each other. The most comprehensive collection of geometry classes can be found in ISO 19107 *Spatial schema*.

The tourism GIS uses four geometry classes of ISO 19107: GM_Point, GM_PolynomialSpline, GM_LineString, and GM_Polygon. The class GM_Polygon denotes surface-type features.

ISO 19107 distinguishes between primitives and complexes. Primitives are geometries that *do not* include their end-points. Complexes are geometries that *do* include their end-points. If a topological network underlies our tourism GIS, the geometries must be connected at their end-points. Thus, the geometry consists of complexes.

The ISO 19100 family does not standardize the way the geometry and topology are handled by the database. It does not standardize data types nor details of the topology. Advanced systems only store one point at one position, allowing rapid searching of neighboring features. Simpler systems only store individual geometries and allow multiple points at a position.

All geographic positions of the data are defined according to a coordinate reference system. ISO 19111 *Spatial referencing by coordinates* sets the rules for the definition of coordinate reference systems. In the case of our tourism GIS, a local coordinate reference system is a sufficient solution. A local coordinate reference system is an *engineering* coordinate reference system according to ISO 19111. To simplify the usage of coordinates it is advisable to avoid negative values. For this purpose the complete definition area of the GIS must lie in the first quadrant, or seen from another perspective, the origin of the coordinate reference system must be beyond the west and south of the definition area. The x- and y-axis might point east and north, respectively. The datum (= origin) and the prime meridian (= axes to north) provide a local reference only. ISO 19111 does not standardize any parameter describing global or local coordinate reference systems.

Descriptive parameters are kept independent of the ISO 19100 family of standards. To guarantee standardized use of important parameters, ISO 19100 provides one or more registries. The rules for creating these registries are described in ISO 19135 *Procedures for item registration*. A specific registry for coordinate reference systems is defined in ISO 19127 *Geodetic codes and parameters*. If parameters are needed, they can be requested from one of the ISO-approved registration authorities.

Data Display. According to ISO 19117 *Portrayal*, the graphic representation is handled independently from

Table 13.8 Portrayal catalogue of a tourism GIS

PF_FeaturePortrayal	PF_PortrayalRule
Beach	Light brown area, border with black solid line, thickness 0.2 mm, letter B at the representativePoint
Bridge	Place bridge symbol
Campground	Light brown area, border with black solid line, thickness 0.2 mm, letter C at the representativePoint
Field	Light brown area, border with black solid line, thickness 0.2 mm
Hiking trail	Dashed black line, line 2 mm, space 2 mm, thickness 0.2 mm
Lake	Light brown area, border with black solid line, thickness 0.2 mm
Parking	Light brown area, border with black solid line, thickness 0.2 mm, letter P at the representativePoint
Road	Two black solid parallel lines with thickness of 0.2 mm each, one line 1 mm to the left and the other line 1 mm to the right of the road's axis, interrupt lines to open roads at intersections, show roads at highest priority if overlay with other graphics occurs
Stream	Black solid line, thickness 0.2 mm
Theater	One circle, and two concentric semicircles, black solid lines, thickness 0.2 mm
Wood	Light brown area, border with black solid line, thickness 0.2 mm, place tree symbols at irregular positions

the feature data. In the case of the tourism GIS, an individual feature portrayal is defined for each of the features such as the roads and hiking trails. All necessary feature portrayals are summarized in a listing called the *feature catalogue* that contains one entry for each feature in the dataset. Consequently, the feature catalogue of the tourism GIS has 11 entries.

Each feature portrayal points to a portrayal function that will be applied when drawing that feature. To handle more sophisticated graphics, such as the automatic opening of a road intersection, ISO 19117 allows the usage of external functions. The summary of all portrayal elements is the portrayal specification. During the output of the feature data, this specification is applied to the data stream to generate the cartographic representation.

Table 13.8 presents the portrayal catalogue of the tourist GIS (class PF_PortrayalCatalogue).

Data Exchange. ISO does not standardize any exchange format, but data exchange is addressed in ISO 19118 Encoding, which recommends that an exchange format be built upon the currently widely used XML. Also, ISO does not deal with the technical details of transferring data between different hardware platforms. ISO 19118 only states that the application schemas of the two systems between which the data exchange takes place must be alike. This simply means that a system to which the tourism GIS data may be transferred has to provide the same feature types: lake, wood, beach, etc., and the same structural information. If the feature types do not match, information is lost during the transfer. If, for example, in the second system only one feature for traffic is available, then roads and hiking trails would become the same feature and could not be distinguished from one another.

Reference Model (ISO 19101)

Among geomatics specialists, a consensus has emerged that the field of geographic information is a specialization within the information technology field. At the same time, there is a growing recognition among users of information technology that indexing by location is a fundamental way of organizing and using digital data. To meet these needs, standardization of geographic information in the ISO 19100 series is based on the integration of the concepts of geographic information with those of information technology. Whenever possible the development of standards for geographic information considers the adoption or adaptation of generic information technology. It is only when this cannot be done that geographic information standards have been developed. The basic principles of information technology can be found in standards of ISO and IEC.

Viewpoints. The usage of viewpoints is a common method of decomposing large distributed software systems during the design process. This core model is standardized as ISO/IEC 10746 *Information technology – Open distributed processing – Reference model*. It is also the foundation of the reference model for the ISO 19100 family of standards.

ISO/IEC 10746 describes five viewpoints.

1. The *enterprise viewpoint* is concerned with the purpose, scope, and policies of an organization in relation to GIS. This viewpoint is used to generate requirements and varies among different organiza-

tions, and therefore, it is not within the purview of the ISO 19100 family of standards.

2. The *information viewpoint* is concerned with the semantics of information and information processing. A specification developed from this viewpoint provides a model of the information in a GIS and defines the processing that is performed by such a system. The information provides a consistent common view on information that can be referenced in a GIS. The information viewpoint is the most important viewpoint for the ISO 19100 family of standards.
3. The *computational viewpoint* is concerned with the patterns of interaction among services that are part of a larger system. A service may be the interaction between the system and the client, such as the window interface on the screen, or between a set of other services, such as data retrieval from a database in the background. The computational viewpoint is the second most important viewpoint for the ISO 19100 family of standards.
4. The *engineering viewpoint* is concerned with the design of implementations within distributed, networked, computing systems that support system distribution. As implementation is not the focus of the ISO 19100 standards, there is little emphasis placed on this viewpoint.
5. The *technology viewpoint* is concerned with the provision of the underlying hardware and software infrastructure within which services operate. Again, as this is out of scope of the ISO 19100 family of standards, there is little emphasis placed on this viewpoint.

Figure 13.6 displays the viewpoints graphically.

ISO 19101 *Reference model* defines a hierarchically structured reference model for the ISO 19100 family of standards. Primarily, this reference model is a special application of the *information viewpoint* which is identified as the most important one for the standardization of geomatics. One component of the reference model is based on the *computational viewpoint* that addresses the services.

The majority of individual standards of the 19100 family are considered as services that operate on datasets. The services are discussed in detail in Sect. 13.4.2.

ISO 19101 is primarily for standard developers. However, understanding this standard is also helpful for users of the other geomatics standards, because it leads to an understanding of the rationale of the ISO 19100 series.

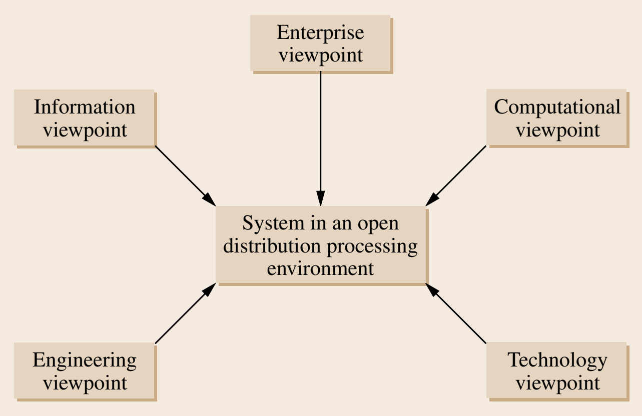


Fig. 13.6 Viewpoints of the ISO/IEC 10746 *Open distributed processing – Reference model*

Conceptual Schema Modeling Facilities. The background for structuring the reference model of geographic information is a number of principles that information technology has agreed upon. ISO/IEC 14481 *Conceptual schema modeling facilities (CSMF)* lays out a schema for the design of computer software that has four levels of abstraction.

The *meta-metamodel level* is the highest level. Though the name is somewhat obscure, the meaning of the meta-metamodel is simple. It is the description of a software system in natural language. The meta-metamodel level is not a matter of standardization.

The *metamodel level* is below the meta-metamodel level in the hierarchy. It contains the description of the concepts of a software system in a formalized language that, in the case of the ISO 19100 standards, is the Unified Modeling Language (UML). The concepts include terminology, operations, and assumptions needed to construct applications. Typical examples of metamodels are the UML diagrams found in this handbook and throughout the ISO 19100 standards.

The *application model level* exists below the metamodel level. An application model contains all detailed definitions needed to tailor a software system to a specific application. In the case of geographic information, this might include the definition of feature types such as roads and buildings and their possible attributes and operations. The documentation of an application model is called an application schema.

The *data model level* contains the datasets and is the lowest level. In the case of geographic information, the datasets are composed of one or many features, including their attributes and positions. The datasets are the actual data, whereas the application schema only sets the frame for the possible features.

Meta-metamodel and Metamodel. Any consideration on modeling starts with the real world. The chosen piece of the real world that one wishes to describe in a model is known as the Universe of Discourse. A first result of the modeling process is a conceptual model that describes and limits the Universe of Discourse. A model is an abstraction and represents only a part of the real world. An example of the real world could be the landscape depicted in the map in Fig. 13.4. A conceptual model is the list of features relevant for the tourism GIS in Table 13.7.

A conceptual schema language provides the semantic and syntactic elements used to rigorously describe the conceptual model and to convey consistent meaning. A conceptual model described using a conceptual schema language is called a conceptual schema. A conceptual schema of the tourism GIS is shown in Fig. 13.7. The conceptual schema language prescribed in the ISO 19100 series is UML. The feature types that are shown represent the semantics. The lines specifying the exact type of associations are the syntactic elements. The conceptual schema language is addressed in more detail in Sect. 13.4.1.

Application Model. The application model of a GIS completely defines its data elements (classes) and their interrelation. The heart of the application model is a detailed description of the data structures. This description is called an application schema. The tools to describe the data structure are the feature catalogue and the GFM. The feature catalogue is a formal list of the feature types that are determined as relevant and qualified for the application. The GFM sets the frame for the definition of every feature type. An example of a feature catalogue is provided in Sect. 13.3.4. The GFM is explained in detail in Sect. 13.4.2. Both tools have dedicated ISO 19100 standards.

An application schema also consists of components that are relevant to all feature types. These components are the coordinate reference system and elements describing data quality. The coordinate reference system is explained in detail in Sect. 13.4.2, and the quality aspects are addressed in Sect. 13.4.2. Both components have their own standards in the ISO 19100 family.

Data Model. The data model contains the data being collected for an application and the services that operate on the data. The data model includes all features and their describing data that make up the complete GIS. The data consist of the dataset and the metadata. The dataset includes only the features and their positions.

The metadata is the describing data. ISO 19115 *Metadata* provides a good guideline for the selection of metadata. ISO 19115 provides a standardized list of metadata elements. Further describing elements that are not available in ISO 19115 may be modeled as metadata elements beyond the scope of ISO 19115 or as attributes of the feature classes.

Programs that use the dataset and the metadata to serve a certain purpose for the user are called geographic information services. In the ISO 19100 standards, it is stated that services operate on the dataset and reference additional information from the metadata. Most of the ISO 19100 standards define such services.

Conceptual Modeling and Domain Reference Model. Based on the conceptual schema modeling facilities, ISO 19101 sets forth the process for conceptual modeling, the domain reference model, the architectural reference model, and profiles.

The conceptual modeling covers the metamodel. According to ISO/IEC 14481, a number of principles govern the use of conceptual modeling and the development of conceptual schemas. The most important principles are listed below:

1. The *100% principle* states that all (100%) of the relevant structural and behavioral rules about the Universe of Discourse shall be described in a conceptual schema. Thus, the conceptual schema defines the Universe of Discourse.
2. The *conceptualization principle* states that a conceptual schema should contain only those structural and behavioral aspects that are relevant to the Universe of Discourse. All aspects of the physical external or internal data representation should be excluded.
3. The *self-description principle* states that normative constructs defined in the standards and profiles of the ISO 19100 series shall be capable of self-description.

The domain reference model covers the application model and the data model. The details of the domain reference model have been explained above. Figure 13.7 summarizes the relations between the metamodel, the application model, and the data model.

Architectural Reference Model. The term "architecture" is used here in the context of service architecture. The ar-

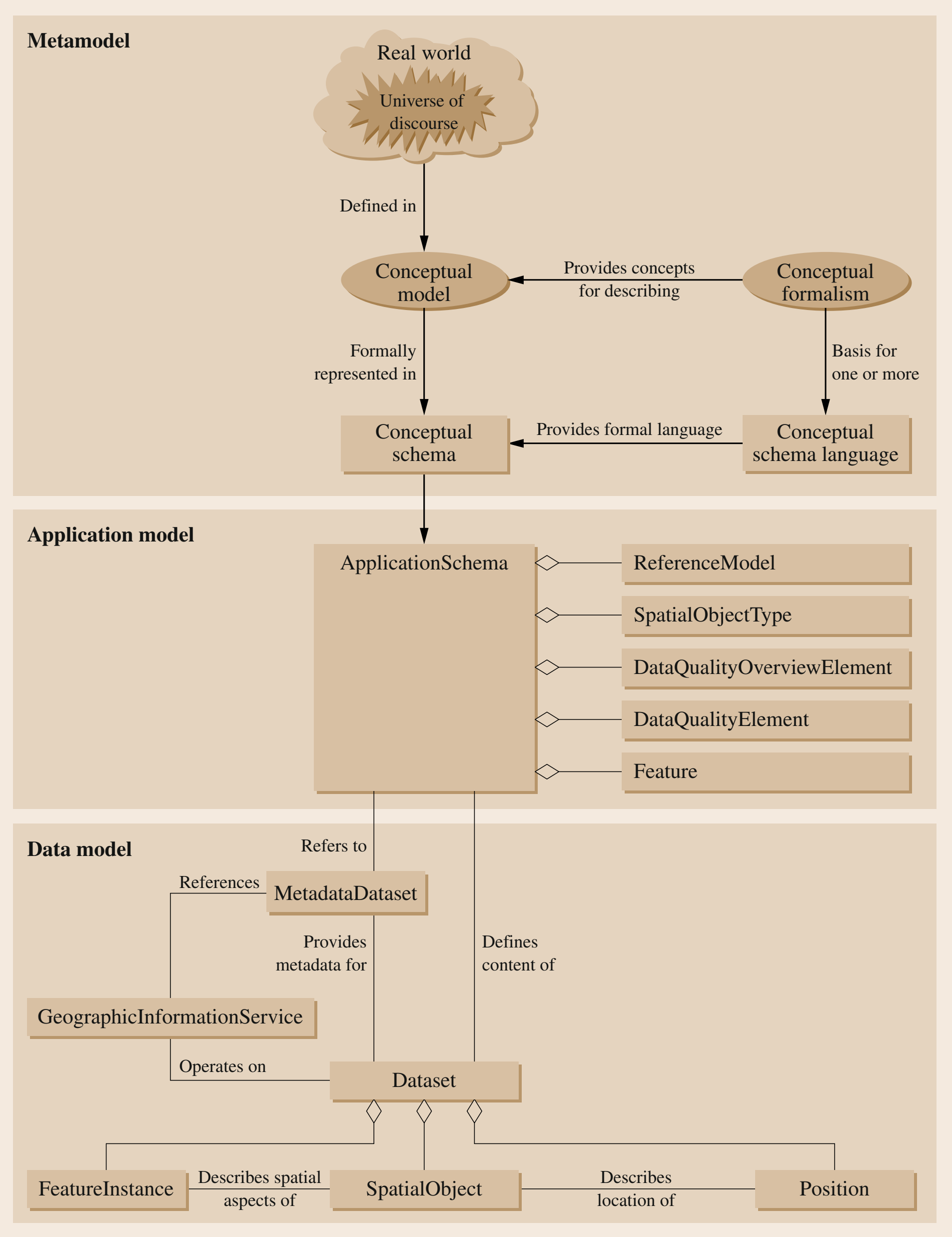


Fig. 13.7 Conceptual modeling and domain reference model (after [13.38])

chitectural reference model lays out a concept for structuring the great number of geographic information services involved. The basis for the architectural reference model is ISO/IEC Open systems environment reference model (OSE-RM) described in ISO/IEC TR 14252. This standard completely addresses the services for information technology. The ISO 19101 standard defines an *extended* open systems environment (EOSE) reference model that includes the specific services for geomatics. Figure 13.11 provides a complete view of the IT services and the geographic information services.

Profiles. A profile of a standard defines a subset of the elements of the standard in order to meet specific needs and to eventually avoid heavy overload of functionality. Profiles of the ISO 19100 standards may combine subsets of different standards including the ISO 19100 family and others. A special case of future profiles are functional standards that have been developed outside the world of the ISO 19100 standards before the work of ISO/TC 211 had started. These functional standards were planned to become profiles of the ISO 19100 family. However, full replacement of domain-specific standards by the ISO 19100 family turned out to be the better solution, as in the case of the S-100 series, the IHO geospatial standard for hydrographic data (Sect. 13.3.1).

Reference Model – Part 2: Imagery (ISO 19101-2)

ISO/TS 19101-2 *Reference model – Part 2: Imagery* defines a reference model for imagery. Its development turned out to be necessary because Earth observation and remote sensing have become key topics of geographic information. Unfortunately, the original reference model, ISO 19101, provides guidelines primarily for vector-oriented GIS.

The key topic of ISO/TS 19101-2 is geographic imagery. This is defined as imagery whose data are associated with a location relative to the Earth and contrasts with the term "image", which is not addressed in this technical specification because of its numerous meanings in various user contexts.

ISO/TS 19101-2 offers a very broad view on geographic imagery, ranging from technical details such as encoding formats to the process of decision-making, when it claims that the ultimate application of imagery data is the support of decisions. From the perspective of ISO/TS 19101-2, most geographic imagery will never be directly accessed by humans in the future. Instead, semantic processing will be required, i.e., automatic detection of features and mining based on geographic concepts. One of the major technical challenges of imagery is the huge volume of data.

In the ISO 19100 family of standards, an image is regarded as a type of coverage which can be structured using a grid. As defined in ISO 19123, a grid is a network composed of two or more sets of curves in which the members of each set intersect the members of the other sets in an algorithmic way.

Imagery is built of a matrix of pixels. Using the terminology of the ISO/TC 211 standards, an image is a gridded coverage whose attribute values are a numerical representation of a physical parameter, e.g., light intensity.

It is useful to distinguish between imagery as used in the ISO/TS 19101-2 from the colloquial use of the term "image." As used in ISO/TS 19101-2, imagery is a representation of image data within a computer system. To view an image, a presentation process is required to convert the pixel values called digital numbers (DN) to a viewable representation.

Enterprise Viewpoint. As done with ISO 19101 Reference model, ISO/TS 19101-2 also applies the Reference model for Open distributed processing (RM-ODP) as the basis for defining an information system. For the topic of imagery, the enterprise viewpoint and the information viewpoint are the two most important ones.

ISO/IEC 10746-1 *RM-ODP* defines the enterprise viewpoint as the one that focuses on the purpose, scope, and policies for that system.

Figure 13.8 depicts the geographic imagery scenario that forms the basis for the structure of ISO/TS 19101-2. A closer look at this UML use-case diagram reveals its remote-sensing and potentially military origin. In the upper part a mission is planned, while after sensing the outcome is analyzed in the lower part.

Information Viewpoint. The geographic imagery information viewpoint in ISO/TS 19101-2 identifies the various types of geographic information and shows the relationships of raw sensed data to higher semantic content information.

Figure 13.9 illustrates the structure of the information viewpoint.

For imagery, the data consist of the results of measurements by a sensor. Meaning is assigned to data by applying conventions or agreed-upon codes so that it becomes information. As information is gathered, observed regularities are generalized and models are developed, forming the transition to knowledge. The knowledge base is used in the formation of pragmatic decisions.

13.3.3 Future of Geomatics Standardization

Implementation Strategies

After the development of the basic standards of the ISO 19100 family reached completion, their implementation was started. The strategies for implementing the mostly abstract ISO 19100 standards is not a standard on its own. However, some typical approaches can be reported.

ISO/TC 211 has about 60 member countries and 30 external liaison organizations. While participating in the

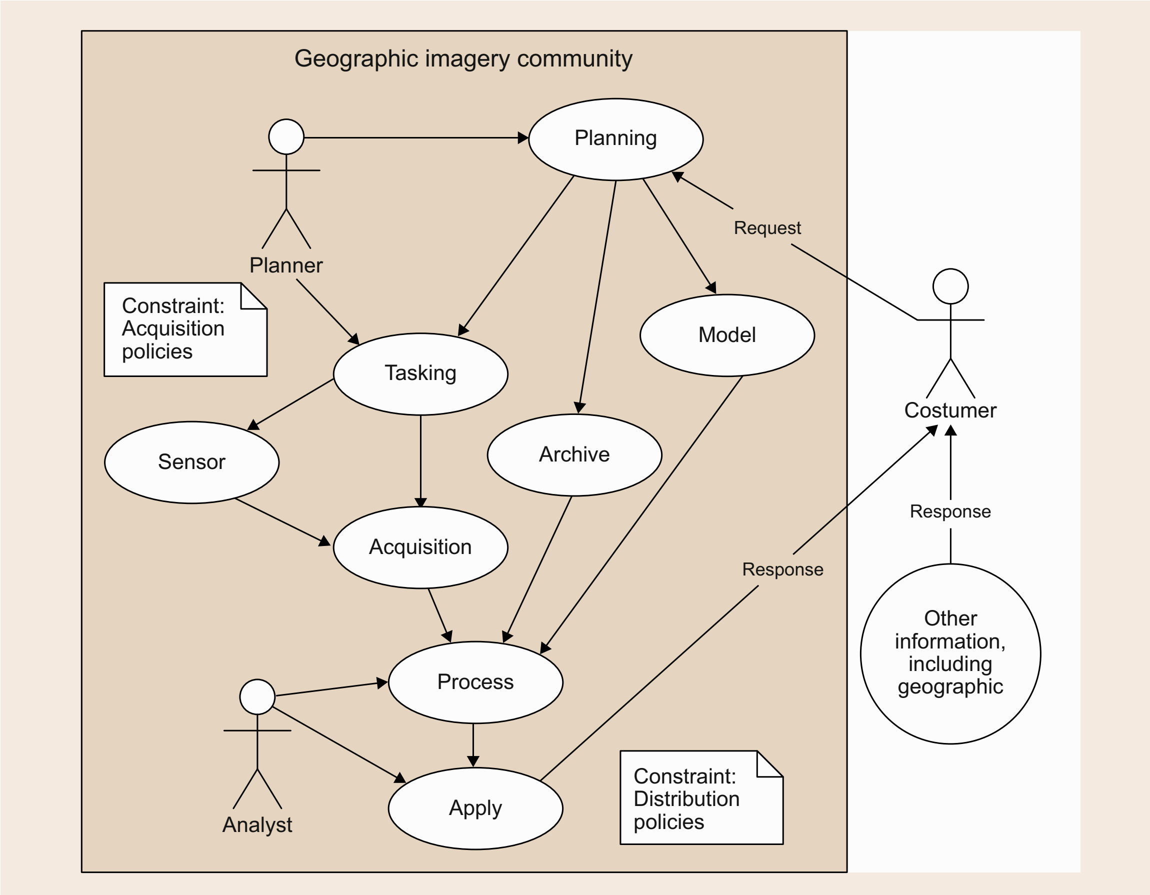


Fig. 13.8 UML use-case diagram of geographic imagery scenario (after [13.39])

work of ISO/TC 211, the members committed themselves to adopt the resulting standards in their home environment. However, the implementations will vary from country to country, from organization to organization, and in some cases even from province to province.

Hardly any implementation will require the complete functionality of the ISO 19100 series. Instead, mostly only a subset of the abstract standards will be substantiated. The implementations remain compatible as far as their application schemas overlap. The usage of ISO 19100 guarantees a common underlying abstract model that enables compatibility if the applications schemas are the same.

The OGC plays an important role at the implementation level. In theory, ISO/TC 211 develops the abstract standards and the OGC develops the implementation standards. In practice, the borderline is not drawn that clearly.

ISO/TC 211 has created some of the ISO 19100 standards based on proposals from the OGC. Two typical examples are ISO 19123 *Schema for coverage*

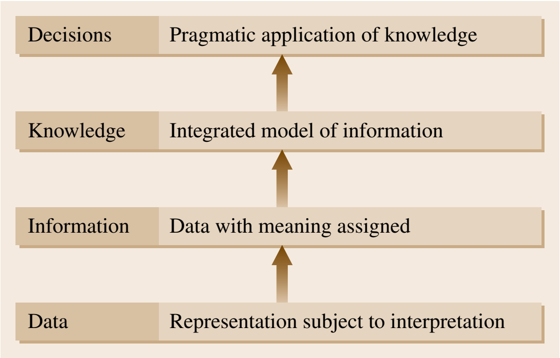


Fig. 13.9 Structure of the information viewpoint

geometry and functions and ISO 19133 *Location-based services – Tracking and navigation*. Those standards are implementation standards. On the other hand, the OGC has developed a comprehensive abstract specification that was completed in 1999 but hardly touched since.

The partitioning of the work between ISO/TC 211 and the OGC has turned out to be fruitful for the geomatics community. The development of an ISO standard may take up to 5 years. This is acceptable for long-term abstract standards that enjoy a consensus among the large international community, but that time is far too long for implemented computer software. Programmed tools would just ignore the official standards. The implementation became the domain of the OGC. An example is GML version 3.x (GML 3.x). GML 3.x is an almost complete implementation of ISO 19107 *Spatial schema*. It was questioned whether GML 3.0 needed to become an ISO standard too. However, GML became ISO 19136 in 2007.

Many member countries and liaison organizations of ISO/TC 211 will adopt the implementation of the ISO 19100 standards from the OGC.

Ongoing Work of ISO/TC 211

Though the major standards of the ISO 19100 family have been completed, the work of ISO/TC 211 is ongoing. The present projects focus on broadening the basis of the geomatics standards (ontology), on extending the methods for georeferencing features, and on implementation of the completed work. The projects also address a refinement of location-based mobile services.

The structure of this section is adopted from Sect. 13.4.

Infrastructure Standards.

Ontology (ISO 19150-x). ISO 19150 *Ontology* does not exist with this generic name. Still in an early stage of its development, the technical specifications ISO 19150-x are intended to consist of six parts finally [13.41], which are:

1. ISO 19150-1 *Ontology – Part 1: Framework*,
2. ISO 19150-2 *Ontology – Part 2: Rules for developing ontologies in the Web Ontology Language (OWL)*,
3. ISO 19150-3 *Ontology – Part 3: Semantic operators*,
4. ISO 19150-4 *Ontology – Part 4: Service ontology*,
5. ISO 19150-5 *Ontology – Part 5: Domain ontology registry*,
6. ISO 19150-6 *Ontology – Part 6: Service ontology registry*.

Draft documents of the first two existed when this handbook was published.

The driving force behind the creation of an ISO standard for ontology is the strong international and thematic integration of geospatial data and as a consequence the need to express the details of geographic information in many different languages and disciplines. In this sense, ontology stands for a formal representation of the phenomena of a Universe of Discourse with an underlying vocabulary that makes the intended meaning explicit and describes the phenomena and their interrelationships. With the help of ontologies, data from different disciplines including geographic information can be integrated and contribute to addressing specific (e.g., oil spill) to global problems (e.g., climate change).

Ontologies are addressed in detail in Chap. 15.

Basic Standards.

Georeference – Place Identifier (PI) Architecture (ISO 19155). ISO 19155 specifies an architecture that defines a reference model for an identifier of a place. The concept of *place* includes places not only in the real world but also in the virtual world. These places are identified using coordinate reference systems, geographic identifiers, or virtual world identifiers such as URIs. In ISO 19155 an identifier of a place is referred to as a place identifier (PI).

The reference model defines a mechanism to match multiple place identifiers to the same place, a data structure, and a set of service interfaces.

If the place is identified with coordinates it is called a *position*, and if the place is identified with geographic identifiers it is called a *location*. Figure 13.10 illustrates the relation to ISO 19111 and ISO 19112.

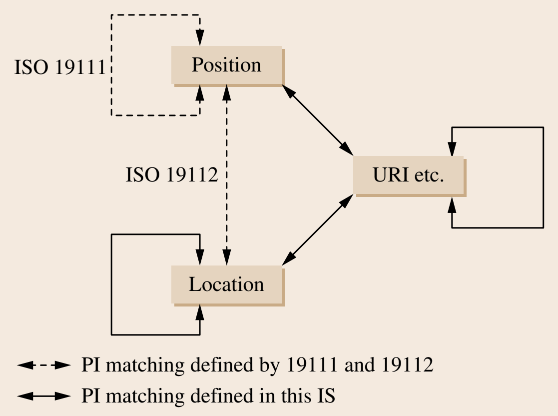


Fig. 13.10 Place identifier matching (after [13.40])

Georeference – Addressing (ISO 19160). The intended standardization project ISO 19160 *Addressing* which is (in 2011) in its preliminary stage may be considered as a specialization of ISO 19112 *Geographic identifiers*. However, address information is not purely geographic and thus not only the domain of ISO/TC 211. It is also a key issue of electronic business and postal systems. Therefore, quite a few other stakeholders are involved in address standardization, such as OASIS (Organization for the Advancement of Structured Information Standards), ISO/TC 154 *Processes, data elements and documents in commerce, industry and administration*, and the Universal Postal Union (UPU).

Before ISO 19160 can be completed, a formal collaboration among the stakeholders must be established in order to investigate and formulate their requirements in relation to addressing. It is in the interest of the standardization community for geographic information to reach consensus and integrate the addressing model into the TC 211 model of geomatics standards [13.42].

Implementation.

Procedures for Item Registration – Part 2: XML Schema Implementation (ISO/TS 19135-2). ISO 19135-2 *Procedures for item registration – Part 2: XML schema implementation* has been requested by the user community, e.g., DGIWG, because current implementations come up with their own XML schema implementations for ISO 19135, which will inevitably lead to interoperability issues. ISO 19135-2 aims at harmonizing such encodings [13.43].

Metadata – XML Schema Implementation – Part 2: Extensions for Imagery and Gridded Data (ISO/TS 19139-2). ISO 19115-2 *Metadata – Part 2: Extensions for imagery and gridded data* extends the first metadata standard ISO 19115 by a group of additional metadata regarding imagery and gridded data. ISO/TS 19139-2 will define the related XML implementation [13.44].

Location-Based Services.

Transfer Nodes (ISO 19147). ISO 19147 *Transfer nodes*, which is in an early stage of its development, is intended to become a link between the existing ISO 19133 *Location-based services – Tracking and navigation* and ISO 19134 *Multimodal location-based services for routing and navigation* as well as similar activities in ISO/TC 204 *Intelligent transport systems* and CEN/TC 278 *Road transport and traffic telematics* [13.45].

A transfer node is a location that establishes a link between two of more means of transportation. Typically this is a station that links long-distance with commuter trains or the road with the railroad network.

ISO 19147 will define transfer nodes and their attributes, a feature catalogue for transfer nodes, and how transfer nodes can be linked to real-world locations.

Ubiquitous Public Access – Reference Model (ISO 19154). ISO 19154, in 2011 still in its early development phase, is intended to establish a framework for a ubiquitous public access environment, in which general public users are no longer passive consumers of geographic information, but rather active participants in the entire lifecycle of geographic information, from the production, distribution, consumption, to sharing of geographic information.

Ubiquitous public access (UPA) to geographic information can be understood by three concepts: (1) ubiquity, (2) public access, and (3) ubiquitous public access.

Ubiquity or omnipresence is the property of being present everywhere. In ISO 19154, the definition of the ubiquity of geographic information is given as an environment to provide geographic information in every place at any time for any device (Fig. 13.11).

Directions and Activities

The work of ISO/TC 211 *Geographic information/Geomatics* has completed its first lifecycle. All base standards have been published and consequently moved to practical implementations with responsibilities devolving to industry and national or supranational government institutions. The earlier publications are presently under their first revision.

Trends. Though the future direction of ISO/TC 211 is not known in detail, the prevailing trends are clear. The ISO/TC 211 member countries are committed to continue adoption of the ISO 19100 standards. Many of the project teams are working on mostly minor issues that have come up after implementing the standards in comprehensive work environments. Examples of such work are the definition of XML interfaces for metadata and registries, or the merging of formerly three quality standards to a single future document.

There will be a strong case for using profiles and application schemas of the ISO 19100 family to build well-tailored environments for specific fields of applications. One example of these fields is the property cadastre.

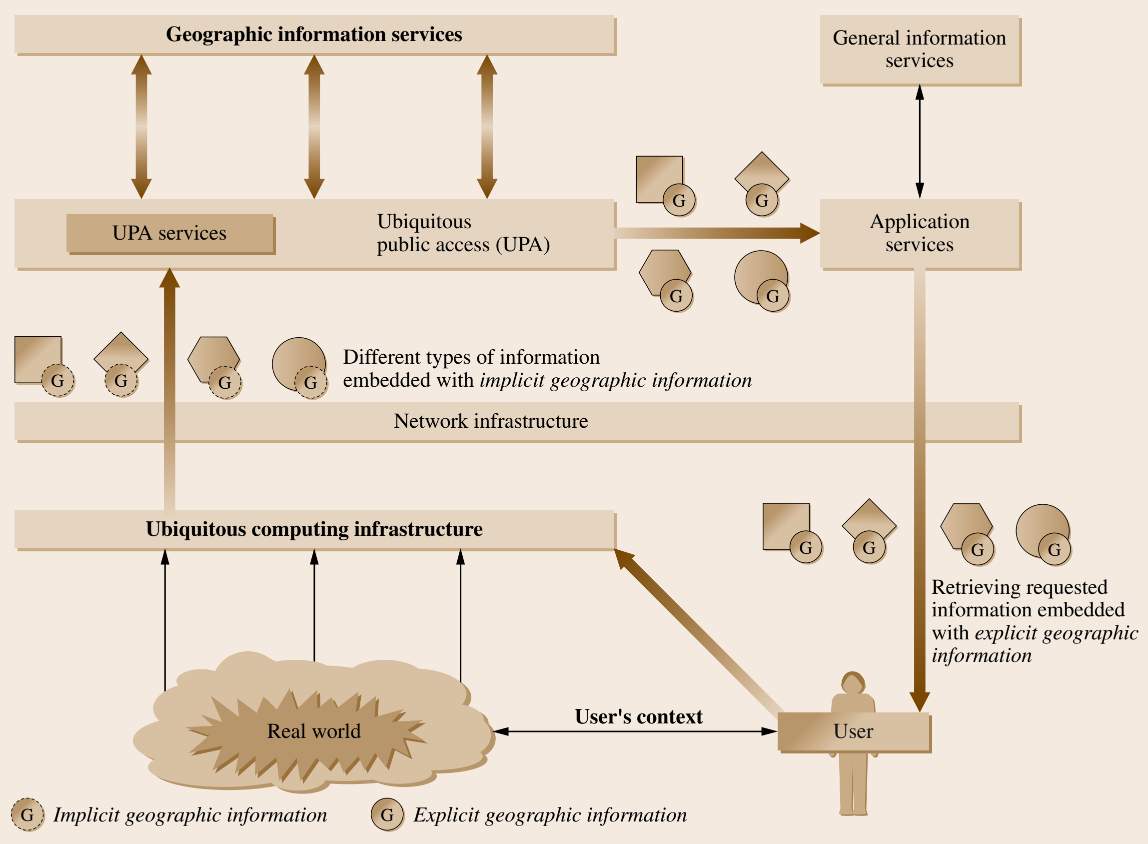


Fig. 13.11 Conceptual framework of ubiquitous public access to geographic information (after [13.46])

ISO/TC 211 will also be shifting its focus to neighboring areas of work where the industry has expressed a need for standardization. The most prominent example of such a new area is location-based mobile services.

Strength. ISO/TC 211 has become the worldwide-accepted umbrella group for standardization of geomatics. It has succeeded in engaging the national bodies and kindred organizations in the development of a suite of international standards. ISO/TC 211 has evolved as the competent group that is able to represent geomatics, fairly independently of national and industrial influences and with a sufficiently clear border to other fields of ISO.

Weakness. In geomatics a lot of private standards are already in place, with some of them being de facto standards. The newer ISO standards cannot replace them on a short-term basis, and it might therefore take a long period until the ISO standards are implemented.

Opportunities. ISO/TC 211 has formulated the abstract basis for the whole world of geomatics. Through its neutral position, it has become the coordinator of many activities in the geomatics business. Productive collaborations among liaison and national members have been or will be initiated. The first cooperative agreement was signed with the OGC, followed by the IHO. Other organizations such as the Defence Geospatial Information Working Group (DGIWG) have followed too. Close cooperation with national associations is also anticipated.

The registry (ISO 19135) opens a flexible interface from the ISO 19100 standards to a wide range of worldwide applications. The registry will not only allow keeping track of ISO-compliant standards but will also be a continuously growing source of geomatics implementations beyond the scope of ISO/TC 211.

The ISO 19100 standards were chosen as the reference for a number of emerging technologies.

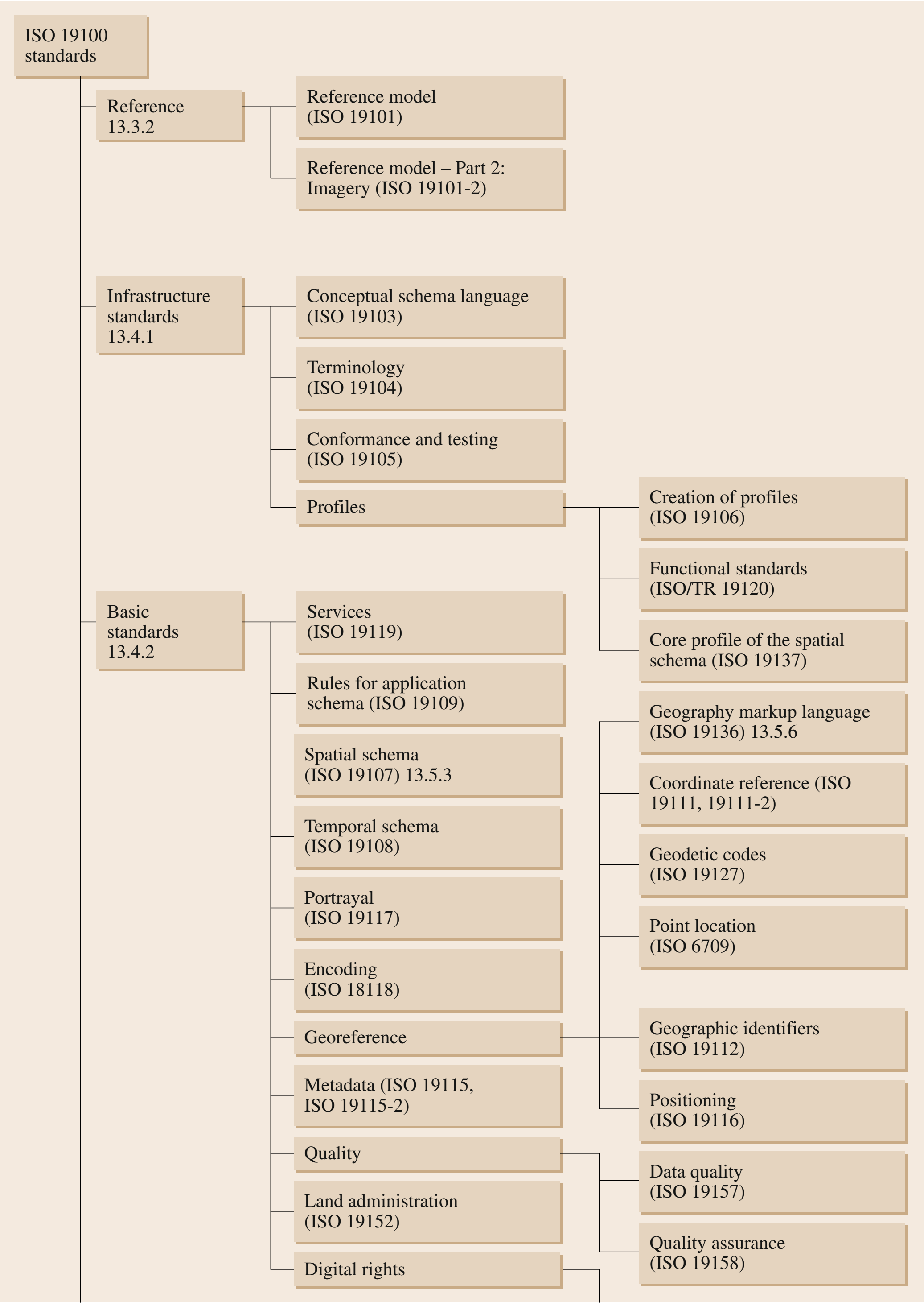


Fig. 13.12 Roadmap to the ISO 19100 standards

Fig. 13.12 (continued)

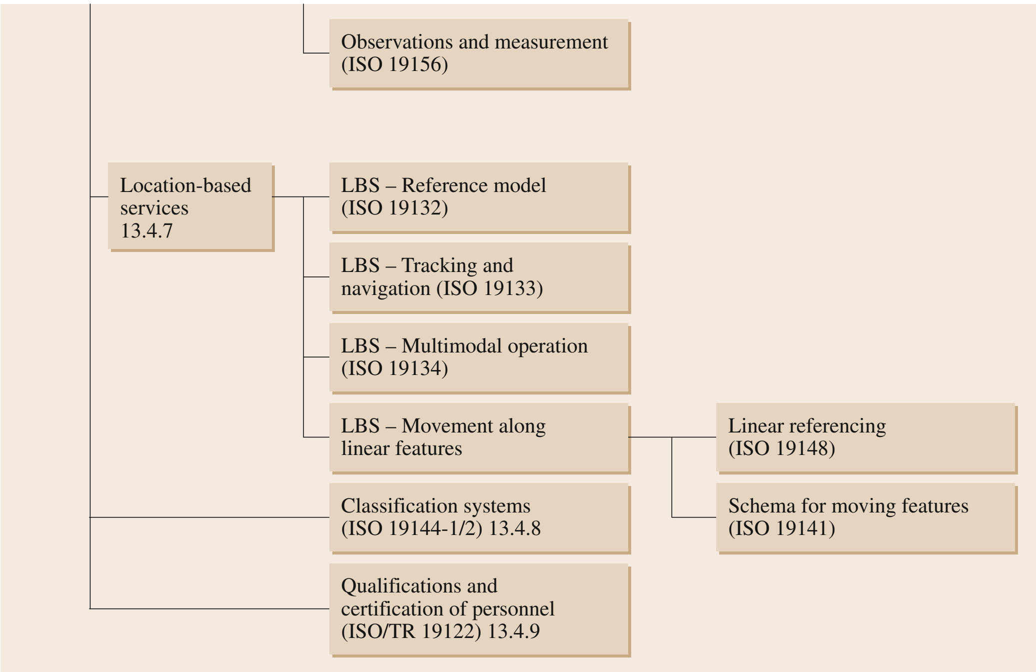


Fig. 13.12 (continued)

The Global Spatial Data Infrastructure (GSDI) is promoting a globally coordinated approach to geomatics.

The Infrastructure for Spatial Information in Europe (INSPIRE) sets the framework for a geomatics infrastructure in Europe. The United Nations (UN) is going to build its implementations in geomatics based on ISO 19100 standards.

ISO/TC 211 has established an advisory group on strategy to address future directions and report to the chairman.

Promotional Activities. In the past there were concerns about the ISO 19100 standards not being well known and as a consequence not widely used. ISO/TC 211 has therefore started an outreach campaign to create awareness of its standards.

The creation of awareness will support application-oriented activities including implementation of transfer standards by vendors, implementation of data cataloguing standards by data producers, and implementation of metadata standards by vendors and general users. The development of awareness will include education and training as well as the creation of user communities. ISO/TC 211 has established an advisory group on outreach to follow up the promotional activities.

Political Background. Many countries are beginning to understand the tremendous value of GIS and their data for governing the commonwealth. In the USA, homeland security takes a strong interest in building a geographic data infrastructure for improving emergency management including the fight against terrorism and better disaster management. The USA also supports the development of a GSDI, because GIS is believed to offer an effective weapon against global terrorism.

The development of the European spatial data infrastructure is governed by the long tradition and high quality of the property cadastre and topographic portrayal on this continent. Another strong component is led by the needs for environmental protection. The INSPIRE initiative provides an integrated approach for all countries of the European Union.

13.3.4 Roadmap to the ISO 19100 Standards

Figure 13.12 shows a roadmap to all ISO 19100 standards and points to the chapters of this book.

The roadmap shows the way of structuring the ISO 19100 standards that is used in this book. The top-categories – infrastructure, basic, imagery, catalogue, and implementation standards – are not official terms.

However, they are often used in internal discussions, and they are helpful to understand the overall structure of the ISO 19100 family.

The basic standards designate those standards that belonged to the original scope of ISO/TC 211 and that do not apply to all other standards such as the infrastructure standards. The basic standards must not be confused with the base standards, which have the property of enabling the derivation of profiles. The georeference category is unofficial too.

13.4 Nongeometry Standards

Section 13.4 explains all ISO 19100 standards apart from the reference models (ISO 19101, ISO 19101-2) and the geometry-oriented standards, which are ISO 19107 *Spatial schema*, ISO 19123 *Schema for coverage geometry and functions*, ISO 19125-1/2 *Simple feature access*, and ISO 19136 *Geography Markup Language*. ISO 19101 and ISO 19101-2 are explained in Sect. 13.3. The other four standards are explained in detail in Sect. 13.5.

13.4.1 Infrastructure Standards

The infrastructure standards set rules that apply to all pieces of the ISO 19100 family. They define the *infrastructure* for the development of the standards themselves and for the development of application schemas and profiles. The infrastructure standards include the conceptual schema language (ISO/TS 19103), terminology (ISO 19104), conformance and testing (ISO 19105), and profiles (ISO 19106). Originally, ISO 19102 *Overview* was meant to provide a general introduction to the ISO 19100 family. The project was later canceled because it was difficult to continuously update it while standards evolved. The Internet and textbooks such as this may provide much better access to the ISO 19100 standards.

Conceptual Schema Language (ISO 19103)

Today, if experts meet to discuss the design of a computer system they talk in a conceptual schema language. Admittedly, they speak in English, French, or German, or any other language of the world, but a conversation like this remains informal and fuzzy until someone starts drawing a diagram, mostly in UML, the Unified Modeling Language, to express the ideas using the formal tools of classes or packages and their relationships. Therefore, it is essential for everybody who works in this field to be able to communicate in a conceptual schema language. ISO/TS 19103 *Conceptual schema language* defines a UML profile for geographic information. This handbook assumes that the reader has basic knowledge of UML and focuses on the extensions of UML for geographic information.

Background. A conceptual schema language is based upon a conceptual formalism that provides the rules, constraints, inheritance mechanisms, events, functions, processes, and other elements that make up a conceptual schema language. For the ISO 19100 family of standards, the applicable conceptual formalism is object-oriented modeling as described by the Object Management Group (OMG) [13.47]. A conceptual schema language has to be capable of representing 100% of the semantics in a domain of discourse. The 100% requirement refers to the level of detail that is appropriate for modeling the domain in question. Traditional conceptual schemata such as the entity–relationship model cannot describe numerical or logical relationships between values of concept. Therefore, they are not able to meet the 100% requirement.

UML has become the strongest of several conceptual schema languages that have been developed over the last decades. The roots of UML were independent but similar to developments by three well-known American *software methodologists*: Booch, Rumbaugh, and Jacobson, who pooled their efforts and created a company, Rational Software Corp., that has become one of the leading developers of software engineering tools. Today, UML is an international standard: ISO/IEC 19501, prepared by the ISO/IEC JTC1/SC7 [13.48]. Today, Rational Software Corp. is a division of IBM.

EXPRESS is a conceptual schema language being used in the field of mechanical engineering and was standardized by ISO/TC 184 *Automation systems and integration* [13.49]. Conceptual schemas in UML are based on graphical and lexical elements, whereas the schemas of EXPRESS primarily rely on text.

According to the standards of the ISO 19100 series, both languages are available for modeling of geographic information. UML is preferred, however, as it has turned out to be far more feasible for modeling geomatics. Therefore, this handbook uses UML as the only conceptual schema language. Today, ISO/TC 211 recommends Enterprise Architect developed by Sparx Systems as the preferred UML modeling tool.

UML Elements for Geographic Information. ISO/TS 19103 *Conceptual schema language* requires use of UML as defined in ISO/IEC 19501. Specific rules and recommendations have been established for the following aspects: classes, attributes, data types, operations, associations, and stereotypes. In addition, naming conventions and modeling guidelines maintain the unique appearance of the whole family of ISO 19100 standards.

Classes. Normative models use class diagrams and package diagrams. Other UML diagram types, such as use-case diagrams, may be used for information. All normative models contain complete definitions of attributes, associations, operations, and appropriate data type definitions.

According to the ISO 19100 family, a class is viewed as a specification and not as an implementation. Attributes are considered to be abstract, and do not have to be directly implemented. For each class defined according to the ISO 19100 family, its set of defined attributes together with the sets of attributes of other classes (that are accessible either directly or indirectly via associations) shall be sufficient to fully support the implementation of each operation defined for that particular class.

Attributes. All attributes must be typed, and the type must exist among the set of legal base types. A type must always be specified; there is no default type.

Data Types. Table 13.9 presents the primitive data types defined by ISO/TS 19103. Some of the data types are adopted from UML, while others are adopted from the Object Constraint Language (OCL) that is a component of the comprehensive UML standard. Some other data types belong to both.

The primitive types are the fundamental types for representing values.

Relationships and Associations. A relationship in UML is a ratified semantic connection among model elements. Generalization, dependency, and refinement are class-to-class relationships. In the ISO 19100 family of standards, they are used according to the standard UML notation and usage.

Association, aggregation, and composition are object-to-object relationships. An association is used to describe a relationship between two or more classes. An aggregation is a relationship between two classes, in which one of the classes plays the role of a container and the other plays the role of a content. A composition is a strong aggregation. In a composition, if a container object is deleted, then all of its content objects are deleted as well (Chap. 1).

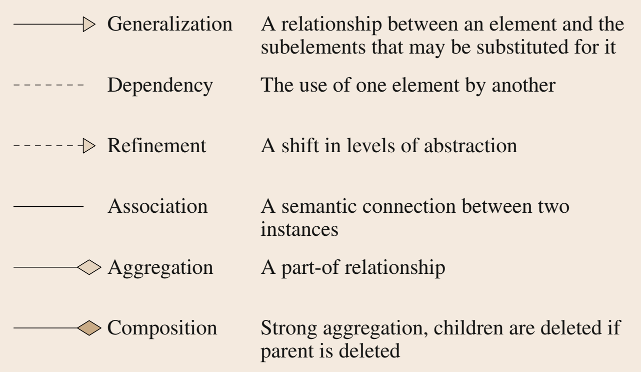
Table 13.9 Primitive types in ISO/TS 19103

Data type	Examples	Defined in	
		UML	OCL
Integer	123, −65 547	×	×
Decimal	12.34		
Real	12.34, -1.234×10^{-4}	×	×
Vector	(123, 456, 789)		
CharacterString	*This is a nice place*	×	×
Date	2003-02-19		
Time	13.59:30 or 13:59:30–05:00	×	
DateTime	2003-02-19T13:59:30		
Boolean	true, false	×	×

Stereotypes. Stereotypes are a method of classifying UML classes in order to augment the readability of larger UML class and package diagrams. Stereotypes indicate the context in which a class shall be applied. ISO/TS 19103 defines 13 stereotypes as being relevant for geographic information (Table 13.10).

Example for a UML Class Diagram of a Small GIS. The purpose of this example is to clarify the use of UML class diagrams in the context of geographic information.

The purpose of the example GIS is the computation of the fastest route between two cities (Fig. 13.14).



Generalization	A relationship between an element and the subelements that may be substituted for it
Dependency	The use of one element by another
Refinement	A shift in levels of abstraction
Association	A semantic connection between two instances
Aggregation	A part-of relationship
Composition	Strong aggregation, children are deleted if parent is deleted

Fig. 13.13 Kinds of relationships in UML (after [13.50])

Table 13.10 ISO/TS 19103 (stereotypes)

<<applicationSchema>> is a package representing an application schema as defined in ISO 19109

<<baseSchema>> is a package defining items of geographic information

<<codeList>> is a flexible enumeration that uses string values for expressing a list of potential values

<<dataType>> is a set of properties that lack identity (independent existence and the possibility of side-effects). A data type is a class with no operations whose primary purpose is to hold information

<<enumeration>> is a fixed list of valid identifiers of named literal values. Attributes of an enumerated type may only take values from this list

<<featureType>> is a feature type as defined by the GFM in ISO 19109

<<interface>> is an abstract classifier with operations, attributes, and associations, which can only inherit from or be inherited by other interfaces. Other classes may realize an interface by implementing its operations and supporting its attributes and associations (at least through derivation)

<<leaf>> is a package that contains definitions, without any subpackages

<<metaclass>> A class whose instances are classes. Metaclasses are typically used in the construction of metamodels, and a metaclass exists at a higher level of abstraction; for example, FeatureType and AttributeType are metaclasses for Feature and Attribute

<<metamodel>> is a package that defines a language for expressing a model

<<union>> is a type consisting of one and only one of several alternatives (listed as member attributes). This is similar to a discriminated union in many programming languages

<<voidable>> identifies an attribute or association role as optional, i. e., a value of "void" is a valid value of the property

<<type>> is a set of abstract attributes and associations. Abstract means that their specification does not imply that they have to be concretely implemented as instance variables [13.51]

The sketch map shows the cities and two roads connecting them, including the required attributes about road condition and speed limits. Other aspects, such as the population of the cities, are outside the model because they are irrelevant to the purpose of the GIS.

The application program used for the route computation requires the data of the GIS. The data are partitioned into the dataset and the metadata.

The program involved falls into the category of geographic information services. This service is a software program that uses the data supplied in the dataset and in the metadata.

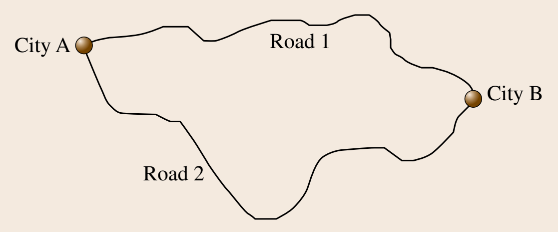


Fig. 13.14 Example GIS with two roads and two cities

The dataset contains the cities and the roads, and the underlying geometries such as points, lines, and coordinates. The cities and roads are called geographic features. A specific city A and another city B are called feature instances. The points and lines are called spatial objects and the coordinates are referred to as DirectPositions.

The metadata contains attributes such as road condition and speed limit. In this example, one metadata exists for one feature instance of a road.

The most frequently used type of UML diagram is a class diagram which consists of classes and their interrelations. A class may be anything that the developer has defined to have common properties. In this example three classes have been defined

1. City
2. Road
3. RouteFinder

The class RouteFinder may be called a title class of the classes Road and City. The class RouteFinder can also be called a parent class whereas the other two are child classes.

Later in the development the model might have to be refined. Let us assume that different types of computations are required for routes using the main roads and the local roads. For this purpose, the class roads would be split into subclasses according to the road classification. As far as possible, properties such as the length of the road would be kept in the superclass. Only the properties that are unique to a subclass such as the maximum speed or winter closure have to be placed there.

A UML class has a name, a set of attributes, a set of operations, and constraints. In our example, the class names are City and Road. It is required that a class name be unique in a model. Thus, in larger models the class name is often a combination of the identification of the submodel and the name, such as FR_City and FR_Road, where "FR" stands for the program's purpose, i. e., *fastest route*. Class names must start with an upper-case character.

The second case of the model, which includes the main road and the local road, is shown in Fig. 13.15.

Attributes are values that are related to the class. In our example, the length of the road is an attribute. Another attribute may be a status tag such as *road open* or *road closed*.

Operations are functions that are related to the class. Many classes have the two rather basic functions setAttributes and getAttributes that allow writing and reading of the attributes of the class. Another operation that might make some sense in our example could answer the question of whether the whole length of the road can be traveled within 1 h going at a speed of 80 km/h. The function would address the attributes of length and availability, and return the result.

Constraints are limitations within a class or within other parts of the model. In our example the number of values per attribute is constrained to be one value. This reflects the fact that a road can usually have only one length. However, we can easily think of other road attributes that may exist many times, such as intersections with other roads.

Associations are semantic connections between classes. It is easy to understand that the class RouteFinder is associated with the classes Road and City, as both are subclasses of the class RouteFinder. The class Road is also directly associated to the class City, because roads start and end at cities. Finally, the class Road has associations to its subclasses MainRoad and LocalRoad.

The quality of these associations differs slightly. The route-finder system is composed of cities and roads. This part of the relationship is called an aggregation. Both Road and City have a relationship called aggregation toward the class RouteFinder. The class RouteFinder is called the parent class, and the classes Road and City are called the children.

If we consider our route-finder system as being complete without any plans for later expansion, the classes Road and City are essential for the life of the system. A strong dependency exists between the children and the parent class, and without these classes the system would no longer work; for example, if the class Road should be deleted, the class RouteFinder no longer makes sense and must be deleted as well.

If we consider our model as being open towards other applications in the future, we can keep the term aggregation. An example of a future application might be the search for the fastest railroad connection. A new class railroad would have to be created and then aggregated to the class RouteFinder. In this scenario, we should keep the association between the classes RouteFinder and Roads on a weaker level and set it to aggregation only. With an aggregation we can indicate that our route-finder system is not just bound to the first application in place.

The classes MainRoad and LocalRoad are specializations of the class Road. A road is either a main road or a local road, but UML also puts it the other way round: the association between the class Road and the classes MainRoad and LocalRoad is called generalization.

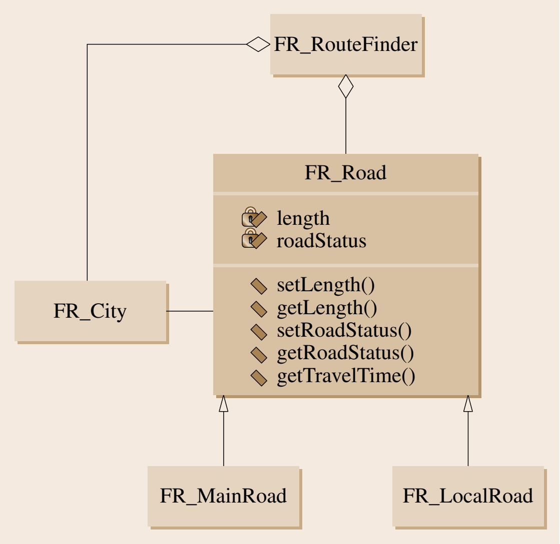


Fig. 13.15 UML class diagram of the route-finder example (FR = fastest route)

UML class diagrams are used in all stages of a development process. A UML model may contain the final product with all classes well defined. It may also display the system in an immature state with a number of open questions within the model. Let us imagine that the development of our route-finder GIS started before it has been decided whether it will calculate routes on roads or on railroads or on both. In this case it is helpful to create a so-called abstract class TransportationLines without determining ahead of time whether it will represent roads, railroads, or both.

The following three examples show the application of three standards of the ISO 19100 family.

Example for UML Class Diagrams Taken From ISO 19100 Standards. This example has been taken from ISO 19111 *Spatial referencing by coordinates*. Basically, it consists of two generalization trees, one with the root class RS_ReferenceSystem and the other with the root class SC_Datum. The trees are associated with a number of other classes as well as with themselves. Enumerations define the attribute values. Notes are used for clarification. The class diagram is normative (Fig. 13.16).

Example for a UML Package Diagram. This example has been taken from ISO 19107 *Spatial schema*. It displays the geometry package with the class content and the internal dependencies. The package diagram is normative (Fig. 13.17).

Example for a UML Use-Case Diagram. This example has been taken from ISO 19116 *Positioning services*. It illustrates the use cases for which the standard is primarily intended. The use-case diagram is informative and, therefore, is not normative (Fig. 13.18).

Terms

This section discusses the ISO/TC 211 approach to maintaining a consistent terminology within the technical committee and the strategy to align with the terminology from other domains.

Terminology (ISO 19104). ISO 19104 *Terminology* provides guidelines for collection and maintenance of terminology in the field of geomatics. The main concept for setting up terminology demands that the same term be used for the same concept throughout the whole family of standards. ISO 19104 also lays down the guidelines for maintenance of the terminology repository [13.52].

Each standard addresses its segment of geographic information and uses the most appropriate terms found there. The ISO terminology standard guarantees the consistency of all involved terms through the specification of a terminological record and the description of principles for definition writing.

In practice, consistent terminology among all ISO 19100 standards has not yet been achieved. This is due to the fact that some of the standards have been developed outside the ISO/TC 211 environment. Examples are ISO 19123 *Schema for coverage geometry and functions*, which was proposed by the OGC, and ISO 19136 *GML*, which was originally developed by a private company.

Much of the terminology has now been harmonized. The terms that still have to be kept with different meanings are marked in the list of definitions.

As ISO standards have to be reviewed every 5 years, a family of standards undergoes minor, but continuous, change. To guarantee current and efficient management of common terms, a terminology repository has been established. The database covers all ISO 19100 terms, showing their definitions and providing notice where multiple concepts for the same term apply. The database is continuously updated. The handbook section *Terms and Definitions of the ISO 19110 Standards* is an outcome of it as of 2011.

Cross-Domain Vocabularies (ISO 19146). Typically, geographic information lies at the point of intersection of many kinds of disciplines. They range from the local cadastre to world meteorological maps, or from car navigation systems to health monitoring. Consequently, terminologies from very distinctive domains meet, which often leads to overlap of terms or their underlying concepts [13.53].

ISO 19146 *Cross-domain vocabularies* defines a methodology to overcome this terminology problem that is caused by adopting the technical vocabularies from different industry-focused geospatial communities. Words can have several meanings depending on the context, while concepts can be referenced by several words, each communicating different connotations and levels of emphasis.

ISO 19146 does not intend to define an ontology or taxonomy for geographic information. The ontology, i. e., the explicit specification of the concept of geographic information, is the topic of the ISO 19150-x group of standards. The taxonomy, i. e., the science and practice of classification, has not yet been addressed by ISO/TC 211, apart from a brief section in ISO 19144-1 *Classification systems – Part 1: Classification system structure*.

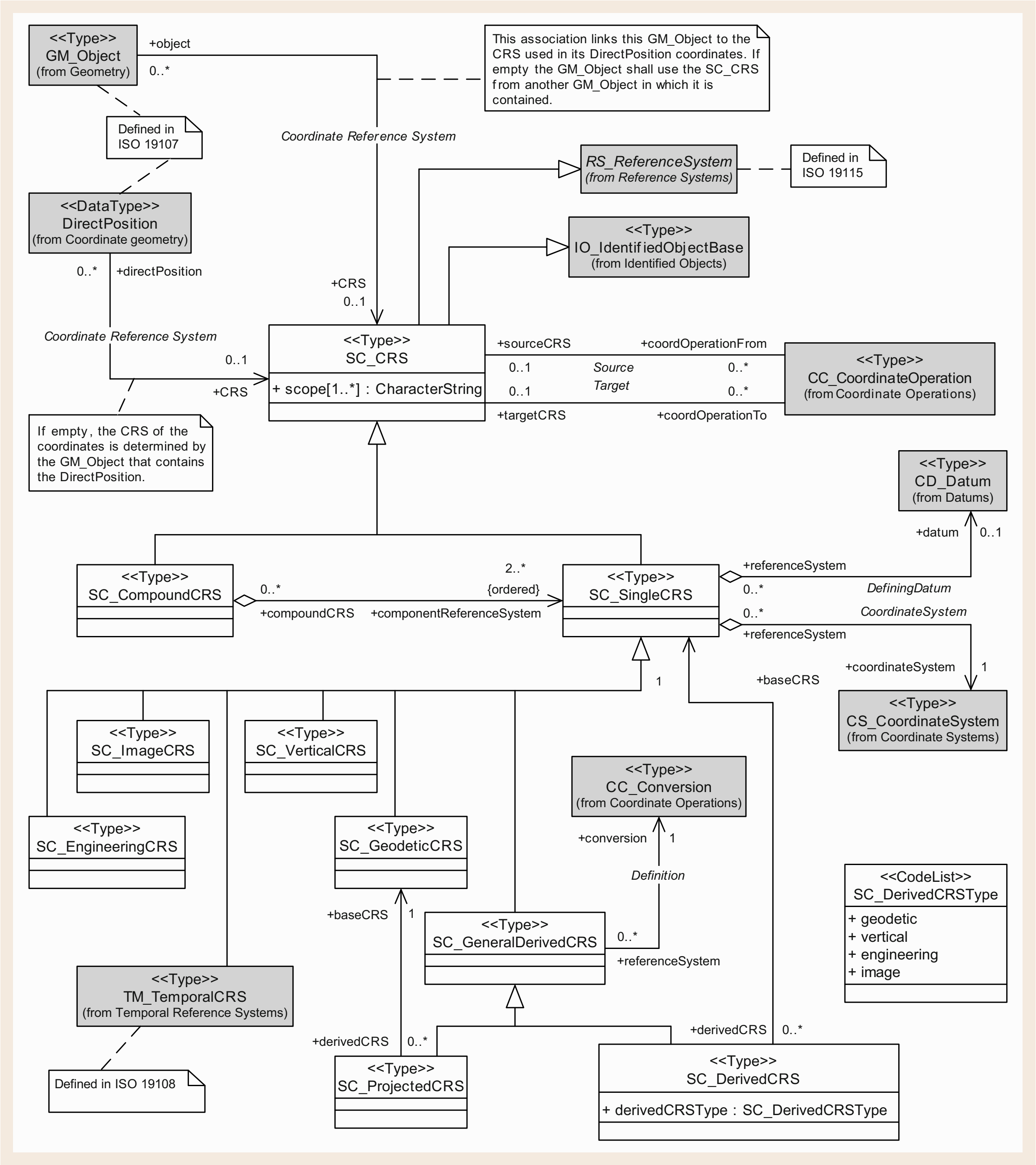


Fig. 13.16 UML class-diagram from ISO 19111 *Spatial referencing by coordinates* (after [13.54])

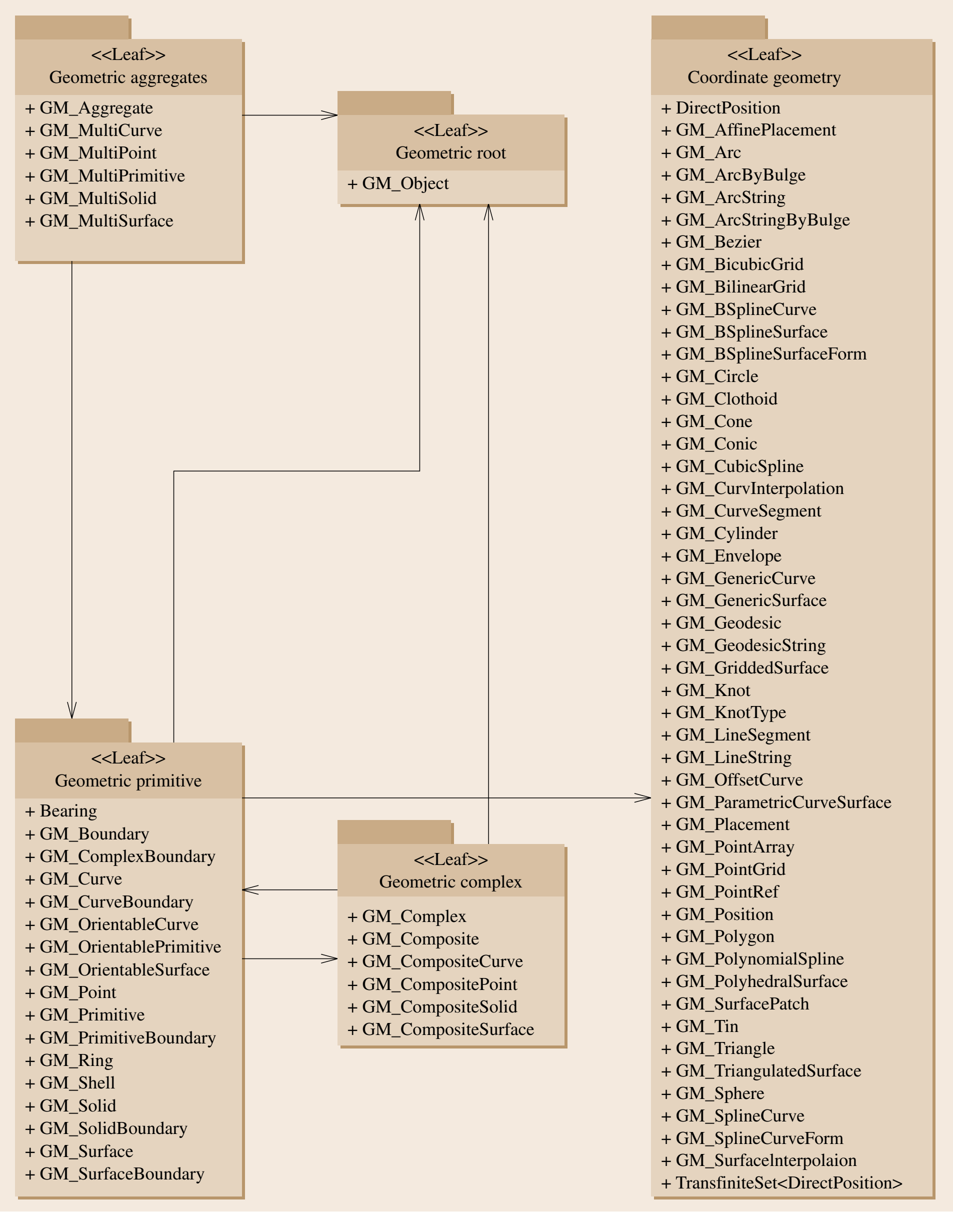


Fig. 13.17 UML package diagram from ISO 19107 *Spatial schema, geometry package* (after [13.55])

ISO 19146 sets seven principles for cross-mapping of vocabularies.

1. The terminology is to be consolidated rather than proliferated.
   The purpose of vocabulary cross-mapping is to standardize the association of specific terms with specific concepts. However, it should not be used as a mechanism for permanently entrenching unnecessary duplication in terminology conventions.
2. The vocabulary cross-mapping shall provide a thesaurus, not a taxonomy or ontology.
   The standard assumes that the developers of the relevant standards have already established the subject area vocabularies.

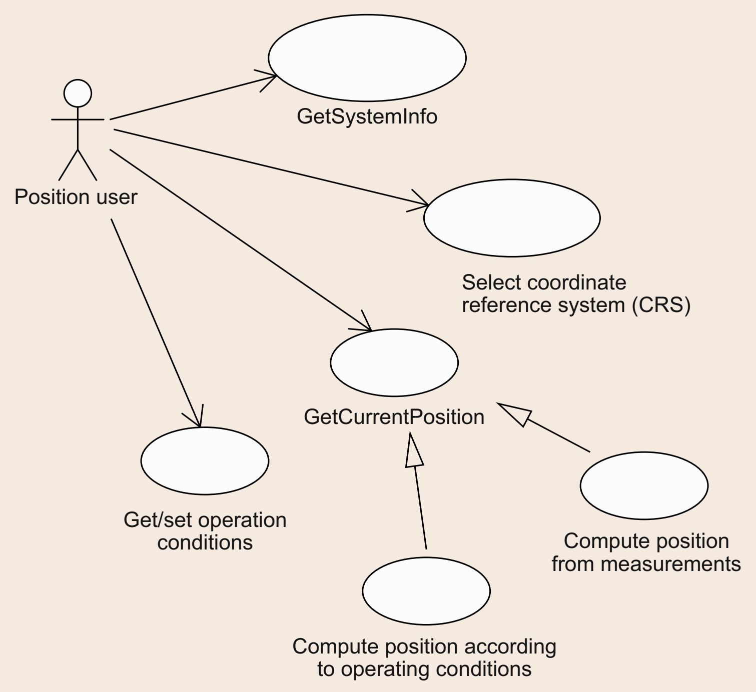


Fig. 13.18 UML use-case diagram from ISO 19116 *Positioning services* (after [13.56])

3. A stable reference vocabulary, maintained by a recognized standards body, shall be adopted for all cross-mapping undertakings involving a particular discipline.
   In the case of ISO/TC 211 the basis is its multilingual glossary of terms. The terms in the handbook section *Terms and Definitions of the ISO 19110 Standards* are based on this glossary.
4. Cross-mapping shall proceed as a collaborative venture.
   During the process, each community of interest should be acknowledged as the ultimate authority regarding correct use and interpretation of its terms and definitions.
5. Cross-mapping shall not circumvent established processes.
   In spite of this principle, cross-mapping may trigger other processes within the collaborating organizations to deprecate terms or to improve concept system structures.
6. Cross-mapping should be recognized through publication in a register.
   ISO 19135 *Procedures for item registration* shall be applied for defining the register.
7. Cross-mapping should accommodate continuous change.The cross-mapping of concepts should be periodically reviewed to identify and accommodate any changes [13.53].

Conformance and Testing (ISO 19105)

If it is claimed that a data file is written in a standardized format such as TIFF, then it would be easy to test conformance with the standard. If a correct TIFF reader is able to open and display the file, then, as far as the content is concerned, both the file and the reader conform to the standard. In larger systems, however, it becomes more difficult to decide if they conform to certain standards. In order to execute a test that is independent of the system manufacturer and the user, independent institutions such as testing laboratories and accreditation bodies often become involved. Testing of conformance represents a major step during the introduction of the system to the market. ISO 19105 *Conformance and testing* sets the rules for the conformance tests of all ISO standards for geographic information [13.57].

Similar to many other basics of the ISO standards for geographic information, the original rules for conformance testing were developed by the information technology community [13.58–60]. These rules were enhanced for use within the ISO 19100 series. Conformance testing means testing of a candidate product for the existence of specific characteristics. The testing addresses the capabilities of an implementation compared with the

1. Conformance requirements as defined in each standard document and the
2. Product description of the manufacturer.

The first is a test according to conformance class A, and the second is a test according to conformance class B.

ISO 19105 defines two types of conformance tests. The *basic test* provides limited testing of an implementation under test (IUT) to establish whether or not it is appropriate to perform more thorough testing. The *capability test* should exercise an implementation as thoroughly as is practical over the full range of conformance requirements specified in the *standard*.

Conformance testing does not include testing the robustness of an implementation, acceptance at the client site, or system performance.

All testable ISO geographic information standards contain a conformance clause that specifies all the requirements that must be satisfied in order to claim conformance to that standard. The conformance clause serves as an entry point for conformance testing. The conformance clause is hierarchically structured into the upper level of an abstract test suite, the medium level of abstract test modules, and the lower level of abstract test cases. The precise definition of the test purpose is the key statement of every test module and every test case. An example of a test purpose may be: *Test the generation of a polygonal line as a sequence without self-intersection.* This is a small example, but it indicates that the abstract test suite of the major standards may become rather voluminous documents. It is for the standard's developer to create a conformance clause that includes all test methods and test cases necessary to guarantee complete conformance to the standard.

An implementation that is to undergo a conformance test is called an *implementation under test* (IUT). ISO 19105 *Conformance and testing* structures the test into four steps: preparation for testing, test campaign, analysis of results, and conformance test report. The conformance assessment process is carried out by an independent testing laboratory.

The formalized approach to testing of implementations has some important intrinsic properties. A test must be repeatable, in that two or more tests of the same implementation are comparable and have mainly the same results. The test is also auditable in that the work of the independent testing laboratory may be subject to audit.

Profiles

Creation of Profiles (ISO 19106). The family of international standards for geographic information covers an immense range of possible applications with reference to the Earth. However, the complete ISO 19100 family of regulations would overload most real applications. Therefore, only a subset of the ISO 19100 standards is normally required. A profile according to ISO 19106 *Profiles* is a subset of the ISO 19100 standards.

The ISO 19100 standards provide two approaches for the creation of a specific application, profiles, and application schemas. While a profile narrows the functionality, an application schema extends it beyond the scope of a given standard in order to meet specific needs. Accordingly, an application schema is developed in two steps.

1. Definition of a profile of the ISO 19100 standards.
2. Creation of an application according to ISO 19101 *Reference model* and ISO 19109 *Rules for application schema* for all additional components.

A profile may become a standard on its own and is then called an international standardized profile (ISP). In the mid 1990s, the joint technical committee of the ISO and IEC (ISO/IEC JTC1) created the international standardized profile as a new type of document. To receive the status of an ISO standard, the document describing a profile has to follow the procedures for the development of an international standard. As a result, it receives its own ISO number. Profiles defined according to the ISO Profile standard may become this type of international standard.

One may argue that, in times of fast computers and the availability of enormous amounts of disc space, it is not necessary to artificially narrow the options offered by a large environment such as the ISO 19100 family of standards. However, the idea of the introduction of profiles is to promote better interoperability between systems by restricting the choices. It is easier for users and system suppliers to agree on a smaller set of common standards then on a large set.

How is a profile defined?

- A profile is a subset of the base standards of the ISO 19100 family of standards or other information technology standards.

- A profile determines how they are used together.
- A profile explains the usage details as far as required.

ISO 19106 distinguishes between two types of profiles.

- Conformance level 1 designates a profile that is purely derived from elements of the ISO 19100 family of standards and possibly other ISO standards.
- Conformance level 2 specifies profiles that integrate elements of non-ISO standards with elements from the ISO standards.

The development of profiles has been opened according to conformance level 2, because the existing suite of standards cannot yet claim to meet *all* requirements. This is despite the great effort that has been put into a generalized and comprehensive approach towards geographic information. A profile of conformance level 2 cannot become an ISO standard of the international standardized profile type.

Functional Standards (ISO/TR 19120). From a long-term perspective, the standards of the ISO 19100 family will become the only internationally agreed foundation for geographic information technology. However, while ISO has been developing the standards, other international organizations have already agreed upon their geographic data environments. Thus, it is ISO's objective to develop a generic suite of standards that is capable of integrating existing environments. It is the challenge of ISO/TR 19120 *Functional standards* to identify existing environments and to provide assistance with the development of profiles [13.62].

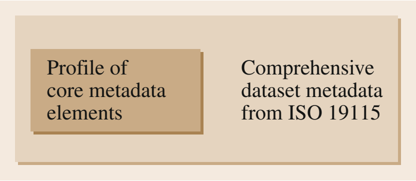


Fig. 13.19 Example of a profile using concepts and structures from one standard (after [13.61])

A functional standard is an existing geographic information data standard developed specifically for the transfer of data between entities in different nations. The efforts of ISO/TR 19120 resulted in a report that considers three functional standards that should be harmonized with the ISO 19100 series.

- The Digital Geographic Exchange Standard (DIGEST), which is used to support the military digital geographic information requirements amongst NATO nations. The standard is maintained by the Defence Geospatial Information Working Group (DGIWG).
- The Geographic Data File (GDF), which is used to define and exchange digital road databases with a particular emphasis on navigation applications. ISO/TC 204 *Intelligent transport systems* has created an international standard for global GDF.
- The International Hydrographic Organization (IHO) Transfer Standard S-57, which is intended to be used for exchange of digital hydrographic data between national hydrographic offices and for distribution to manufacturers, mariners, and other data users.

As the ISO 19100 standards become available, other functional standards were meant to be identified in the future. Therefore, the report was only considered the

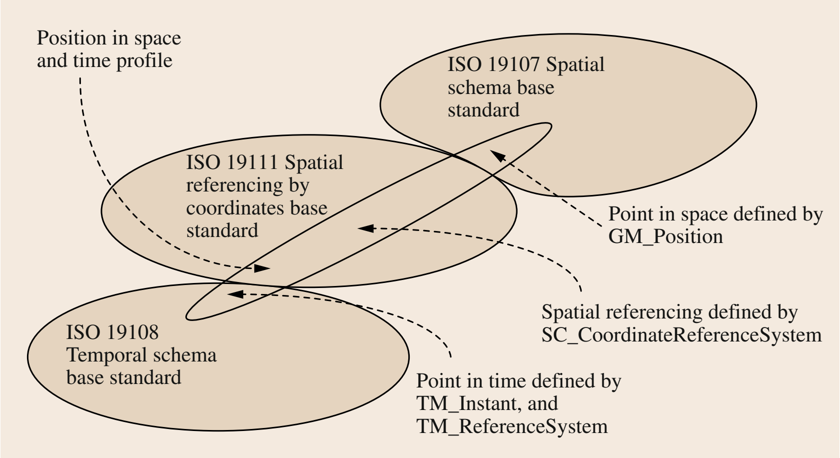


Fig. 13.20 Example of a profile using concepts and structures from more than one standard (after [13.61])

starting point for a feedback cycle between the functional standards communities and ISO/TC 211 experts, and its function is to support the maintenance and future revisions of the ISO 19100 standards. However, since the ISO/TC 211 standards have gained broad acceptance, organizations still maintaining older community standards tend to develop new and ISO-compatible versions.

Core Profile of the Spatial Schema (ISO 19137). ISO 19137 *Core profile of the spatial schema* was intended to provide a small subset of the large number of classes of ISO 19107 *Spatial schema* in order to simplify some applications [13.63]. However, another standard, which implements almost 100% of the spatial schema, became a lot more popular in the meantime, namely ISO 19136 *Geography Markup Language (GML)*.

At present (in 2011), ISO 19137 is under revision. It is open whether this standard will be revised or integrated as a section of another standard such as ISO 19107.

13.4.2 Basic Standards

As stated in Sect. 13.3.4, the members of the ISO 19100 family of standards can be unofficially categorized into the groups infrastructure, basic, imagery, catalogue, implementation, web, location-based services, and classification standards. The basic standards comprise the aspects of services, space, time, georeference, portrayal, encoding, metadata, quality, land administration, digital rights, and application schemas.

Services (ISO 19119)

The IT community decomposes computer software systems by using five different viewpoints. One of them, the computational viewpoint, addresses the services. ISO 19119 *Services* provides the framework to structure services in the context of geographic information. In the case of geomatics, services may be pure information technology services such as querying a database or specific geographic information services such as finding a location in a coordinate reference system (CRS).

Services are defined as the capability to provide for manipulating, transforming, managing, or presenting information. A special case is the service interfaces that are the boundaries across which services are invoked and across which data are passed between a service and an application, external storage device, communications network, or a human being. Following these definitions, the ISO 19100 standards fall into two categories: infrastructure standards and service standards. Infrastructure standards are guidelines that are applicable for all other standards. Examples are ISO 19101 *Reference model* and ISO 19104 *Terminology*. With few exceptions, all standards with numbers between ISO 19107 and ISO 19119 are service standards.

ISO 19101 *Reference model* sets forth the conceptual modeling, the domain reference model, and the architectural reference model. The latter embraces the IT services as defined in the Reference model for Open distributed processing (RM-ODP) and standardizes the extended open system environment reference model (EOSE-RM) for the specific services for geographic information. The general open system environment reference model (OSE-RM) is standardized in ISO/IEC 10746 [13.64].

Figure 13.21 summarizes all IT and geographic information services. Without claiming completeness, the diagram also relates the ISO 19100 standards to the three service categories of geographic information. The acronyms are explained below.

The OSE-RM defines six types of services and five types of interfaces through which the services communicate with other applications or peripheral devices.

- IT service types
  - a) Human interaction service (ITHS).
    An example is the interaction of an operator with the graphic interface while logging on.
  - b) Model management service (ITMS).
    An example is the software-supported creation of an UML diagram while designing a geographic application.
  - c) Workflow/task service (ITWS).
    An example is the setting of a later start time for an overnight run of a large processing job.
  - d) System management service (ITSS).
    An example is the creation of a new user with access rights to a geographic database.
  - e) Processing service (ITPS).
    An example is the calculation of the average density of population in a given dataset.
  - f) Communication service (ITCS).
    An example is the provision of map data over the Internet.
- Interface types
  - a) Application programming interface (API).
    All services communicate via an API with the GIS applications.
  - b) Human technology interface (HTI).
    The best known examples are the window systems on the screen.

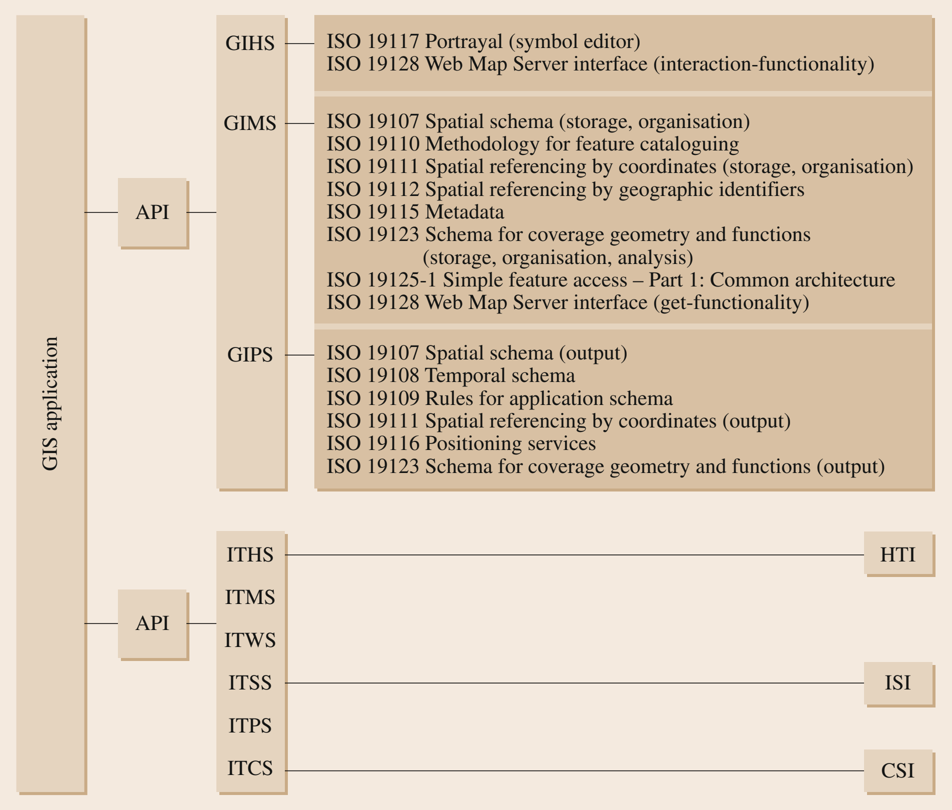


Fig. 13.21 Architectural reference model showing the services and their relations; mapping of the ISO 19100 standards to the extended OSE categories (after [13.38, 65])

c) Information service interface (ISI).
The ISI establishes the link to all data sources, such as the databases from where data shall be retrieved.

d) Communications service interface (CSI).
The CSI is the link between the computer and the network.

e) Network-to-network interface. This is the network itself.

In addition, the EOSE-RM includes the following services. Theoretically every IT service has an equivalent geographic information service. In fact, only three categories are relevant for geographic information:

- GI service types
  a) Geographic information human interaction service (GIHS).
  An example is the interaction of an operator with the graphic interface while picking a line.
  b) Geographic information model management service (GIMS).
  An example is the storage of a geographic feature according to an application schema.
  c) Geographic information processing service (GIPS).
  An example is the output of a map to a screen.

Rules for Application Schema (ISO 19109)

The ISO 19100 standards address the full range of geographic information. A certain application only uses a subset of the available standards, combined with many additional details that are beyond the scope of the abstract standards. An example is a feature catalogue for a given application.

The ISO 19100 standards provide two approaches to creating a specific application: profiles and application schemas.

The kernel of ISO 19109 is the definition of a geographic feature. A feature stands for anything in the real world; for example, a feature can be a single corner stone of a land parcel, a whole country, a digital elevation model, or a satellite image. In order to integrate a feature into the models of geographic information in a homogeneous way, ISO 19109 defines the GFM.

The GFM defines an abstract feature with attributes and operations. Attributes contain all the static information such as the quality of the feature or its geometric properties (point, curve, surface, or solid). Operations contain information about the change of a feature according to external influences such as a road being closed in winter or a road being displayed only within the scale range 1 : 5000 to 1 : 25 000. This change is also called the behavior of the feature.

As these examples show, features can differ in importance and size. In practice, this often leads to a hierarchical grouping of features; for example, public buildings and private buildings are both *buildings*. The GFM allows for the construction of a generalization tree where the feature types (class GF_FeatureType) public and private buildings are specializations within the feature type building.

Generally, features reside independently in the dataset. In the case of a three-dimensional dataset the relations between features can be computed in all spatial dimensions. The over, under, or level situation at intersections is a particularly important case for mapping and network computation. A three-dimensional dataset implicitly contains the necessary information. A two-dimensional dataset does not allow for these computations. To supply the missing information, the GFM includes associations between features that contain the information regarding which feature is above the other, or if both are at the same level. In this case, the association type (class GF_AssociationType) would be *intersection*, and the association roles (class GF_AssociationRole) would be under, over, or level, respectively.

In some cases, it may be advisable to impose constraints on the definition of a feature. A theoretical example may be that a feature of type curve must not have more than 1,000 points. The GFM allows the formulation of these constraints (class GF_Constraint).

An application schema is usually created by the definition of the features. All details are collected in a feature catalogue. The methodology for building feature catalogues is covered by ISO 19110.

Spatial Schema and GML (ISO 19107 and ISO 19136)

ISO 19107 *Spatial schema* is a standard to describe the geometry and topology of geographic information. This standard comprises a comprehensive definition of the geometric elements required to build a geographic dataset.

The standard primarily addresses vector data up to three dimensions. For the two-dimensional case, the standard includes provisions that guarantee seamless coverage of a complete area.

ISO 10107 defines a method to describe the position of a geometric element. A position is named DirectPosition. It includes the coordinates such as x, y, and z depending on the CRS of the dataset and its dimension. This method is used throughout other important standards of the ISO 19100 family such as ISO 19123 *Schema for coverage geometry and functions*.

This standard does not address graphic portrayal of the geometric elements.

ISO 19136 *Geography Markup Language (GML)* defines an almost complete implementation of ISO 19107 in XML.

Section 13.5.3 contains a detailed description of ISO 19107. Section 13.5.6 discusses the GML standard.

Temporal Schema (ISO 19108)

As far as geomatics is concerned, temporal characteristics are standardized in ISO 19108 *Temporal schema*. Many geographic applications require a time stamp related to the physical reality, therefore the standard deals with the valid time, which is the time when the event occurred in the abstracted reality. The standard does not address the transaction time, when the data becomes available in a database [13.66].

In many applications, time is handled as a metadata element only. More advanced applications require time as a further dimension. This enables modeling of the behavior of a feature as a function of time, such as a satellite's position along its orbit. The time dimension may be combined with spatial and parametric coordinate reference systems to form a compound CRS [13.54, 67].

The standard distinguishes between the geometry of time and the topology of time. The geometry of time has the four major classes

1. The instant: a certain time.
2. The period: the time elapsed between two instances.
3. The order: the sequence of instances.
4. The relative position: temporal relation of earlier and later instances.

The topology of time describes the temporal connectivity between two or more occurrences. If two or more occurrences take place at one instant, that instant is called a node. More precisely, the period between the occurrences is smaller than the resolution of time. If two or more occurrences take place simultaneously during the period, that period is called an edge.

More temporal aspects are a part of ISO 19136 *Geography Markup Language (GML)*, discussed in Sect. 13.5.6.

Georeference

This section addresses spatial referencing by coordinates and parametric values (ISO 19111, ISO 19111-2), geodetic codes and parameters (ISO/TS 19127), geographic point locations (ISO 6709), spatial identifiers (ISO 19112), and positioning services (ISO 19116).

Coordinate Reference (ISO 19111, ISO 19111-2). ISO 19111 *Spatial referencing by coordinates* models coordinate systems and coordinate operations for the ISO geomatics standards. This model contains the horizontal and vertical coordinate references for geographic features. According to this standard, coordinate reference systems may be one-, two-, or three-dimensional, and do not change over time.

The third dimension may be a nonspatial parameter such as pressure. However, this case is addressed in a separated standard, namely ISO 19111-2 *Spatial referencing by coordinates – Part 2: Extension for parametric values* [13.54, 67].

Both standards have been jointly developed by ISO/TC 211 and the Open Geospatial Consortium (OGC).

Coordinate Reference System. A coordinate reference system is a coordinate system that has a reference to the Earth by a so-called datum. ISO 19111 standardizes the details in order to fully define a coordinate reference system.

A CRS may be geodetic, vertical, engineering, or image.

A geodetic CRS using 2-D ellipsoidal coordinates (latitude and longitude) is used when positions of features are described on the surface of the ellipsoid. Vertical CRSs make use of the direction of gravity to define the concept of height or depth.

In addition, three more subtypes of CRS shall be distinguished: derived, projected, and compound.

A derived coordinate reference system is one which is defined by applying a coordinate conversion to another coordinate reference system. A projected coordinate reference system is derived from a base geodetic CRS by applying a coordinate conversion known as a map projection to latitude and longitude ellipsoidal coordinate values. A reference that is defined by two different coordinate reference systems, one of which is an elevation system, is called a *compound* CRS. A compound CRS is usually used to provide an independent reference for horizontal and vertical coordinates.

For spatial coordinates, a number of constraints exist for the construction of compound CRSs. Valid combinations are

- geodetic 2-D + vertical,
- geodetic 2-D + engineering 1-D (near vertical),
- projected + vertical,
- projected + engineering 1-D (near vertical),
- engineering (horizontal 2-D) + vertical,
- engineering (1-D linear) + vertical.

A CRS is called fully defined if it has a datum and a coordinate system. Historically, the datum was often the position of an observatory near the center of a country where the position and the orientation of the coordinate system are defined in relation to the physical reality of the Earth. The prime meridian defines the origin of the coordinate values of the first ellipsoidal axis.

The following text provides an example for a compound CRS.

If it is an ellipsoidal system, the three coordinates are longitude, latitude, and ellipsoidal height. In most applications, longitude and latitude are referred to as geographic coordinates. Because ellipsoidal heights are sometimes difficult to relate to the topographic Earth's surface, the third coordinate is usually not related to the ellipsoid. Instead it could be given in an independent elevation reference system. This method is acceptable, because in small-scale and medium-scale applications, the decrease of the height accuracy caused by introducing a second reference system is insignificant compared with the accuracy of the height values.

Datum and Coordinate Systems. ISO 19111 defines eight types of coordinate systems (Table 13.11).

A geodetic datum gives the relationship of a coordinate system to the Earth. It is geodetic, vertical, engineering, or image (see above). In many cases, it requires an ellipsoid definition. A prime meridian defines the origin from which longitude values are specified. Most geodetic datums use Greenwich as their prime meridian.

Engineering datums are used in a local sense, often being applied to platforms such as satellites and ships. An image CRS is an engineering CRS applied to images with small extension, such as an affine transformation.

Coordinate Operations. The details of the specification of a CRS become important if datasets with a refer-

Table 13.11 Coordinate system subtypes (after [13.54])

CS subtype	Description	Used with CRS type(s)
affine	Two- or three-dimensional coordinate system with straight axes that are not necessarily orthogonal	Engineering Image
Cartesian	Two- or three-dimensional coordinate system which gives the position of points relative to orthogonal straight axes. All axes shall have the same unit of measure	Geodetic Projected Engineering Image
cylindrical	Three-dimensional coordinate system consisting of a polar coordinate system extended by a straight coordinate axis perpendicular to the plane spanned by the polar coordinate system	Engineering
ellipsoidal	Two- or three-dimensional coordinate system in which position is specified by geodetic latitude, geodetic longitude, and (in the three-dimensional case) ellipsoidal height	Geodetic
linear	One-dimensional coordinate system that consists of the points that lie on the single axis described. Example: usage of the line feature representing a pipeline to describe points on or along that pipeline This international standard only lends itself to be used for simple (= continuous) linear systems. For a more extensive treatment of the subject, particularly as applied to the transportation industry, refer to ISO 19133	Engineering
polar	Two-dimensional coordinate system in which position is specified by distance from the origin and the angle between the line from the origin to the point and a reference direction	Engineering
spherical	Three-dimensional coordinate system with one distance, measured from the origin, and two angular coordinates. Not to be confused with an ellipsoidal coordinate system based on an ellipsoid *degenerated* into a sphere	Geodetic Engineering
vertical	One-dimensional coordinate system used to record the heights (or depths) of points dependent on the Earth's gravity field. An exact definition is deliberately not provided, as the complexities of the subject fall outside the scope of this specification	Vertical

ence to two or more CRSs are processed in the same environment. The coordinates of all features have to be made available in the same CRS. Consequently, positions given in other systems must be converted or transformed. The standard describes the information required to change coordinate values from one CRS to another by operations.

The operation is a generalized term for conversion and transformation (supertype). The standard also sets the frame for changing coordinates between two different CRSs and distinguishes between *conversion*, where the involved CRSs have the same datum, and *transformation*, where the involved CRSs have different datums. In addition, the standard defines the concatenated operation and the pass-through operation.

A *conversion* changes coordinates from one coordinate system to another based on the same datum. In a coordinate conversion, the parameter values are exact. The coordinate conversion includes the map projection, the coordinate conversion of ellipsoidal coordinates to three-dimensional Cartesian coordinates, unit changes, and the shifting of the origin towards a local grid. A map projection converts three-dimensional ellipsoidal coordinates (excluding height) to two-dimensional Cartesian coordinates. In all cases, the conversion is based on exact formulas that are well known in the scientific literature and that are described in Chap. 8. An example for a map projection is the conversion between ellipsoidal coordinates on the Hayford ellipsoid to projected coordinates in Universal Transverse Mercator (UTM) (Hayford ellipsoid), and vice versa. Elevations are not taken into account.

A *transformation* changes coordinates between different CRSs with different datums. The shift, rotation, and scaling between different CRSs are derived from identical non-error-free defined points. The orientation of global CRSs is always an estimation, because it is based on a number of well-defined (but differently selected) reference points, where the residuals are minimized according to an adjustment method. Because the exact geometric relation between the CRSs is not exactly known, a transformation can only be performed with an accuracy level that corresponds to the lowest accuracy of the definition of the system parts itself; for example, if coordinates given in WGS84 (WGS84 ellipsoid) are needed in the German Gauss–Krüger system (Bessel ellipsoid), they must be transformed.

The concatenated operation puts two or more operations in a sequence, for instance, the three-step operation conversion–transformation–conversion. An example is the change of point coordinates from the German datum to ETRS89, which has to be performed by converting the coordinates to the Bessel ellipsoid followed by transforming them to the GRS80 ellipsoid, and finally converted them to ETRS89 projected coordinates.

The pass-through operation has been defined to overcome the problem that in compound coordinate reference systems a coordinate operation may only be applied to one coordinate system and not to the other. For instance, computations of the horizontal coordinates x and y do not necessarily influence the height z. This may be obvious but may cause severe problems in automated processes. The pass-through operation allows the two coordinate systems to be isolated.

To illustrate the meaning of ISO 19111, Table 13.12 provides examples for different types of coordinate reference systems.

ISO 19111-2. ISO 19111-2 *Spatial referencing by coordinates – Part 2: Extension for parametric values* defines the mechanism to combine a horizontal spatial coordinate reference system with a nonspatial third dimension. The *pressure altitude* universally used in aviation is a coordinate of this kind. This is distinct from the situation where a measure of the parameter is present as an attribute of the spatial object, such as the air temperature at a given position.

The spatial and the nonspatial CRS form a compound CRS, as defined in ISO 19111. This compound CRS may also be combined with one or more temporal CRSs according to ISO 19108.

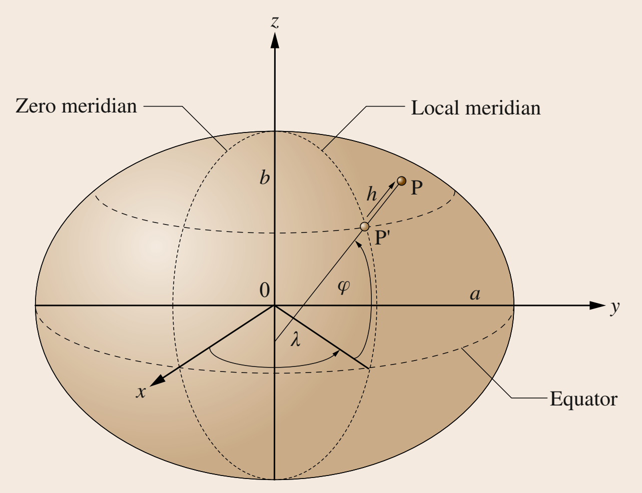


Fig. 13.22 Ellipsoidal and Cartesian coordinate system (after [13.54])

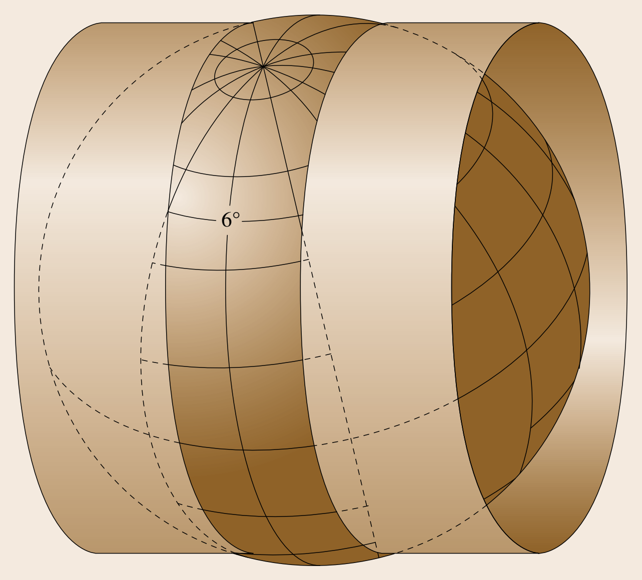


Fig. 13.23 Ellipsoidal and projected coordinate reference system (CRS). Example: Universal Transverse Mercator (UTM) projection with strips 6° wide in longitude (after [13.68])

Geodetic Codes (ISO/TS 19127). Within the ISO 19100 family of standards, CRSs are addressed in ISO 19111 *Spatial referencing by coordinates*, but they do not standardize a specific CRS. Therefore, the ISO technical specification ISO/TS 19127 *Geodetic codes and parameters* bridges the gap between the abstract frame of ISO 19111 and practical needs.

Table 13.12 Examples for different types of coordinate reference systems (CRS)

Geodetic CRS with ellipsoidal CS (longitude, latitude, ellipsoidal height)	
WGS84 (φ, λ, h)	World Geodetic System 84 (1984)
Geodetic CRS with cartesian CS (X, Y, Z)	
WGS84 (X, Y, Z)	World Geodetic System 84 (1984)
ETRS 89 (X, Y, Z)	European Terrestrial Reference System 89 (1989)
Projected CRS (X, Y)	
NAD83/Alabama East	North American Datum (1983)
Compound CRS: Geodetic 2-D + Vertical (longitude, latitude, gravity-related height)	
OSGB36 + ODN	Ordnance Survey of Great Britain 1936 + Ordnance Datum Newlyn
Compound CRS: Projected + Vertical (X, Y, gravity-related height)	
ETRS89 (projected) + EVRS2000	European Terrestrial Reference System 89 (1989) + European Vertical Reference System 2000
DHDN + DHHN	Deutsches Hauptdreiecksnetz (Gauss–Krüger Germany) Deutsches Haupthöhen Netz (German vertical datum)

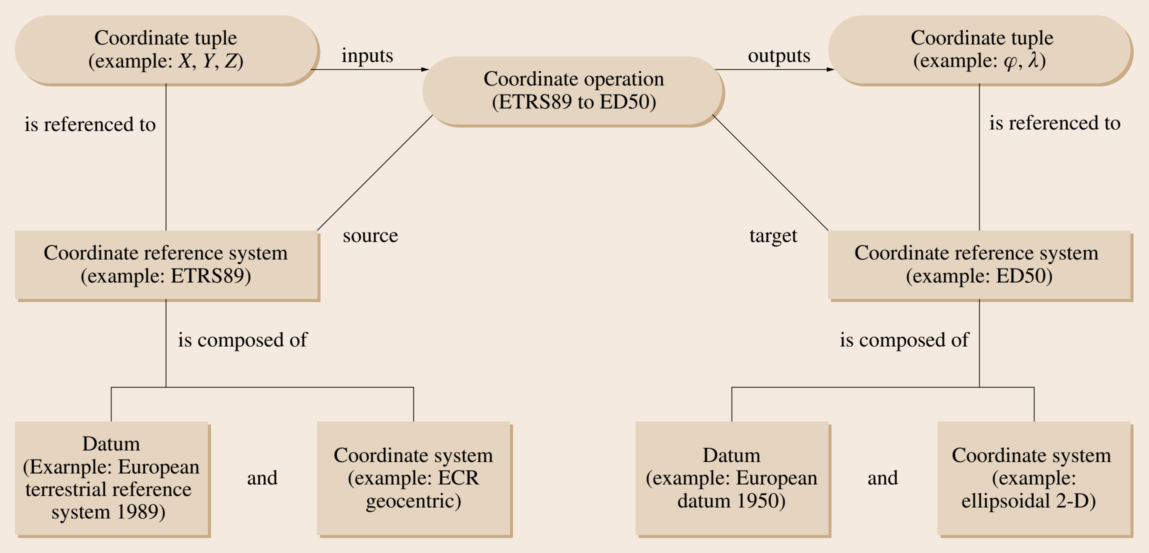


Fig. 13.24 Conceptual model for spatial referencing by coordinates and coordinate operations with a transformation as the central part

Within the geographic information community, many references exist defining geodetic codes and parameters, none of which are in full compliance with ISO 19111. ISO/TS 19127 *Geodetic codes and parameters* provides the required guidance to apply ISO 19111 *Spatial referencing by coordinates* in an appropriate manner.

The mechanism in the ISO 19100 family for creating publicly available lists of codes and parameters is a registry (ISO 19135). ISO/TS 19127 provides rules for the creation and maintenance of registers for geodetic codes and parameters [13.69].

Standard Representation of Geographic Point Location by Coordinates (ISO 6709). The latest version of this standard, ISO 6709:2008, defines a model to describe a three-dimensional position by longitude, latitude, and height or depth in a computer- and human-readable form. The previous version, ISO 6709:1983, was not fully fit for geographic information in that it did not support many requirements such as an XML representation and the depth needed for hydrography [13.70, 71].

The model set in ISO 6709:2008 allows for processing of point coordinates in a generalized manner in order to include existing standards such as

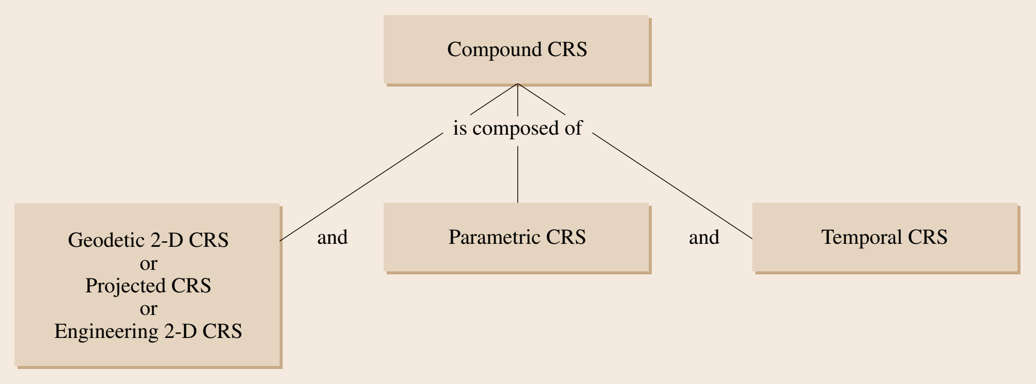


Fig. 13.25 Compound coordinate reference system including spatial (ISO 19111), parametric (ISO 19111-2), and temporal (ISO 19108) CRSs (after [13.67])

- ISO 6709:1983 *Standard representation of latitude, longitude and altitude for geographic point locations*,
- DCMI Point encoding scheme (Dublin Core Metadata Initiative),
- KML (keyhole markup language),
- GeoVRML (geographical data using the virtual-reality modeling language),
- GML Point profile (Geography Markup Language).

The number of this standard does not comply with the ISO 19100 family because the original ISO 6709:1983 *Standard representation of latitude, longitude and altitude for geographic point locations* was developed by ISO/IEC JTC1.

In the year 2002, maintenance of ISO 6709 was transferred to ISO/TC 211.

Geographic Identifiers (ISO 19112). The position of geographic features is often described through their spatial relation to other geographic features. This relation may be a containment, a local measurement, or a loose relation. An example of containment is a city within a province, an example of a local measurement is the distance to the next major road intersection, and an example of a loose relation is a restaurant *between the museum and city hall*. A typical application is the partitioning of an area using postal codes. These types of positions are addressed in ISO 19112 *Spatial referencing by geographic identifiers*.

All positions are related to a spatial reference system. The spatial reference system comprises a subdivision of a territory such as the hierarchy province–city–address. The core element of the reference system is a gazetteer that adds a descriptive position to every geographic feature in the territory.

A gazetteer is a file that contains a master record for every geographic feature and the related descriptive position. If required, any descriptive position can be related to coordinates according to ISO 19111 *Spatial referencing by coordinates*. The coordinates may be expressed as point coordinates or as a bounding box for curves or surfaces.

A location type according to ISO 19112 is a territorial unit of the spatial reference system. Examples of location types are an administrative area, town, locality, street, and property. A geographic feature in this context is called a location instance. A geographic feature is listed in the gazetteer and is related to one or more location types; for example, the city hall is a geo-

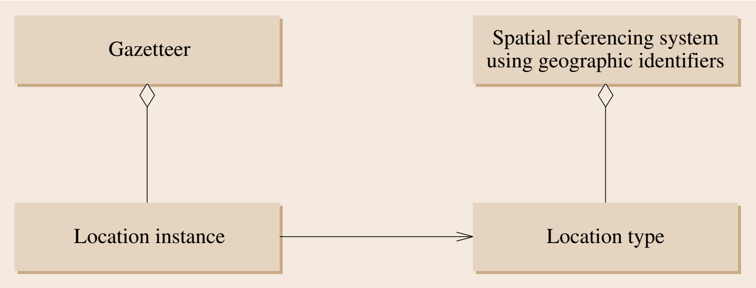


Fig. 13.26 Spatial reference system using geographic identifiers (after [13.72])

graphic feature that has one record in the gazetteer, and this record contains a position that may be expressed in three ways: as an address, or as a containment in the city, or as a containment in the province.

Positioning (ISO 19116). Positioning services are computer techniques that deliver positions of an object relative to the Earth or to some other position. These techniques include Global Navigation Satellite Systems (GNSS), inertial systems, and total stations. ISO 19116 *Positioning services* standardizes a data model for the basic information independent of the system type, and a group of operations to handle those data. A system-specific section is dedicated to GNSS only.

Finding a position is no longer the domain of a skilled navigator or experienced surveyor, but any user can still suffer from the great variety of different and incompatible interfaces among positioning systems. ISO 19116 standardizes this interface and isolates the client from the multiplicity of protocols.

Within the ISO 19100 family, positioning services are among the processing services identified in ISO 19119.

Figure 13.27 gives an overview of the application cases of the positioning services. The diagram covers the standardized types including some future conceptual types.

Figure 13.28 shows the hierarchical structured data model for the basic information. The position information refers to ISO 19111 *Spatial referencing by coordinates*. The "Link to spatial referencing system" means a control point or a similar link between the instrument coordinate system and the Earth in order to control accuracy aspects.

Portrayal (ISO 19117)

Originally, the graphic presentation of geographic information was strictly the domain of cartography but has now also become an important section of geomatics. ISO 19117 *Portrayal* defines a schema to create graphic output for datasets and metadata of the ISO 19100 family of standards. The scope of ISO 19117 does not include standardization of cartographic symbols, standardization of symbol graphics such as Scalable Vector Graphics (SVG), portrayal services such as Web Map Server (WMS), dynamic maps, map generalization, or the third dimension as used in simulations.

Chapter 11 of this handbook gives a comprehensive view on the science of cartography.

Portrayal Catalogue. According to ISO 19117, the cartographic symbolization is kept separate from the feature types of the dataset. The definition of the cartographic representation for a feature is stored in a portrayal catalogue. Essentially, the catalogue is a reference list that relates each feature code that is used to identify different feature types to an individual cartographic portrayal.

The portrayal catalogue contains portrayal symbols and portrayal functions. The symbols are meant to hold

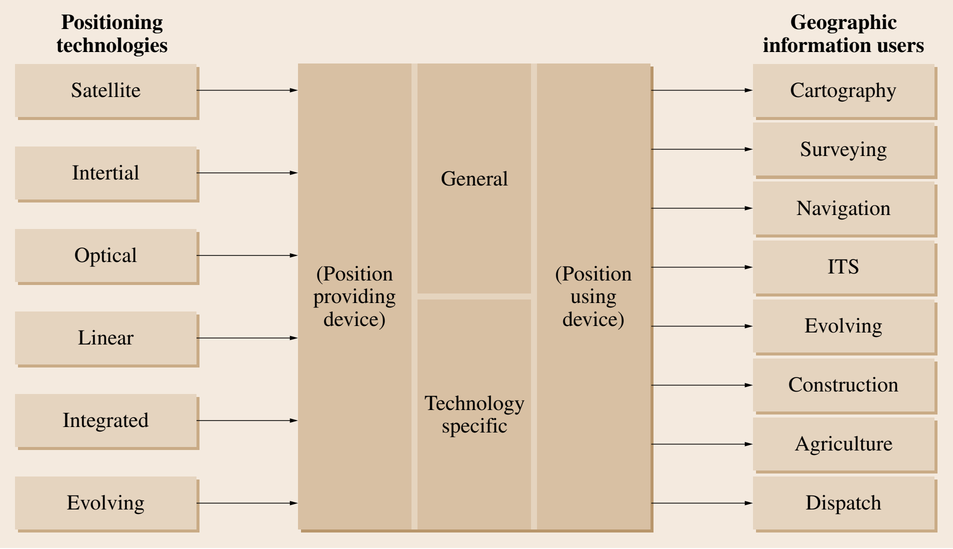


Fig. 13.27 Overview of application cases of the positioning services (after [13.56]) (ITS – intelligent transport system)

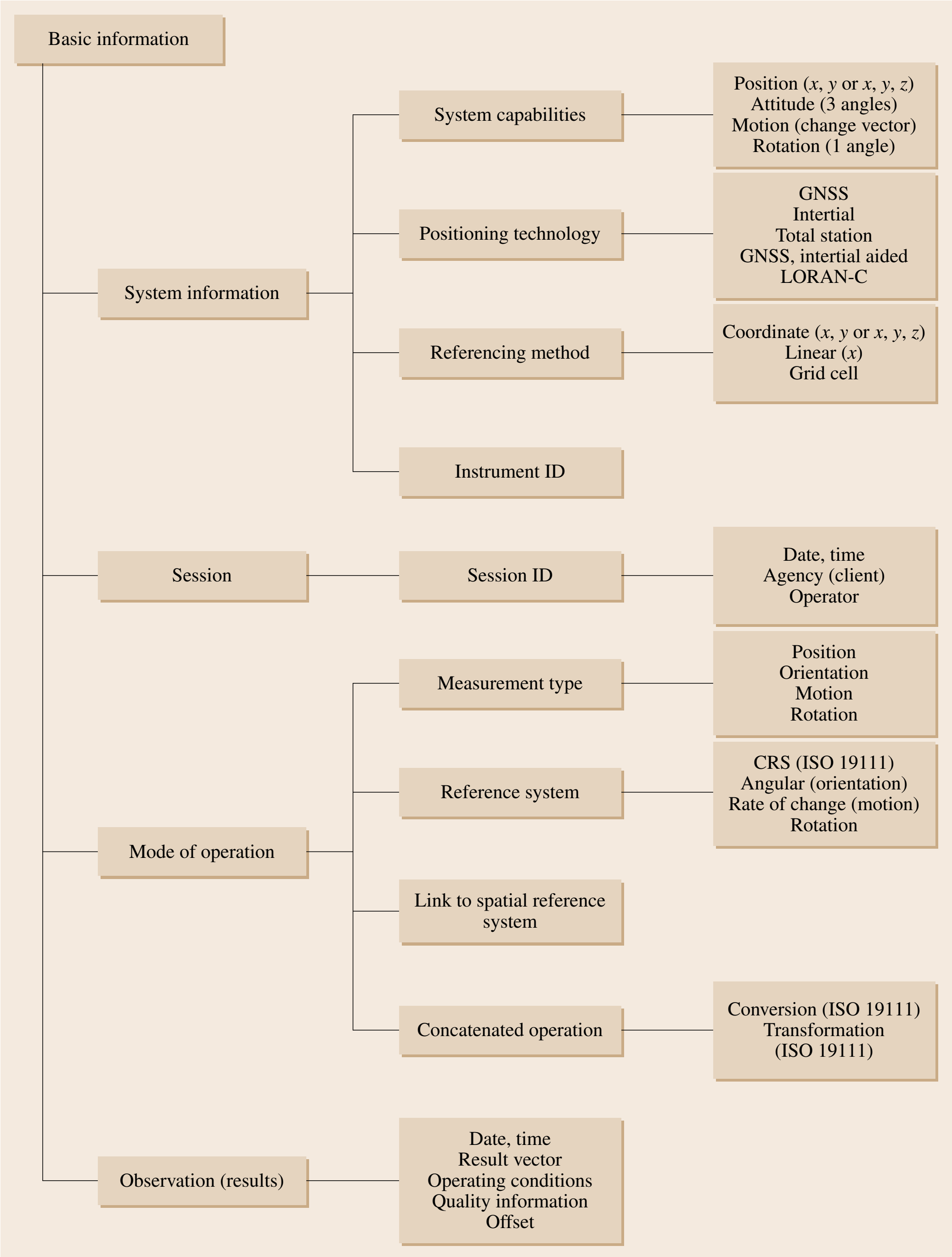


Fig. 13.28 Data model for the basic information of the positioning services

their basic geometry and graphics. The functions modify those properties to adapt to the mapping scale and other display parameters.

Conditional Portrayal Functions. The standard distinguishes between two types of functions: conditional and context.

The conditional functions can test for feature attributes, geometry, and other properties of the feature; for instance, this function determines which symbol shall be selected for a given feature. The function may be simple, such as a *black solid line* to portray a local road, or sophisticated, such as a *double dashed red line* to portray a major road that carries 10 000 or more vehicles daily and that is maintained by the provincial government.

Examples of topographic feature types are streams, fields, and elevation points. A portrayal catalogue contains one cartographic representation for each feature type. For these examples it may contain a blue line for streams, a green fill-area symbol for fields, and a brown point for elevation points.

Context Portrayal Functions. The context function can test for external factors such as display scale and viewing conditions, which are relevant for instance in mobile applications. An example is a car navigation system that will always display the map with the driving direction up.

Default Representation, Priority, External Functions. The portrayal specification contains all the attributes and operations required to derive the graphic representation for the given feature type according to the applicable function. The catalogue will always specify a default representation if the function search for a given feature type fails.

More than one portrayal catalogue may be defined for one dataset to allow for different types of maps.

Dense graphics may result in uncontrolled overlay of elements. A priority attribute allows defining the top element that hides the others in the case of multiple elements at the same position.

To adapt the graphics to any given symbolization catalogue, external functions may be applied to the individual functions or to the whole dataset.

Encoding (ISO 19118)

The concept of the exchange of geographic information datasets is standardized in ISO 19118 *Encoding*. It defines a system-independent data structure for transport and storage and normatively demands the usage of XML for encoding. Presently, the ISO 19100 family of standards defines two XML encoding rules: ISO 19136 and ISO/TS 19139 *Metadata – XML schema implementation*. Either rule set may be applied depending on the use case.

The primary goal of the ISO 19100 family of standards is to enable full interoperability between heterogeneous geographic information systems. To achieve this goal, two fundamental issues need to be resolved. The first issue is to define the semantics of the content and the logical structures of geographic data. This is achieved by implementing the same application schema. The second issue is to define a system- and platform-independent data structure that can represent data corresponding to the application schema; for example, equal semantics and logical structures can be guaranteed by using the same feature catalogue in the two systems involved. A system- and platform-independent data exchange format has to be created according to ISO 19118 *Encoding*.

Model for Data Exchange. The generic model for the data exchange assumes two systems that run on differ-

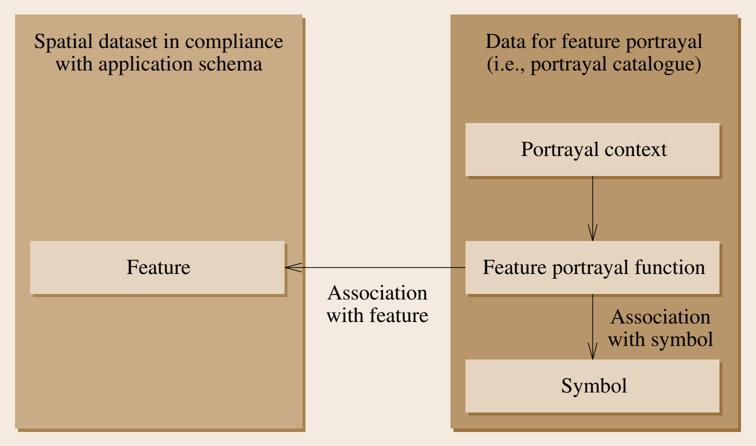


Fig. 13.29 Overview of portrayal (after [13.73])

ent computer platforms and have different application schemas. The transfer of a dataset between such systems is modeled in six steps.

- Step 1: The source system translates its internal data into a data structure that is according to the common application schema.
- Step 2: An encoding service applies the encoding rules to the data, creating a file or transferring the data to a transfer service.
- Step 3: The source system invokes a transfer service to send the encoded dataset to the destination system.
- Step 4: The destination system receives the dataset.
- Step 5: The destination system applies the inverse encoding rule to interpret the encoded data.
- Step 6: The destination system must translate the application schema specific data into its internal database.

Steps 2 and 5 are standardized in ISO 19118 that describes the encoding and the decoding of the dataset. These two steps are handled by an encoding service that is a software component that implements the encoding rule and provides an interface to encoding and decoding functionality.

The encoding rule specifies the data types to be converted as well as the syntax structure and coding schemes used in the resulting data structure, preferably an XML document.

Steps 3 and 4 use general information technology transfer services to send and receive data.

Steps 1 and 6, the internal translations within the source and destination systems, are outside the scope of this standard.

Encoding Using Extensible Markup Language (XML). As the XML is recommended for data exchange, ISO 19118 *Encoding* defines a mapping for application schemas that are written in the UML to the corresponding data structures of XML. There are two views to that mapping:

1. The *abstract view* is independent from any dataset. This is the *application schema*. It contains the classes and other components, such as attributes and associations, that fully describe all geographic feature types belonging to a certain application and their relations. A representation of the application schema is a feature catalogue. In XML the application schema is expressed as a Document Type Definition (DTD) or as an XML Schema document (XSD). Both contain the rules according to which an XML document has to be built.
2. The *implementation view* addresses a specific geographic dataset. This is the *application data*. It is, for example, a map compiled according to a feature catalogue. As every geographic feature is an *instance* of one class of the application schema, the dataset is addressed as the *instance model* in ISO 19118. For the purpose of exchanging the dataset, the instance model is encoded in an XML document. The structure and the tags of that XML document are built according to the XML DTD or to the XML XSD.

Metadata (ISO 19115, ISO 19115-2)

ISO 19115 *Metadata* describes the metadata for documenting geographic information. It provides information about the identification, extent, quality, spatial

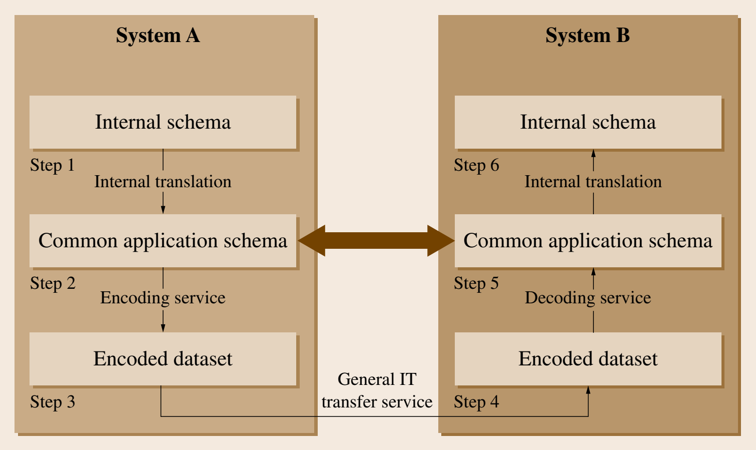


Fig. 13.30 Model for data exchange, simplified (after [13.74])

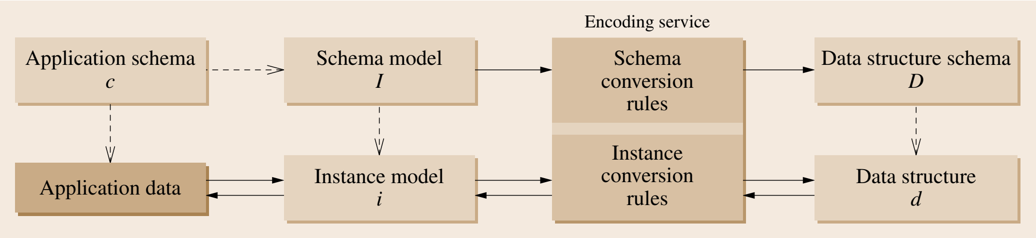


Fig. 13.31 XML-based conversion rules (after [13.74])

and temporal schema, spatial reference, and distribution of digital geographic data. This standard is applicable for describing geographic datasets, dataset series, and individual geographic features and feature properties. This standard can be used for cataloguing datasets, clearinghouse activities, and the full description of datasets.

The standard contains the complete listing of all metadata elements of the ISO 19100 family with a short explanation of each, however the detailed description of most elements can only be found in the individual standards.

Table 13.13 Core metadata for geographic datasets

Core metadata elements
Dataset title (M)
Dataset reference date (M)
Dataset responsible party (O)
Geographic location of the dataset (C)
Dataset language (M)
Dataset character set (C)
Dataset topic category (M)
Spatial resolution of the dataset (M)
Abstract describing the dataset (M)
Distribution format (O)
Additional extent (vertical, temporal) (O)
Spatial representation type (O)
Reference system (O)
Lineage statement (O)
Online resource (O)
Metadata file identifier (O)
Metadata standard name (O)
Metadata standard version (O)
Metadata language (C)
Metadata character set (C)
Metadata point of contact (M)
Metadata date stamp (M)

(M) = mandatory, (O) = optional, (C) = conditional = mandatory under certain conditions

Metadata is a prerequisite to reuse geographic datasets. In a heterogeneous computing environment that has a variety of available data sources as well as a great number of different applications for the data, the metadata provide guidance to find the most appropriate dataset for a certain application. The metadata are capable of locating, evaluating, extracting, and employing the required datasets.

The current version of ISO 19115 refers primarily to vector data. This standard is about to be renamed as ISO 19115-1. ISO 19115-2 *Metadata – Part 2: Extensions for imagery and gridded data* is an add-on for imagery-type data (raster).

Content of ISO 19115. The metadata elements in ISO 19115 are grouped into two levels: the core metadata elements and the full list (also called comprehensive metadata elements).

The core metadata elements are required to identify a dataset that is typically used for catalogue purposes. The core metadata answer the questions

- Does a dataset exist on a specific topic? (What?)
- Does a dataset exist for a specific place? (Where?)
- Does a dataset exist for a specific date or period? (When?)
- Which is the point of contact that enables you to learn more about or order the dataset? (Who?)

The metadata elements of the full list are packaged according to Fig. 13.32. For the most part, the packages relate to other ISO 19100 standards; for example, the data quality information refers to ISO 19157 *Data quality*.

Content of ISO 19115-2. ISO 19115-2 *Metadata – Part 2: Extensions for imagery and gridded data* extends the metadata identified by the ISO 19115 for the purpose of imagery applications. Imagery data have characteristics that differ from those of vector data, for instance, in terms of volume or semantics. ISO 19115-2 addresses

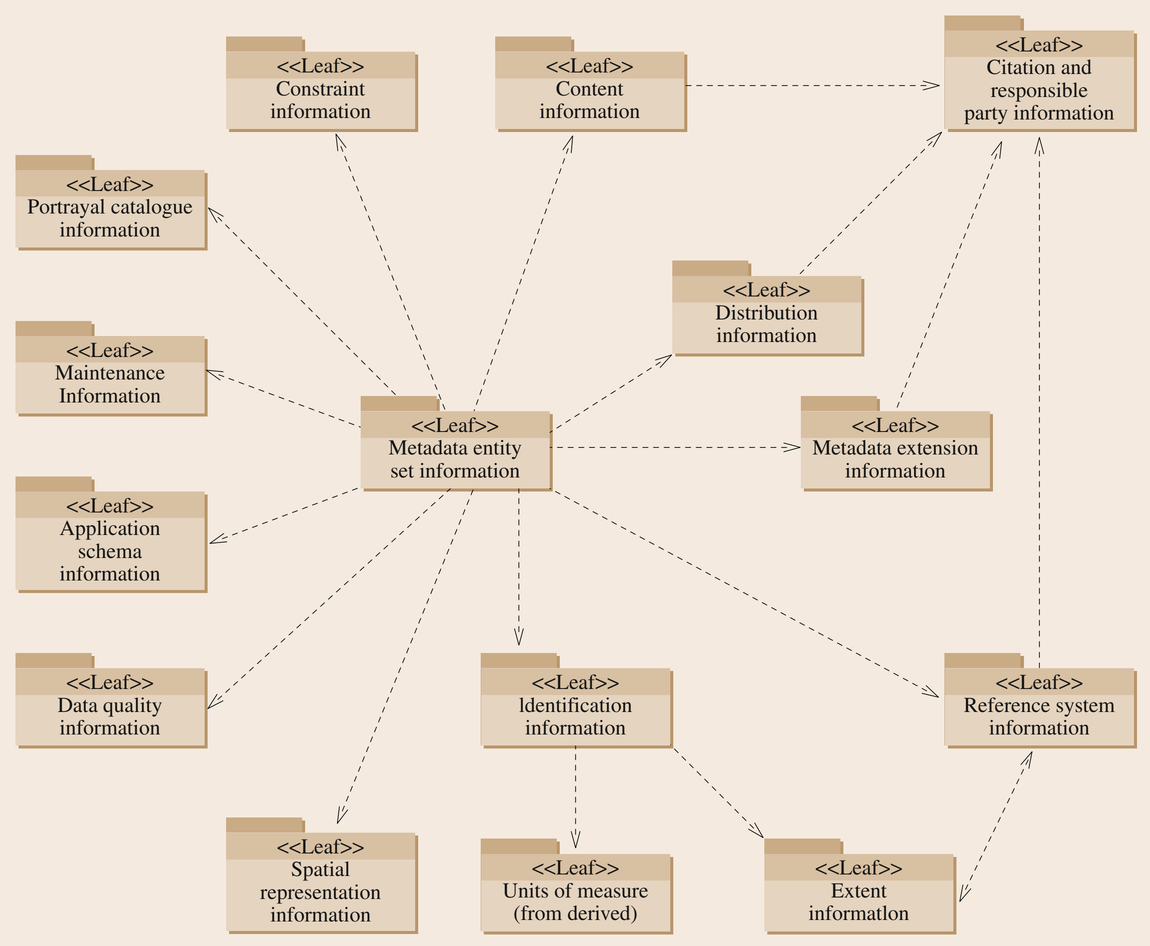


Fig. 13.32 UML package diagram from ISO 19115 *Metadata* (after [13.75])

the imagery metadata, including the description of the measuring equipment.

Concept of Metadata. In the past, metadata were supplied as additional but separate pieces of information to a dataset. However, the concept of ISO 19115 currently considers metadata as an integral part of the data that travels with data when copied, moved, renamed, or exported, and never gets lost. Metadata is implemented using standard technology such as XML, and large GIS manufacturers have made the ISO 19115 metadata part of their system software [13.76].

Hierarchy of Metadata. Metadata standards existed before the work on ISO 19115 started, as the development of ISO 19115 intended to make it a superset of the existing metadata standards in the field of geographic information. A basic approach to metadata is the Dublin Core [13.77] (see below), but the most comprehensive existing source is the Federal Geographic Data Committee (FGDC) standard of the USA. The design of ISO 19115 follows ISO/IEC 11179, which addresses the specification and standardization of data elements.

Work is currently continuing in an attempt to align the existing metadata standards to ISO 19115.

The Dublin Core metadata element set is a basic standard for resource description in the IT business and, in particular, in library management. This standard was developed by the Dublin Core metadata initiative in cooperation with the National Information Standards Organization (NISO), USA, and approved by ANSI as ANSI/NISO Z39.85 – 2001. The Dublin Core defines

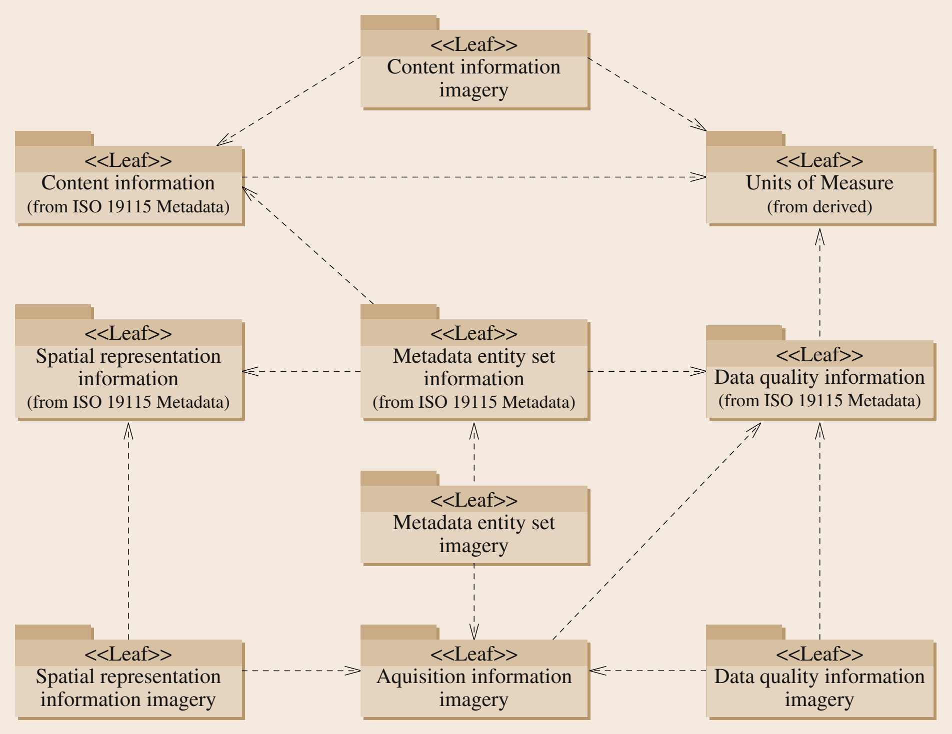


Fig. 13.33 UML package diagram of the metadata standard for imagery (after [13.78])

only 15 metadata elements, because simplicity lowers the cost of creating metadata and promotes interoperability. On the other hand, simplicity does not accommodate the semantic and functional richness supported by complex metadata schemes. The design of the Dublin Core mitigates this loss by encouraging the use of richer metadata schemes in combination with Dublin Core. The name Dublin core refers to Dublin, Ohio, USA, where the first workshop of the initiative was held in 1995. For further reading see Chap. 12.

Quality

Data Quality (ISO 19157). The value of geographic data is directly related to their quality. The views on quality differ among the various user communities; for example, cadastral applications require positional accuracy within a few centimeters, whereas a nautical chart requires a positional accuracy of only a few meters. Geographic datasets are being increasingly shared, interchanged, and used for purposes other than their producer's intended ones. The purpose of describing the quality of geographic data is to facilitate the selection of the geographic dataset best suited to application needs or requirements. ISO 19157 *Data quality* defines the principles for describing the quality. This standard, which is still under development, will centralize the three formerly separate standards ISO 19113 *Quality principles*, ISO 19114 *Quality evaluation procedures*, and ISO/TS 19138 *Data quality* measures, which are going to be withdrawn [13.15].

Quality Principles. The *data quality elements* contain *quantitative* quality information. ISO 19157 defines six groups to subdivide the elements.

- *Completeness*. Presence and absence of features, their attributes and relationships.
  Negative example: missing road data in a remote part of the province.
- *Logical consistency*. Degree of adherence to logical rules of data structure, attribution, and relationships.
  Example: The application schema distinguishes between public and private buildings. The dataset distinguishes between low buildings and high-rises.
- *Spatial accuracy*. Accuracy of the position of features in relation to the Earth.
  Example: The absolute point accuracy is 10 cm (diagonal).

- *Temporal quality*. Quality of the temporal attributes and temporal relationships of features.
  Example: The date of the data compilation was August 2010.
- *Thematic accuracy*. Accuracy of quantitative attributes and the correctness of nonquantitative attributes, as well as the classification of features and their relationships.
  Example: Areas have been classified according to remotely sensed imagery as meadow although, in reality, they were swamps.
- *Usability*. Degree of adherence to a specific set of data quality requirements.
  Example: A product specification fully applies for the intended purpose. However, the data are 12 years old.

Tables 13.14–13.20 contain a complete register of the data quality measures defined in ISO 19157. After the end of the tables, the formulas of three important cases and one detailed description are given as examples.

The three following examples demonstrate how quality measures are documented in ISO 19157.

Quality Measure C.30: Bias of Positions (1-D, 2-D, and 3-D). For a number of points N, the measured positions are given as $x_{\mathrm{m}i}$, $y_{\mathrm{m}i}$, and $z_{\mathrm{m}i}$ coordinates depending on the dimension in which the position of the point is measured. A corresponding set of coordinates, $x_{\mathrm{t}i}$, $y_{\mathrm{t}i}$, and $z_{\mathrm{t}i}$, are considered to represent the true positions. The errors are calculated as

- single deviations

$$e_{xi} = x_{\mathrm{m}i} - x_{\mathrm{t}i} \,,$$
$$e_{yi} = y_{\mathrm{m}i} - y_{\mathrm{t}i} \,,$$
$$e_{zi} = z_{\mathrm{m}i} - z_{\mathrm{t}i} \,;$$

- bias

$$a_x = \frac{\sum e_{xi}}{N_x} \,,$$
$$a_y = \frac{\sum e_{yi}}{N_y} \,,$$
$$a_z = \frac{\sum e_{zi}}{N_z} \,,$$
$$a_p = \sqrt{a_x^2 + a_y^2} \,,$$
$$a_{3\text{-D}} = \sqrt{a_x^2 + a_y^2 + a_z^2} \,.$$

A criterion for establishing correspondence should also be stated (e.g., allowing for correspondence to the closest position, correspondence on vertices or along lines). The criterion/criteria for finding the corresponding points shall be reported with the data quality evaluation result.

Quality Measure C.34: Covariance Matrix. The covariance matrix generalizes the concept of variance from one to n dimensions, i. e., from scalar-valued random variables to vector-valued random variables (tuples of scalar random variables).

For 1-D coordinates (e.g., height data):

- Vector-valued random variable:

$$x = \begin{pmatrix} x_1 \\ \vdots \\ x_{1n} \end{pmatrix} .$$

Table 13.14 Completeness data quality measures

	Commission	
C.1	Excess item	Indication that an item is incorrectly present in the data
C.2	Number of excess items	Number of items within the dataset that should not have been in the dataset
C.3	Rate of excess items	Number of excess items in the dataset in relation to the number of items that should have been present
C.4	Number of duplicate feature instances	Total number of exact duplications of feature instances within the data
	Omission	
C.5	Missing item	Indicator that shows that a specific item is missing in the data
C.6	Number of missing items	Count of all items that should have been in the dataset and are missing
C.7	Rate of missing items	Number of missing items in the dataset in relation to the number of items that should have been present

Table 13.15 Logical consistency data quality measures

	Conceptual consistency	
C.8	Conceptual schema noncompliance	Indication that an item is not compliant to the rules of the relevant conceptual schema
C.9	Conceptual schema compliance	Indication that an item complies with the rules of the relevant conceptual schema
C.10	Number of items not compliant with the rules of the conceptual schema	Count of all items in the dataset that are not compliant with the rules of the conceptual schema
C.11	Number of invalid overlaps of surfaces	Total number of erroneous overlaps within the data
C.12	Noncompliance rate with respect to the rules of the conceptual schema	Number of items in the dataset that are not compliant with the rules of the conceptual schema in relation to the total number of these items supposed to be in the dataset
C.13	Compliance rate with the rules of the conceptual schema	Number of items in the dataset in compliance with the rules of the conceptual schema in relation to the total number of items
	Domain consistency	
C.14	Value domain nonconformance	Indication of whether an item is not in conformance with its value domain
C.15	Value domain conformance	Indication of whether an item is in conformance with its value domain
C.16	Number of items not in conformance with their value domain	Count of all items in the dataset that are not in conformance with their value domain
C.17	Value domain conformance rate	Number of items in the dataset that are in conformance with their value domain in relation to the total number of items in the dataset
C.18	Value domain nonconformance rate	Number of items in the dataset that are not in conformance with their value domain in relation to the total number of items
	Format consistency	
C.19	Physical structure conflicts	Indication that items are stored in conflict with the physical structure of the dataset
C.20	Number of physical structure conflicts	Count of all items in the dataset that are stored in conflict with the physical structure of the dataset
C.21	Physical structure conflict rate	Number of items in the dataset that are stored in conflict with the physical structure of the dataset divided by the total number of items
	Topological consistency	
C.22	Number of faulty point–curve connections	Number of faulty point–curve connections in the dataset
C.23	Rate of faulty point–curve connections	Number of faulty link node connections in relation to the number of supposed link node connections
C.24	Number of missing connections due to undershoots	Count of items in the dataset, within the parameter tolerance, that are mismatched due to undershoots
C.25	Number of missing connections due to overshoots	Count of items in the dataset, within the parameter tolerance, that are mismatched due to overshoots
C.26	Number of invalid slivers	Count of all items in the dataset that are invalid sliver surfaces
C.27	Number of invalid self-intersect errors	Count of all items in the data that illegally intersect with themselves
C.28	Number of invalid self-overlap errors	Count of all items in the data that illegally self-overlap

Table 13.16 Spatial accuracy data quality measures

	Absolute or external accuracy	
C.29	Mean value of positional uncertainties (1-D, 2-D, and 3-D)	Mean value of the positional uncertainties for a set of positions where the positional uncertainties are defined as the distance between a measured position and what is considered as the corresponding true position
C.30	Bias of positions (1-D, 2-D, and 3-D) (for details see later)	Bias of the positions for a set of positions where the positional uncertainties are defined as the distance between a measured position and what is considered as the corresponding true position
C.31	Mean value of positional uncertainties excluding outliers (2-D)	For a set of points where the distance does not exceed a defined threshold, the arithmetical average of distances between their measured positions and what are considered as the corresponding true positions
C.32	Number of positional uncertainties above a given threshold	Number of positional uncertainties above a given threshold for a set of positions. The errors are defined as the distance between a measured position and what is considered as the corresponding true position
C.33	Rate of positional uncertainties above a given threshold	Number of positional uncertainties above a given threshold for a set of positions in relation to the total number of measured positions. The errors are defined as the distance between a measured position and what is considered as the corresponding true position
C.34	Covariance matrix (for details see later)	Symmetrical square matrix with variances of point coordinates on the main diagonal and covariances between these coordinates as off-diagonal elements
C.35	Linear error probable	Half-length of the interval defined by an upper and a lower limit, in which the true value lies with probability 50%
C.36	Standard linear error	Half-length of the interval defined by an upper and a lower limit, in which the true value lies with probability 68.3%
C.37	Linear map accuracy at 90% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value lies with probability 90%
C.38	Linear map accuracy at 95% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value lies with probability 95%
C.39	Linear map accuracy at 99% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value lies with probability 99%
C.40	Near-certainty linear error	Half-length of the interval defined by an upper and a lower limit, in which the true value lies with probability 99.8%
C.41	Root-mean-square error (RMSE) (for details see later)	Standard deviation, where the true value is not estimated from the observations but known a priori
C.42	Absolute linear error at 90% significance level of biased vertical data (alternative 1)	Absolute vertical accuracy of the data's coordinates, expressed in terms of linear error at 90% probability given that a bias is present
C.43	Absolute linear error at 90% significance level of biased vertical data	Absolute vertical accuracy of the data's coordinates, expressed in terms of linear error at 90% probability given that a bias is present
C.44	Circular standard deviation	Radius describing a circle, in which the true point location lies with probability of 39.4%
C.45	Circular error probable	Radius describing a circle, in which the true point location lies with probability of 50%
C.46	Circular map accuracy standard	Radius describing a circle, in which the true point location lies with probability of 90%
C.47	Circular error at 95% significance level	Radius describing a circle, in which the true point location lies with probability of 95%
C.48	Circular near-certainty error	Radius describing a circle, in which the true point location lies with probability of 99.8%
C.49	Root-mean-square error of planimetry	Radius of a circle around the given point, in which the true value lies with probability P
C.50	Absolute circular error at 90% significance level of biased data (alternative 2)	Absolute horizontal accuracy of the data's coordinates, expressed in terms of circular error at 90% probability given that a bias is present
C.51	Absolute circular error at 90% significance level of biased data	Absolute horizontal accuracy of the data's coordinates, expressed in terms of circular error at 90% probability given that a bias is present
C.52	Uncertainty ellipse	2-D ellipse with the two main axes indicating the direction and magnitude of the highest and lowest uncertainty of a 2-D point
C.53	Confidence ellipse	2-D ellipse with the two main axes indicating the direction and magnitude of the highest and lowest uncertainty of a 2-D point

Table 13.17 (continued)

	Relative or internal accuracy	
C.54	Relative vertical error	Evaluation of the random errors of one relief feature to another in the same dataset or on the same map/chart. It is a function of the random errors in the two elevations with respect to a common vertical datum
C.55	Relative horizontal error	Evaluation of the random errors in the horizontal position of one feature to another in the same dataset or on the same map/chart

Table 13.18 Temporal accuracy data quality measures

	Accuracy of a time measurement	
C.56	Time accuracy at 68.3% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the time instance lies with probability 68.3%
C.57	Time accuracy at 50% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the time instance lies with probability 50%
C.58	Time accuracy at 90% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the time instance lies with probability 90%
C.59	Time accuracy at 95% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the time instance lies with probability 95%
C.60	Time accuracy at 99% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the time instance lies with probability 99%
C.61	Time accuracy at 99.8% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the time instance lies with probability 99.8%
	Temporal consistency	
C.62	Chronological error	Indication that an event is incorrectly ordered against the other events

Table 13.19 Thematic accuracy data quality measures

	Classification correctness	
C.63	Number of incorrectly classified features	Number of incorrectly classified features
C.64	Misclassification rate	Number of incorrectly classified features in relation to the number of features that are supposed to be there
C.65	Misclassification matrix	Matrix that indicates the number of items of class i classified as class j
C.66	Relative misclassification matrix	Matrix that indicates the number of items of class i classified as class i divided by the number of items of class i
C.67	Kappa coefficient	Coefficient to quantify the proportion of agreement of assignments to classes by removing misclassifications
	Nonquantitative attribute correctness	
C.68	Number of incorrect attribute values	Total number of erroneous attribute values within the relevant part of the dataset
C.69	Rate of correct attribute values	Number of correct attribute values in relation to the total number of attribute values
C.70	Rate of incorrect attribute values	Number of attribute values where incorrect values are assigned in relation to the total number of attribute values
	Quantitative attribute accuracy	
C.71	Attribute value uncertainty at 68.3% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the quantitative attribute lies with probability 68.3%
C.72	Attribute value uncertainty at 50% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the quantitative attribute lies with probability 50%
C.73	Attribute value uncertainty at 90% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the quantitative attribute lies with probability 90%
C.74	Attribute value uncertainty at 95% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the quantitative attribute lies with probability 95%
C.75	Attribute value uncertainty at 99% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the quantitative attribute lies with probability 99%
C.76	Attribute value uncertainty at 99.8% significance level	Half-length of the interval defined by an upper and a lower limit, in which the true value for the quantitative attribute lies with probability 99.8%

Table 13.20 Usability

	Usability if several different types of data quality elements are concerned. **The data quality element concerned if several results for this element are aggregated.**	
C.77	Product specification passed	Indication that all requirements in the referred product specification are fulfilled
C.78	Product specification fail count	Number of product specification requirements that are not fulfilled by the current product/dataset
C.79	Product specification pass count	Number of product specification requirements that are fulfilled by the current product/dataset
C.80	Product specification fail rate	Number of product specification requirements that are not fulfilled by the current product/dataset in relation to the total number of product specification requirements
C.81	Product specification pass rate	Number of product specification requirements that are fulfilled by the current product/dataset in relation to the total number of product specification requirements

- Its covariance matrix is

$$\Sigma_{xx} = \begin{pmatrix} \sigma^2_{x1} & \cdots & \sigma^2_{x1xn} \\ \vdots & \ddots & \vdots \\ \sigma^2_{xnx1} & \cdots & \sigma^2_{xn} \end{pmatrix} ,$$

$$\text{with} \quad \sigma_{x1xn} = \sigma_{xnx1} ,$$

where σ^2_{x1} denotes the variance of element x_1; its square root gives the standard deviation of this element $\sigma_{x1} = \sqrt{\sigma^2_{x1}}$.

The correlation between two elements can be calculated by $\rho_{xixj} = \frac{\sigma_{xixj}}{\sigma_{xi}\sigma_{xj}}$. If the coordinates are uncorrelated, the off-diagonal elements are of value 0.

Quality Measure C.41: Root-Mean-Square Error (RMSE). The true value of an observable Z is known as z_t, and the estimator

$$\sigma_z = \sqrt{\frac{1}{N}\sum_{i=1}^{N}(Z_{mi} - z_t)^2}$$

yields the linear root-mean-square error RMSE $= \sigma_z$.

A comprehensive introduction to this field is provided in Chap. 2. Table 13.21 demonstrates the style in which the 81 quality measures are documented in ISO 19157.

Data Quality Reporting. Data quality may be reported using metadata or a standalone report. Data quality shall be reported as metadata in compliance with ISO 19157 and ISO 19115. To provide more details than reported as metadata, a standalone report may additionally be created. Its structure is free.

Quality Assurance of Data Supply (ISO/TS 19158). ISO/TS 19158 *Quality assurance of data supply* defines a framework for the producer and customer in their production relationship. It bridges the gap between the quality management systems as defined in the ISO 9000 family of standards and the technical-oriented quality standards of the ISO 19100 family such as ISO 19157 *Data quality*.

Through the application of ISO/TS 19158, there are opportunities for a better understanding of requirements by all involved in production and update, especially within multiple-producer environments. Additional benefits may be reduced data throughput time, reduced rework, improved data quality, and increased confidence within a relationship, leading to lower costs for both supplier and organization.

The existence of ISO/TS 19158 does not impose its application, thus releasing smaller companies from potentially unnecessary organizational overheads. The question of whether a demanded quality level has been reached is answered by second-party accreditation. This is performed by the customer regarding the quality of the supplied data without the involvement of a third-party accreditation body [13.79].

Land Administration Domain Model (LADM, ISO 19152)

ISO 19152 *Land administration domain model (LADM)* is intended to help building modern property cadastre systems, in particular in those countries which do not have a century (or even a lot more) of cadastral tra-

Table 13.21 Detailed documentation of the absolute circular error at 90% significance level of biased data

Line	Component	Description
1	Name	Absolute circular error at 90% significance level of biased data
2	Alternative name	ACE
3	Data quality element	Absolute or external accuracy
4	Data quality basic measure	Not applicable
5	Definition	Absolute horizontal accuracy of the data's coordinates, expressed in terms of circular error at 90% probability given that bias is present
6	Description	Comparison calculation of data (source) and control (reference) is calculated in the following manner: 1. Calculate the absolute error in the horizontal dimension at each point $\Delta H_i = \sqrt{(\text{source}X_i - \text{reference}X_i)^2 + (\text{source}X_i - \text{reference}X_i)^2}$ for $\quad i = 1 \ldots N.$ 2. Calculate the mean horizontal error $\mu_\text{H} = \frac{\sum \Delta H_i}{N}\ .$ 3. Calculate the standard deviation of the horizontal errors $\sigma_\text{H} = \sqrt{\frac{\sum(\Delta H_i - \mu_\text{H})^2}{N-1}}\ .$ 4. Calculate the ratio of the absolute value of the mean error to the standard deviation $\text{ratio} = \lvert\mu_\text{H}\rvert / \sigma_\text{H}\ .$ 5. If ratio > 1.4, then $k = 1.2815$. 6. If ratio 1.4, then calculate k, the ratio of the mean to the standard deviation, using a cubic polynomial fit through the tabular values as defined in the *CRC Handbook of Tables for Probability and Statistics* $k = 1.6435 - (0.999556 \times \text{ratio}) + (0.923237 \times \text{ratio}^2) - (0.282533 \times \text{ratio}^3)\ .$ 7. Compute CE90 = for the source $\text{CE90}_\text{source} = \lvert\mu_\text{H}\rvert + (k \times \sigma_\text{H})\ .$ 8. Compute absolute CE90 $\text{CE90}_\text{abs} = \sqrt{\text{CE90}^2_\text{reference} + \text{CE90}^2_\text{source}}\ .$
7	Parameter	Sample size: minimum of 30 points is normaly used but may not always be possible depending on identifiable control points. For feature level attribution sample, 10% of the feature population
8	Data quality value type	Measure
9	Data quality value structure	–
10	Source reference	1. *Mapping, charting and geodesy accuracy* [13.14] 2. *Handbook of Tables for Probability and Statistics* [13.13]
11	Example	–
12	Measure identifier	49

dition. ISO 19152 is based on the experiences of the advanced countries combined with the data models of the ISO/TC 211 family of standards [13.80].

ISO 19152 defines a reference land administration domain model (LADM) covering all basic information-related components of land administration including those over water as well as land, and elements above and below the surface of the Earth. The standard provides an abstract, conceptual schema with five basic packages related to

1. parties (*people and organizations*),
2. rights, responsibilities, and restrictions (*ownership rights*),

3. spatial units (*parcels, buildings and networks*),
4. spatial sources (*surveying*), and
5. spatial descriptions (*geometry and topology*).

This standard defines also a terminology for land administration, based on various national and international systems, which is as simple as possible in order to be useful in practice and includes the basis for national and regional profiles.

Property cadastre and land administration are usually closely linked to the national legislation. Therefore an ISO standard that sets detailed rules will almost certainly have legal implications of many different kinds. Consequently this is out of the scope of ISO 19152. This

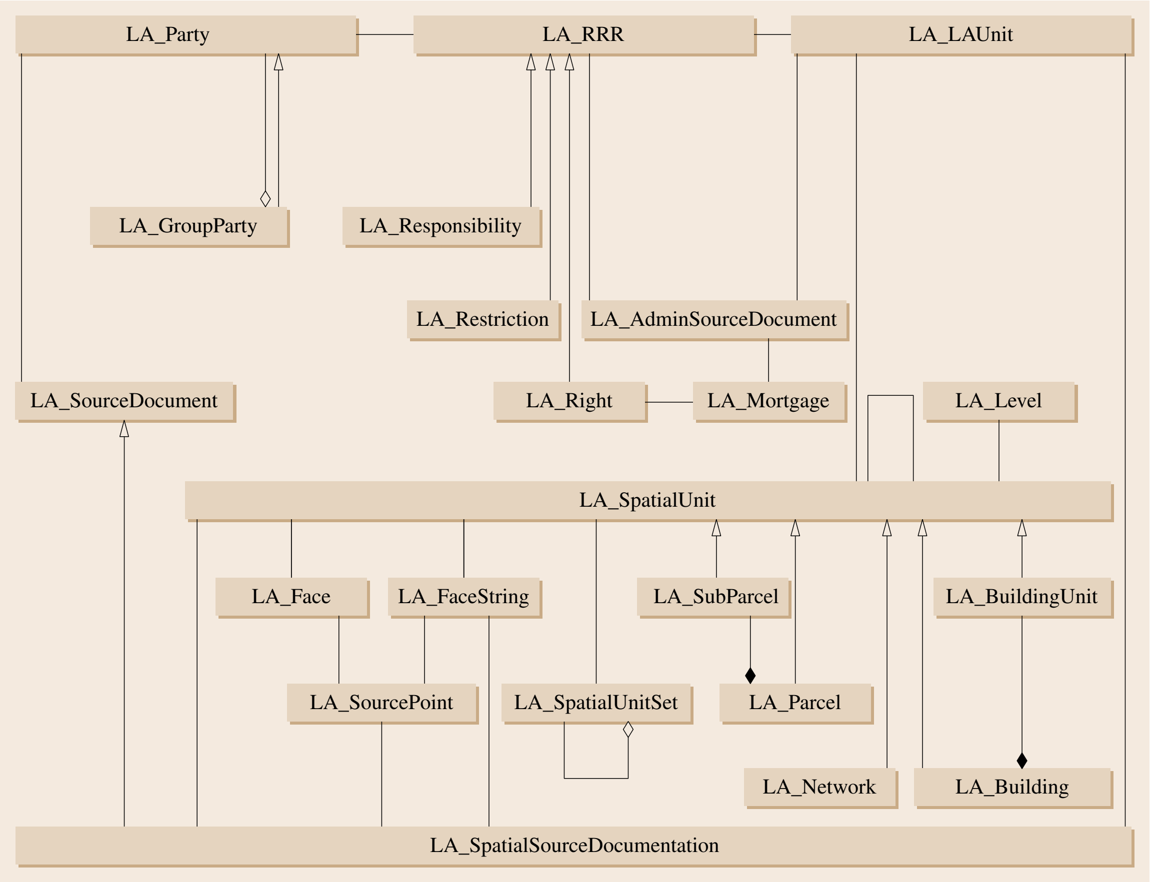


Fig. 13.34 Land administration domain model (after [13.80]) (LA_AdminSourceDocument – source document such as a contract, LA_Building – a description of the legal, recorded, or informal space, not the physical entity, LA_BuildingUnit – a part of a building according to LA_Building, LA_Face – two-dimensional topological primitive (surface), also used to build 3-D geometries, LA_FaceString – line information (geometry), LA_GroupParty – group of parties, e.g., an association, LA_LAUnit – generalized unit that is, e.g., used to associate right, LA_Level – content level such as urban, rural, etc., LA_Mortgage – details of the mortgage, LA_Network – information about networks such as electricity, LA_Parcel – spatial unit with a legal ownership right, LA_Party – involved player, such as a notary, LA_Responsibility – responsibility such as maintenance of a waterway, LA_Restriction – restriction such as a servitude, LA_Right – rights such as ownership, LA_RRR – rights, restrictions, responsibilities, LA_SpatialUnit – a superclass covering parcels, buildings, etc., LA_SpatialUnitSet – set of spatial units such as a municipality, LA_SubParcel – subunit of a parcel according to LA_Parcel, LA_SourcePoint – point information (geometry), LA_SpatialSourceDocument – documentation of land administration surveys)

standard is not intended to interfere with any national land administration laws. Furthermore, the construction of external databases with party data, address data, valuation data, land use data, land cover data, physical network data, and taxation data, is out of scope too. However, ISO 19152 provides blueprint stereotype classes for these datasets which indicate which dataset elements the land administration domain model expects from these external sources, if available.

Figure 13.34 depicts a comprehensive picture of the LADM. The LADM is also addressed in Chap. 19.

Digital Rights

Geospatial Digital Rights Management Reference Model (GeoDRM RM, ISO 19153). ISO 19153 is a reference model for Digital Rights Management (DRM) functionality for geospatial resources (GeoDRM). This ISO standard has evolved from an OGC abstract specification [13.81].

In a digital world, due to the nature of digital resources and commerce, most digital entities are sold in a manner different from traditional trade. When a user acquires an application, he or she actually acquires the right to use a copy of the application. Possession does not equate with ownership, and a system of software and resource licensing has grown up in the digital world that ensures the following types of things.

- The user may legitimately act upon a resource if he or she has a corresponding license for that act.
- The owner should maintain the resource, fixing errors (*bug-fix*) and ensuring a guaranteed level of functionality.
- Optionally, the user may be asked to pay the owner of the resource based upon agreed criteria, whether that is a one-time fee, a per-machine fee, a usage fee, or some other mechanism stated in the legal contract or license between user and owner.
- The user agrees to protect the owner's rights based on the agreement. This usually means he or she cannot backward-engineer code or resource, nor redistribute the resource without proper permission.
- The owner agrees to maintain the resource and allow reasonable access to the users for any fixes that may be required. Again, the extent or degree of maintenance is stated in the user agreement.
- To create and support a large-scale, open market in geospatial resources, this type of protection is needed to ensure that a fair value for work (investment) ethic can be guaranteed so that suppliers can be sure of fair return on individual sales, and users can be sure of fair value for purchases of uses of resources [13.81].

Roadmap. To allow the definition of interfaces and responsibilities, seven possible function packages are defined by ISO 19153. Those packages may be considered as a roadmap to understand this standard.

- *Rights model*. The rights model defines the basis for developing a geospecific rights expression language as well as other specifications necessary to establish a GeoDRM-enabled spatial data infrastructure (SDI).
- *Rights expression language*. This package provides the capabilities to express usage rights in the form of a machine-readable and machine-processable representation. However, the definition of this language is not part of this standard.
- *Encryption*. This package includes required functionality to protect a GeoDRM-enabled SDI against fraud. First, encryption enables the protection of a license so that it cannot be modified by an adversary in order to obtain additional rights. Second, encryption is also useful to protect the digital geographic content against unlicensed use. Because security and trust are not geospecific, ISO 19153 does not define a specific standardization for this type of data.
- *Trust*. An example for a mechanism to establish trust between entities in a Service-Oriented Architecture (SOA) is adding authenticity information on the digital content that is been exchanged between the partners. This mechanism, typically called a digital signature, is not geospecific and therefore is not a relevant topic of ISO 19153.
- *License verification*. License verification has to occur before the rights of the license can be enforced. Because document authentication is not geospecific, it is not a topic for ISO 19153.
- *Enforcement and authorization*. The rights expressed in a GeoLicense need to be enforced. The acceptance or denial decision for a particular request (with its associated licenses) is based on the authorization decision, as derived by the authorization engine. Because enforcement and authorization is geospecific, the appropriate standardization will be based on ISO 19153.
- *Authentication*. The basic requirement for trust, license verification, and enforcement/authorization is proof of identity, as provided by the functionality of this package. Authentication is not geospecific and thus not part of ISO 19153 [13.81].

GeoDRM Roles and Responsibilities. Figure 13.35 depicts various roles which have divided responsibilities. ISO 19153 characterizes these roles as the *primitives* that can be selected and assembled according to the specific needs of a business model.

Rights Expression Language for Geographic Information – GeoREL (ISO 19149). When selling data or other digital resources it is known or at least anticipated that those products are devaluated because of a far wider application then that covered by the granted licenses. The multimedia industry has taken the lead in solving this problem by creating a general model for digital rights protection. This model includes a rights expression language, specifically defined in ISO/IEC 21000-5 *Multimedia framework (MPEG-21) – Part 5: Rights expression language*, or ISO REL for short, that in conjunction with Digital Rights Management (DRM) systems can protect the value of data and still allow it to be distributed subject to a system of licensing, trust, and enforcement.

ISO 19149 extends the ISO REL to encompass the concerns of holders of geographic data and service resources to equally ensure their protection.

This standard is built upon two major sources for foundational material for this work.

The first source is the above mentioned ISO/IEC 21000 *Multimedia framework (MPEG-21)*, a multiple-part standard that defines digital rights management in general. The second source is ISO 19153 *Geospatial digital rights management reference model (GeoDRM RM)*, which enumerates these special cases for geographic information as well as providing an overall reference model using common geographic information terms that ties the work of ISO/IEC 21000 into the spatial standards.

ISO 19149 defines an XML-based vocabulary or language to express rights for geographic information.

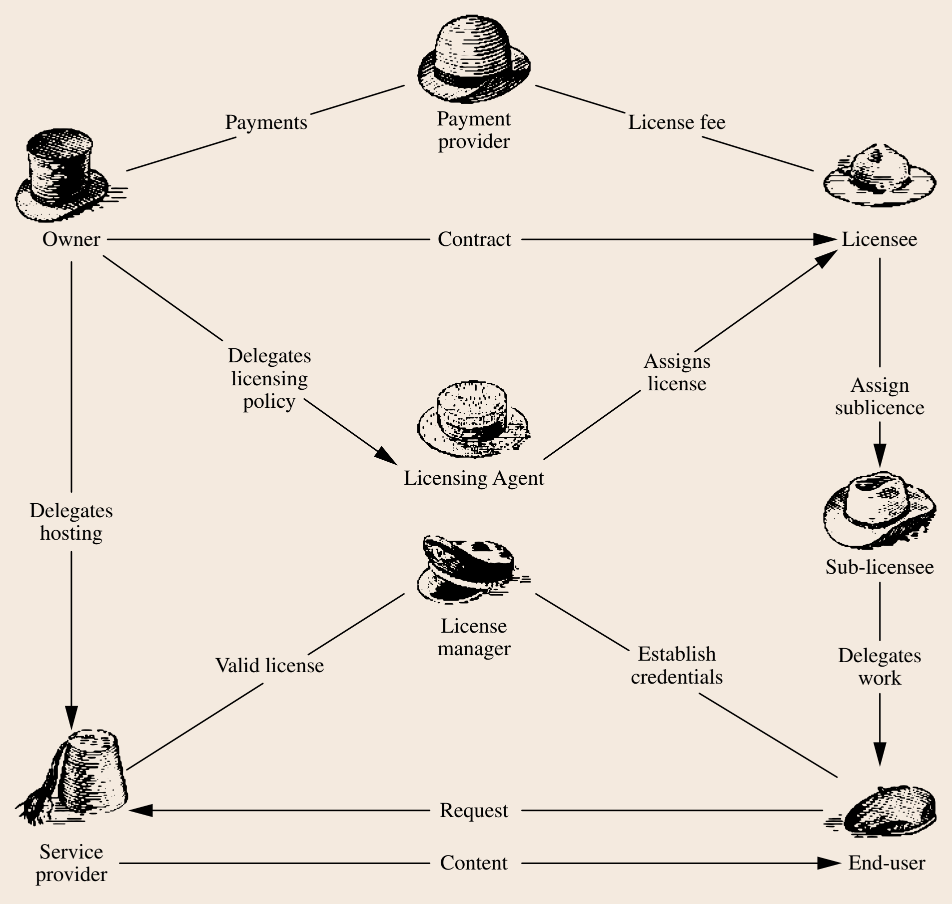


Fig. 13.35 GeoDRM roles and responsibilities (after [13.81])

Table 13.22 GeoDRM roles and responsibilities (after [13.81])

Role	Description	Responsibility
Owner	Owner of the intellectual property. Often the individual or organization that created the content and has legal rights over how that intellectual property is used. Synonyms: Rights holder, content provider, licensor	Original creator of content, holds the intellectual property rights and is the licensor of that intellectual property. Defines the geospatial extents of the geospatial resource, and delegates part or whole of those extents to a licensing agent. Defines the terms and conditions to be applied within the GeoLicense. Conditions may include a pricing model for access to the geospatial resource. Defines the policy to be applied specifically when resource flows across the boundaries defined in the GeoLicensing realm
Licensing agent	Manages the GeoLicense creation according to the constraints specified by the owner, including the delegated GeoLicense extents, terms and conditions, and policy to be applied.	Creates GeoLicenses based on owner-defined constraints. Ensures that any conditions for the creation of a GeoLicense (such as payment) are fulfilled before issuing. Ensures that a copy of the GeoLicense is registered with the license manager for the purposes of enforcement of GeoLicense.
Service provider	Host the geospatial resource on behalf of the owner.	Ensures that access to the geospatial resource is only allowed when a valid GeoLicense is presented, and the request falls within the extents specified. May request GeoLicenses from the license manager based on the end-user's credentials
Payment provider	Manages payment transactions on behalf of owner. NOTE: Payment provider is only required if the terms and conditions of the GeoLicense include a financial compensation for the rights to access the specified geospatial resource	Receives license fee payment details from licensing agent. May maintain outstanding balances between owner and licensees to be settled at a specified account period
License manager	Manages licenses on behalf of the rights-managed network and acts as a trusted third party between the owner and the licensee	Registers new and updated GeoLicenses. Provides GeoLicense validation functions to service provider
Licensee	Acquires rights to access a geospatial resource. Terms and conditions of those rights are defined in the GeoLicense	Organization or individual with an assigned set of rights as defined by the GeoLicense. Rights granted by the GeoLicense may include the rights to sublicense resource
Sublicensee	Acquires or is assigned a subset of rights by the licensee	Sublicensee is assigned a subset of the rights as defined by the GeoLicense
End-user	The individual person who accesses the geospatial resource	Accesses geospatial resource based on the terms and conditions of the GeoLicense. GeoDRM design goal is to make the process of license creation and enforcement as transparent as possible to the end-user

This language, an extension of the rights expression language in ISO/IEC 21000-5 as mentioned above, is to be used to compose digital licenses. The digital rights management system in which these licenses are used can then offer ex ante (before the fact) protection for all such resources [13.82].

13.4.3 Imagery Standards

The topic of imagery includes all geographic data that are stored in an image in the widest sense. The image may display a part of the Earth's surface, or it may contain other fairly evenly spaced data of the Earth's surface or a neighborhood. Examples for imagery-type data are airborne photographs, satellite images, hydrographic soundings, digital elevation models, and coverages according to ISO 19123.

Framework (ISO/TS 19129, ISO/TR 19121, ISO/RS 19124)

When the work on ISO standardization of geomatics started, a great variety of raster data formats were in use already. Examples include the Joint Photographic Experts Group (JPEG) and TIFF formats. Therefore, ISO standardization for imagery started with a comprehensive review of industry and other de facto standards. The results were a technical report (ISO/TR 19121), a review summary (ISO/RS 19124), and a framework standard (ISO/TS 19129) that finally determined the further procedure. The concept of ISO 19129 includes the distribution of imagery elements to existing ISO 19100 standards, the definition of new work item proposals (NWIPs) that will lead to new ISO 19100 standards, and eventually the standardization of remaining topics within ISO/TS 19129 [13.83].

ISO/TS 19129 Imagery, Gridded, and Coverage Data Framework. ISO/TS 19129 is a framework standard for all coverage, imagery, and gridded data of geographic information. The term in the title with the broadest definition is "coverage." This term refers to geographic data that covers a region in some regular or irregular spatial order. The simplest order is a square grid, well known from digital images or digital elevation models. Thus, the concept of coverage data includes imagery and gridded data. A coverage is also considered as a kind of gridded data as well as a method for describing spatial phenomena that include concepts of vector and raster data. Coverages are explained in Sect. 13.5.5.

ISO/TS 19129 standardizes all details that are necessary to handle gridded data in the environment of geomatics unless other standards of the ISO 19100 family have already done so. A close relation exists with ISO/TS 19130 *Imagery sensor models for geopositioning* and to its part 2, both of which deal with georeferencing of imagery data to the Earth. Two spin-off-standards were defined: ISO/TS 19101-2 *Reference model – Part 2: Imagery* and ISO 19115-2 *Metadata – Part 2: Extensions for imagery and gridded data*.

Enhancements of the Existing ISO 19100 Standards. The following paragraphs explain some of the important additions to existing ISO 19100 standards for the needs of imagery.

A lot of ISO and de facto standards exist for encoding of imagery data. Hardly any standards exist for the storage of associated metadata. ISO/TS 19129 recommends applying the picture coding standards developed by JTC1 SC29, which is responsible for audio, picture, and multimedia information, and JTC1 SC24 *Computer graphics, image processing and environmental data representation*, wherever possible.

Tesselation is a method to order space. ISO 19123 *Schema for coverage geometry and functions* contains a comprehensive definition of coverages. They comprise Thiessen polygons, quadrilateral grids, hexagonal grids, and triangulated irregular networks (TINs). For details see Sect. 13.5.5. Additional tesselation methods are required for imagery applications.

A Riemann hyperspatial tessellation that is not documented in ISO 19123 partitions a space according to the density of contents. Riemann proved the applicability of Euclidean geometry to an n-dimensional space. Thus the Riemann space is called a hyperspace. The Riemann hyperspatial tessellation is dynamic. Its basic partition is a multidimensional quadrilateral grid. While irregularly distributed data is stored in the dataset, the atoms of the hyperstructure are filled in with different intensity. Once the fill grade of an atom reaches a threshold value, it is divided by two in each dimension. This means, for example, that in three-dimensonal space a cube is split into eight smaller cubes. The Riemann hyperspatial tessellation is widely used in domains with large amounts of irregularly spaced data such as hydrography. ISO/TS 19129 calls this method Riemann hyperspatial multidimensional grid coverage.

ISO/TR 19121 Imagery and Gridded Data. A survey of existing raster format standards was the starting point for the development of an ISO standard for gridded data. The result of the survey was ISO/TR (tech-

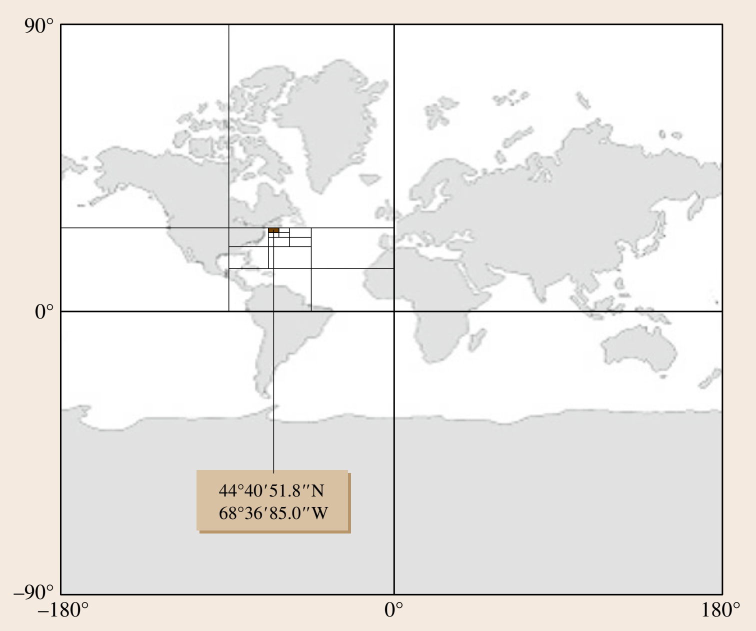


Fig. 13.36 Two-dimensional example of a Riemann hyperspace (after [13.85])

Table 13.23 Raster data formats identified in ISO/TR 19121

Official standards (ISO, IEC, ITU, ISO/IEC JTC1), government standards		**Private standards**	
Name	**Maintenance**	**Name**	**Maintenance**
BIIF	ISO/IEC JTC1/SC24	Coverages	OGC
CEOS CIP	CEOS	Fractal Transform Coding	Microsoft
CEOS Superstructure	CEOS	GeoTIFF	JPL, Intergraph, Spot-Images
DIGEST	DGIWG (NATO)	GIF	CompuServe
HDF (Hierarchical Data Format)	NASA (USA)	PhotoCompactDisk	Eastman Kodak
HDF-EOS (Hierarchical Data Format-Earth Observation System)	NASA (USA)	TIFF	Adobe (origin Aldus)
IP-IIF (Image Processing and Interchange, Image Interchange Facility)	ISO/IEC JTC1		
JBIG (Joint Binary Images Group)	ISO/IEC JTC1/SC29		
JPEG	ISO/IEC JTC1/SC29		
MPEG-2	ISO/IEC JTC1/SC29		
NITF (US National Imagery Transmission Format)	NGA (US National Geospatial Intelligence Agency) (USA)		
PNG	ISO/IEC JTC1/SC 24		
S-57	IHO		
SDTS (US Spatial Data Transfer Standard) raster	ANSI (USA) and other countries		
SQL/MM	ISO/IEC JTC1/SC32		
T.4 and T.6	ITU		
TIFF/IT	ISO/TC 130		

nical report) 19121 that listed the formats listed in Table 13.23 as being relevant for the upcoming standardization. ISO/TC 211 has established formal liaison memberships or other appropriate links with most of the organizations responsible for maintenance of the formats [13.84].

ISO/RS 19124 Imagery and Gridded Data Components. The ISO/TC 211 project 19124 *Imagery and gridded data components* is an intermediate step toward the completion of the ISO standards for gridded data and sensors. The result of the work is a review summary (RS) that is an informal ISO document that expresses the consensus of the project team members. The document reviews the existing standards for imagery and gridded data and analyses their impact on the ISO 19100 family of standards.

The project team decided to take this intermediate step because the development of de facto standards in the field of imagery and gridded data was very advanced outside of ISO. In addition, ISO/TC 211 had agreed on the project 19123 *Schema for coverage geometry and functions* that is considered a superset of gridded data, and both created a situation that strongly required alignment with existing solutions.

The existing standards listed in ISO/TR 19121 were analyzed using the following components: data model/schema, metadata, encoding, services, and spatial registration. These analyses resulted in a proposed amendment of ISO 19115 *Metadata* [13.86].

Sensors (ISO/TS 19130, ISO/TS 19130-2)

Remotely sensed data is an important source for geographic information. Data are called remotely sensed if the sensor has no physical contact with the measured object. For the use of such data in combination with other geographic information, the remotely sensed data must be geometrically referenced to the Earth. ISO/TS 19130 *Imagery sensor models for geopositioning* standardizes the metadata for the *geometric* reference of the originally sensed data to locations on the Earth. This reference allows for more precise data retrieval from the imagery. For most applications it is a prerequisite for appropriate use of the imagery.

For reasons of efficient organization of the standard's development, the topic has been split into two documents. ISO/TS 19130 addresses physical sensor models (line and matrix cameras), true replacement models, and correspondence models. ISO/TS 19130-2 adds synthetic aperture RADAR (SAR)/interferometric SAR (InSAR), light detection and ranging (LIDAR), and sound navigation and ranging (SONAR). The series ISO/TS 19159-x *Calibration and validation of remote sensing imagery sensors* completes the set with a calibration and validation standard for the involved sensors.

Model Classification (ISO/TS 19130). From a conceptual view, the standard comprises sensor models for all remote-sensing sensors. At present, the sensor models shown in Fig. 13.37 are described. The sensor models are modeled as a specialization of the metadata for imagery (ISO 19115-2).

Physical Sensor Model. The physical sensor model stands for the rigorous photogrammetric approach which conceptually tries to describe any geometric offset from the model of the central perspective. The parameter sets are typically named interior orientation (calibrated focal length, principal point of autocollimation, distortion) and exterior orientation (position and attitude of the sensor, and eventually its dynamics).

ISO/TS 19130 defines the use of ground control points as a georeferencing method on its own and puts it under the physical sensor model. The relation between the original image and the Earth's surface is defined by a set of common points. Each point consists of two or three ground point coordinates (x, y, and optional z) and the two related sensor data coordinates (row and column). It is not specified which functional relation between image and Earth shall be used, and thus the type and values of the coefficients remain undefined.

The physical sensor model comprises frame cameras, pushbroom scanners, and whiskbroom scanners.

A *frame camera* produces a matrix of image pixels. Apart from some rare exceptions, the camera is flown on an aircraft.

A *pushbroom sensor* takes the data along a scanline at one moment.

Most scanning linear arrays and pushbrooms are flown on satellite platforms. As the orbit is smooth compared with the ground resolution, the resulting image may be georeferenced by robust transformations (sensor reference, rigorous model) or by functional relations such as polynomial transformations (image reference). If a scanning linear array-type sensor is operated from an airplane, line-by-line rectification is necessary to georeference the data (Chap. 9).

A *whiskbroom scanner*-type sensor scans the terrain within the field of view under the flight track. This sensor scans along one scan line using a rotating mirror or similar device.

True Replacement Model. True replacement models are produced using physical sensor models. The equations that describe the sensor and its relationship to the Earth coordinate reference system are replaced by a set of equations that directly describe the relationship be-

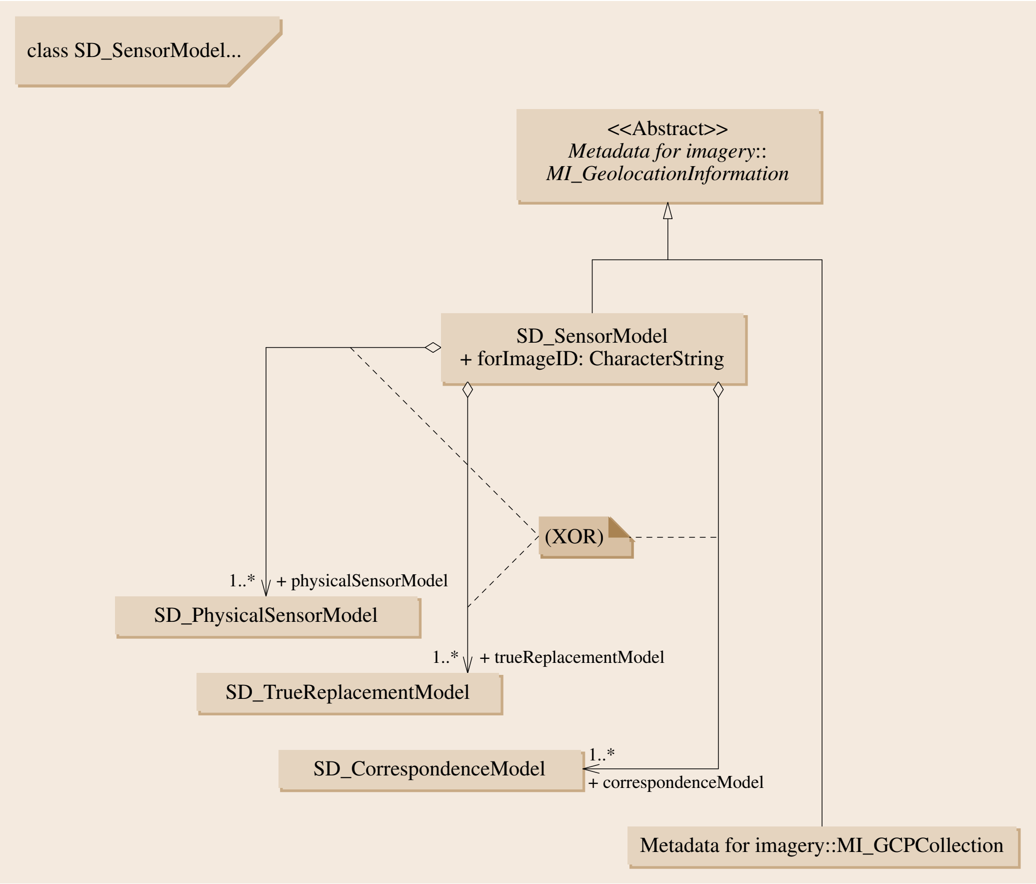


Fig. 13.37 Sensor models in ISO/TS 19130 (after [13.87])

tween image coordinates and Earth coordinates. This method originated from military applications in order to disguise sensor characteristics.

The specification allows different interpolation methods for finding the ground point coordinates within the provided grid, as shown in Fig. 13.41.

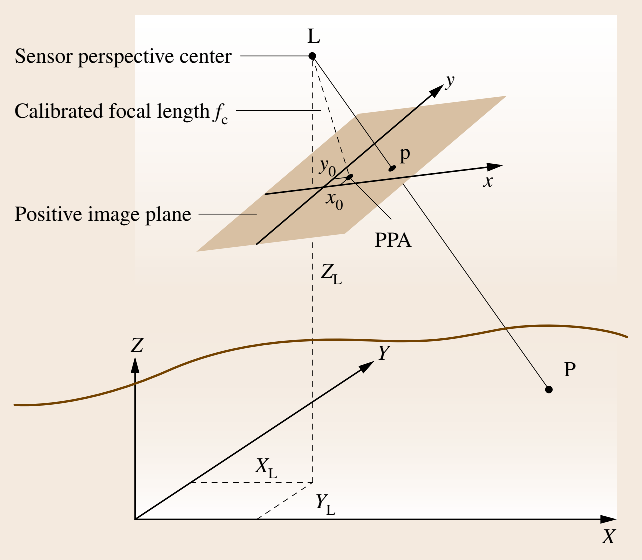


Fig. 13.38 Frame camera image and its exterior orientation (after [13.87])
(f_c – calibrated focal length, given in (mm),
PPA – principal point of autocollimation, given in (mm) in the image coordinate system,
x_0, y_0 – coordinates of principal point of autocollimation,
L – sensor perspective center (projection center), given in (m) in the object coordinate system,
p – image point,
P – object point,
x, *y* – image coordinate system,
X, *Y*, *Z* – object coordinate system) ◀

Grid Interpolation. In this method, geolocation is derived by interpolation in an evenly spaced grid. Similar to the ground control points method, each grid point consists of three ground point coordinates and the two related sensor data coordinates. ISO/TS 19130 does not define the interpolation method to be used between the grid points.

Polynomials. The polynomials method presents the sensor data coordinate (row or line l and column or sample s) as a function of ground point coordinates (X, Y, and optional Z) in the form of a polynomial. For the polynomials, l and s may be written as

$$l = \sum_{k,l,m}^{n} a_{klm} X^k Y^l Z^m \ ,$$

$$s = \sum_{k,l,m}^{n} b_{klm} X^k Y^l Z^m \ .$$

Ratios of Polynomials. Rather than using a single polynomial, this geolocation method uses separate ratios of two polynomial functions of latitude, longitude, and

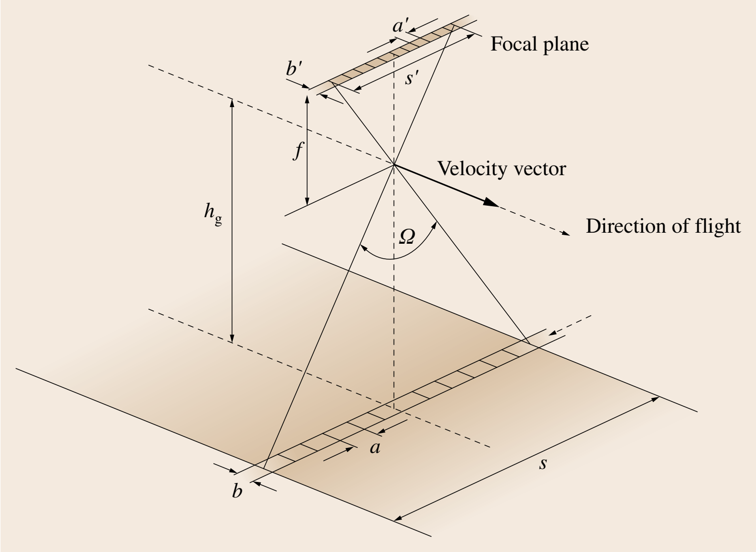


Fig. 13.39 Optical layout of a pushbroom sensor (after [13.87]) (h_g – flying height above ground, f – focal length, $a' \times b'$ – image pixel size, s' – length of scan array, Ω – field of view (FOV), $a \times b$ – object (ground) pixel size, s – swath width)

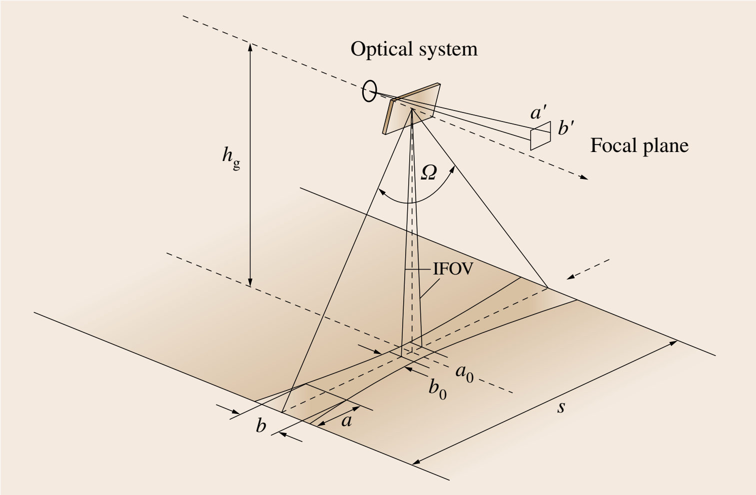


Fig. 13.40 Optical layout of a whiskbroom scanner (after [13.87]) (h_g – flying height above ground, f – focal length, $a' \times b'$ – image pixel size, s' – length of scan array, IFOV – instantaneous field of view, $a \times b$ – object (ground) pixel size, s – swath width)

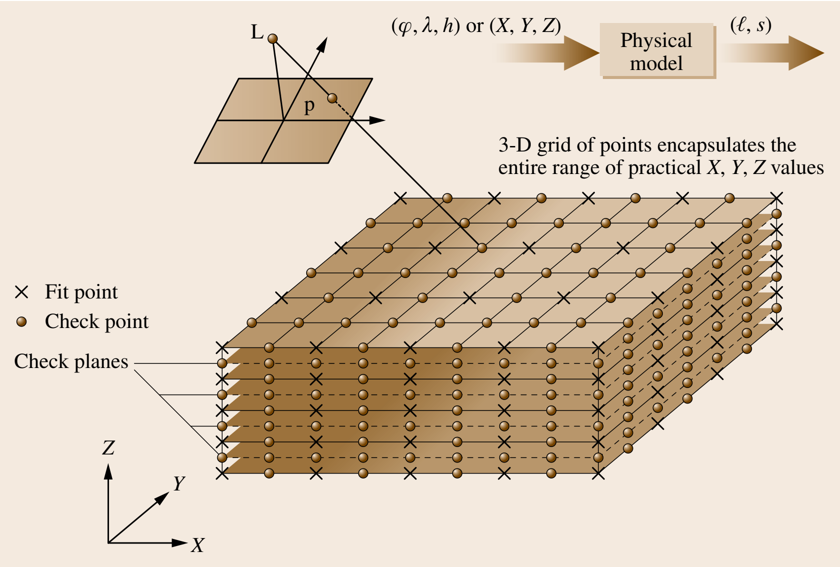


Fig. 13.41 True replacement model generation of points (after [13.87])

height to compute image row and column. It is often called the rational functions model, and the polynomial coefficients are often called rational polynomial coefficients (RPC) data. An image is divided into segments, and different polynomial ratios are used for the different sections. Each polynomial has 20 terms, although the coefficients of some polynomial terms are often zero. In the polynomial functions, the three spatial reference coordinates and two image coordinates are each offset and scaled so that their range over an image segment is from -1.0 to $+1.0$.

For each image segment, the defined ratios of polynomials have the form

$$l = \frac{P_1(X, Y, Z)}{P_2(X, Y, Z)}, \quad s = \frac{P_3(X, Y, Z)}{P_4(X, Y, Z)},$$

where l is the image line coordinate, s the image sample coordinate, and X, Y, Z the object ground coordinates.

The polynomials P have the form

$$P = \sum_{k,l,m}^{n} a_{klm} X^k Y^l Z^m ,$$

where a_{klm} are the polynomial coefficients.

Direct Linear Transform. When the ground coordinates are in a Cartesian CRS, such as geocentric or local space rectangular, the RPC model reduces to the special case containing only 11 coefficients of the form

$$l = \frac{a_0 + a_1 X + a_2 Y + a_3 Z}{1 + c_1 X + c_2 Y + c_3 Z},$$

$$s = \frac{b_0 + b_1 X + b_2 Y + b_3 Z}{1 + c_1 X + c_2 Y + c_3 Z},$$

where l is a line coordinate, s is a sample coordinate, X, Y, Z are object space coordinates, a_0, a_1, a_2, a_3 are the coefficients of the numerator of the rational polynomial that produces a line coordinate, b_0, b_1, b_2, b_3 are the coefficients of the numerator of the rational polynomial that produces a row coordinate, and c_1, c_2, c_3 are the coefficients of the denominator of the rational polynomials.

These equations are known as the direct linear transform (DLT).

Correspondence Model. The correspondence model assembles all of those approaches that make no use of a physical sensor model, and are thus generally less accurate.

The correspondence model is a *functional fit model* that relates an image to the Earth by simply using a set of common points. The points define a functional relation such as the polynomials explained above, which is used to warp the original image towards the geometry of the Earth surface. The functional fit model establishes a so called *image reference* between the remotely sensed data and the ground. Again, the model does not require any knowledge of the sensor.

Models in ISO/TS 19130-2. ISO/TS 19130-2 *Imagery sensor models for geopositioning – Part 2: SAR (synthetic aperture RADAR)/InSAR, LIDAR, and SONAR* adds the sensor types that are quoted in the title to the previously defined ISO/TS 19130. The standard also incorporates a metadata model for aerial triangulation.

SAR, InSAR. Interferometric SAR, or InSAR, is the application of interferometry to SAR images. An interferogram, the interferometric overlay of two SAR images, is produced by taking amplitude (intensity) and phase of both images into account. InSAR allows for three-dimensional measurement of a surface and may be applied for detecting surface deformation or mapping topography.

Synthetic aperture RADAR (SAR)- and *Interferometric SAR* (InSAR)-type sensors are operated from satellite and aircraft platforms. The sensor emits radiation in the microwave band and records the time and phase of the reflection. The system works under any light conditions (i. e., day or night). As microwave frequencies can penetrate clouds, the system's operation is not restricted to good weather conditions (Sect. 9.2).

LIDAR. A *LIDAR* sensor emits laser pulses and records the time until a reflection is received. It is mostly operated from an aircraft in order to determine the shape of the Earth's surface. Airborne LIDAR is also called *laser scanning*. Some systems include seabed surveys in shallow water.

ISO/TS 19130-2 defines four basic types of LIDAR systems.

1. Range finders, which are used to measure the distance from the LIDAR sensor to a solid or hard target.
2. Differential absorption LIDAR (DIAL), which is used to measure chemical concentrations (such as ozone, water vapor, and pollutants) in the atmosphere.
3. Doppler LIDAR, which is used to measure the velocity of a target.
4. Multiple-receiver LIDAR, which allows accurate location of a target in three dimensions by adding multiple receivers at different locations and triangulating the results.

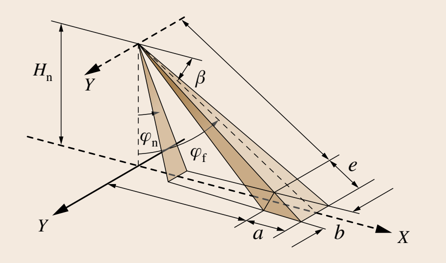


Fig. 13.42 Geometry of side-looking synthetic aperture RADAR (SAR) (after [13.88])
(H_g – flying height,
β – depression angle,
φ_n – near-edge incidence angle,
φ_f – far-edge incidence angle,
a – ground range resolution (x-direction),
b – azimuth resolution (y-direction),
e – slant range resolution)

SONAR. *Hydrographic SONAR* is used to measure the depth of the seabed and emits sound as well as measuring the time until a reflection is received.

ISO/TS 19130-2 defines four basic types of SONAR.

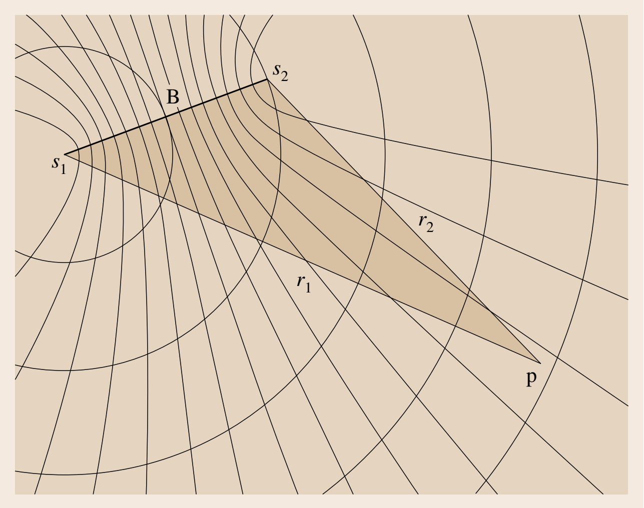


Fig. 13.43 Interferometric point positioning by range and phase difference. B is the base between two independent antennas. The *circles* correspond to *equirange* lines to sensor s_1 and the hyperbolas to *equidifference of range* lines to both sensors. The flight direction is vertical to the drawing plane (after [13.88])

1. A single-beam echo sounder system produces one narrow SONAR beam directly beneath the transducer and receives a return from the closest point at which it intersects the seabed.
2. Swath (multibeam or interferometric) SONAR systems have a single transducer or pair of transducers that transmit a fan-shaped signal perpendicular to the ship's direction of travel.
3. Sweep or boom systems are characterized by several transducers mounted on a boom, which is then operated parallel to the water's surface and orthogonal to the vessel's direction of travel.
4. Side-scan SONAR systems generally have two transducers mounted transversely in a towfish.

Aerial Triangulation. Aerial triangulation is a method of determining the georeference and other parameters of a sensor and the imagery data taken by this sensor. Aerial triangulation requires overlap between neighboring images to allow for the creation of a so-called block, which is the entirety of all images involved in a project.

The model provided by ISO/TS 19130-2 includes general aerial triangulation attributes, the observations such as image points or GNSS measurements, the unknowns such as the exterior orientation of each image, and given information such as control points (Sect. 9.4).

Calibration and Validation (ISO/TS 19159)

ISO/TS 19159-x *Calibration and validation of remote sensing imagery sensors* addresses the calibration and validation of those remote-sensing sensors where a georeferencing method is defined in ISO/TS 19130 and ISO/TS 19130-2. Those sensors operate on airborne and spaceborne platforms and deliver imagery data. Examples are frame cameras, line cameras, e.g., using the pushbroom method, LIDAR, and SAR.

The term "calibration" refers to geometry and radiometry, and includes the instrument calibration in a laboratory as well as in situ calibration methods such as field measurements. The term "validation" denotes a general approach to evaluating the quality of a process or a dataset. This specification defines validation for specific use cases such as the validation of calibration parameters that have been found some time ago.

Essentially, ISO/TS 19159 is a metadata definition that extends ISO 19115 and ISO 19115-2, and a description of calibration and validation processes.

Coverages (ISO 19123)

The term "coverage" has different meanings in the geomatics community. It is often a term synonymous to a layer that is a thematic subdivision of a dataset. Historically, layers were transparent foils that represented one color of a printed map. Within the ISO 19100 family of standards, coverages have an extended and more abstract meaning. Coverages are a concept considered to describe continuous and discrete spatial and temporal features, thus integrating concepts of the worlds of vector and gridded data. The related standard is ISO 19123 *Schema for coverage geometry and functions*.

The term "coverage," in the sense of the ISO 19100 family, has been adopted from the OGC.

Coverages may be discrete or continuous. An example of a discrete coverage is a map showing cities and their population, where an interpolation between them would make no sense. An example of a continuous coverage is a temperature map that provides a temperature value for any position within the boundaries of a region.

Coverages may be two-dimensional or three-dimensional. Examples of two-dimensional coverages could be a soil map and a digital elevation model, where the soil type and the elevation, respectively, are handled as attribute values. An example of a three-dimensional

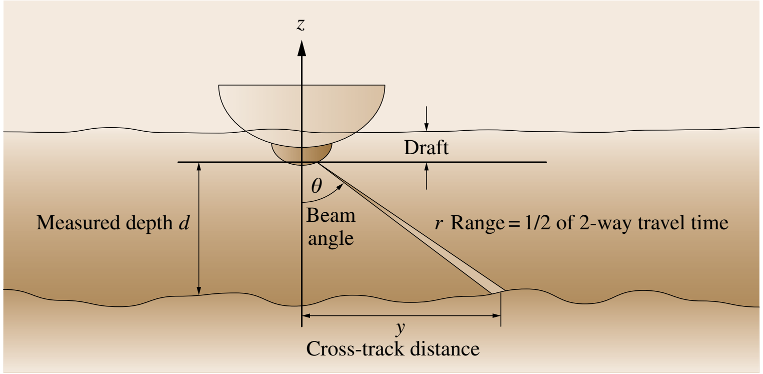


Fig. 13.44 Position and depth calculation for a hydrographic sonar (after [13.89])

coverage is a 3-D grid with values of atmospheric or oceanographic parameters associated with both horizontal position and height (or depth).

Coverages may have a temporal dimension that is the third or fourth dimension in the cases of two- or three-dimensional coverages, respectively. An example of a coverage with a temporal dimension is a dataset that contains the recorded daily temperatures of all weather stations of a region over a period of at least several days.

Space and the time are summarized as the spatiotemporal domain. The attributes belong to the attribute domain, which is also called the range, and a coverage may have multiple attributes at each position.

A coverage is a *world of its own* and is viewed as a geographic feature. A coverage includes the operations that are required to use its data, which leads to the perspective that a coverage is a function that relates the spatiotemporal domain to the attribute domain. An example of such operations is a request for an attribute value at a given position.

ISO 19123 standardizes a number of specific coverages. It comprises the Thiessen polygon coverage, the quadrilateral grid coverage, the hexagonal grid coverage, the TIN, and the segmented curve coverage.

Section 13.5.5 explains the details of ISO 19123.

13.4.4 Catalogue Standards

Procedure for Item Registration (ISO 19135)

As the number of applications for digital geographic information grows rapidly, a centralized registration is a means of promoting compatibility and avoiding duplicate efforts. ISO 19135 *Procedures for item registration* specifies procedures for registration of items of geographical information [13.90].

A registration is the assignment of an unambiguous name to an object. The objects when bound to a set of files form a register. The registry is the information system that maintains one or many registers. The registration authority keeps the registry.

The parties submitting their application to the registration authority are called sponsors. An application may include a profile of the ISO 19100 series of standards, a feature catalogue, or other specifications for geographic information. A typical case for a registry is the registration of coordinate reference systems (CRS). Their definition hardly changes over time, and it is essential that coordinate transformations in different applications use exactly the same parameter sets. With the help of a registry, the parameters can be retrieved online.

The standard allows more than one registration authority, but they must be approved by the ISO. To allow the user of geographic information to keep an overview of the authorities involved, their number shall be kept as small as possible. The registration authority keeps the registry as an Internet database.

The content of a registry includes

- a unique numerical registration identifier,
- a name for the registered object,
- the name of the sponsoring authority,
- the address of the sponsoring authority,
- the date on which the object was entered into the register,
- the registration status of the object, which will have one of the following values: *proposed*, *accepted*, *rejected*, *replaced*, or *obsolete*,
- the date on which the registered object was superseded or made obsolete,
- the registration identifier of the object that replaced it,
- a description of the registered object, including the field of application,
- a description of the relationship of the registered object to existing standards,
- information describing the registered object in compliance with the requirements of the technical standard that defines the object class.

The registry allows dynamic update of the registered objects. The items may, although it is not essential, be specified in an international standard. ISO 19145 *Registry of representations of geographic point location* is an example of such a standard, based on ISO 19135.

Recently, revision of ISO 19135 has begun. Experiences with the initial version of the standard have revealed a need for a more detailed specification of the development and maintenance of registries, as well as a definition of a registry service interface. An XML schema-based encoding shall be defined in ISO 19135-2, which is under development.

Registry of Representations of Geographic Point Location (ISO 19145)

Geographic points may be encoded in many different ways. ISO 6709:2008 *Standard representation of geographic point location by coordinates* defines the model for this encoding.

The automated processing of point encodings requires adequate online access, which is technical established using a register. ISO 19145 *Registry of representations of geographic point location* defines a registry for point locations according to ISO 19135 *Procedures for item registration*.

ISO 19145 does not define a register of CRSs but is concerned with the manner a geographic point location according to ISO 6709 is physically represented in a record or part of it.

For the purpose of unequivocally storage and retrieval of point data in the register, ISO 19145 also defines an XML implementation of ISO 19135 and its specialization for point locations.

Figure 13.45 illustrates the link between the user environment and the point register.

Feature Catalogues (ISO 19110)

The name of ISO 19110 is *Methodology for feature cataloguing*, with a feature being the fundamental unit of geographic information. The details of the modeling of a feature and its relationships to other features are explained in *Rules for application schema (ISO 19109)*. A feature catalogue is compiled of features according to this definition.

A feature catalogue forms a repository for a set of definitions to classify significant real-world phenomena to a particular Universe of Discourse. The catalogue provides a means for organizing the data that represent these phenomena into categories to ensure the resulting information is as unambiguous, comprehensive, and useful as possible.

A feature catalogue has many purposes. The most important ones are listed here.

- A feature catalogue may be sufficient for many applications, thus enabling cost reduction because one catalogue can be applied for many purposes.
- A feature catalogue should present an application-oriented particular abstraction of the real-world represented and in a form readily understandable and accessible to users of the data.
- Often the feature types in different systems have equal or similar names, such as private houses and private buildings. A feature catalogue may serve to clarify where the classification differs.

ISO 19110 provides a template for the organization of feature catalogue information. This template comprises sections for each feature type and the associated attributive information. A feature catalogue with only one feature type is shown in Table 13.24 as an example.

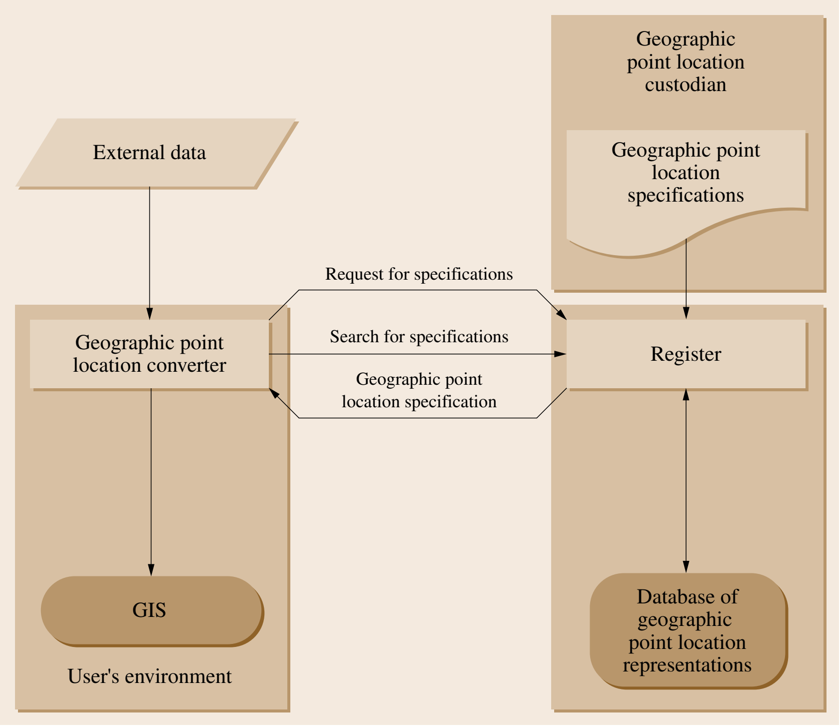


Fig. 13.45 User's environment and register (after [13.91])

Feature Concept Dictionaries and Registers (ISO 19126)

ISO 19126 *Feature concept dictionaries and registers* may be considered as a link between feature catalogues and registers, ISO 19110 and ISO 19135, respectively. ISO 19126 demands in a fairly abstract way the *basic definitions and related information about a set of concepts* that shall be used to describe the features that will become the elements of a feature catalogue. ISO 19126 describes also how those feature concepts can be maintained in a standardized registry [13.92].

The Defence Geospatial Information Working Group (DGIWG) was one of the major promoters of this standardization project. Consequently, an annex of this standard describes the DGIWG feature data dictionary (DFDD), a profile of ISO 19126, as an example of implementation of the feature concept dictionary schema. The *DGIWG feature and attribute data registry* can be accessed online without restrictions.

13.4.5 Implementation Standards

Data Product Specification (ISO 19131)

ISO 19131 *Data product specification* promotes the application of the ISO 19100 standards family for practical uses. A data product is a dataset containing data with a spatial relation to the Earth. A data product specification is a formal document that defines the details of the data product for production, end-users, and other purposes. It is a precise technical description of the data product in terms of the requirements that it will or may fulfill. Therefore, the purpose of the standard is to provide practical help in the creation of such specifications.

The document of ISO 19131 presents the National Road Network of Canada, level 1, as an example for a data product according to this standard.

A good guideline for the content of a data product specification is listed in a normative annex to the ISO 19131 *Data product specification* standard. It helps to

Table 13.24 Example for a feature catalogue with one feature type (bridge)

#	Feature catalogue element	Example data (bridge)
Feature catalogue		
1	Name	Small example feature catalogue
2	Scope	Illustrate principle of feature cataloguing
3	Field of application	Help understanding the standard
4	Version number	1.0
5	Version date	2003-02-20
6	Definition source	None
7	Definition type	Not applicable
8	Producer	Authors of the book
9	Functional language	Not applicable
Feature type		
11	Name	Bridge
12	Definition	Raised structure built to support a road and serving to span an obstacle such as a river
13	Code	1001
14	Aliases	
15	Feature operation names	Opening periods
16	Feature attribute names	Bridge availability, bridge category
17	Feature association names	Feature under the bridge
18	Subtype of	Roads
Feature operation		
21	Name	Opening periods
22	Feature attribute names	Bridge availability
23	Object feature type names	Road
24	Definition	Road closed if bridge is closed
25	Formal definition	

Table 13.24 (continued)

#	Feature catalogue element	Example data (Bridge)		
Feature attribute				
31	Name	Bridge availability		
32	Definition	Status for ordinary use		
33	Code	2001		
34	Value data type	Boolean		
35	Value measurement unit			
36	Value domain type			
37	Value domain			
Feature attribute				
31	Name	Bridge category		
32	Definition	Type of transportation facility supported		
33	Code	2002		
34	Value data type	Character		
35	Value measurement unit			
36	Value domain type	1 (*enumerated*)		
37	Value domain			
Feature attribute value				
38	Label	Generic/unknown	Road	Pedestrian
39	Code	0	1	2
40	Definition	Not applicable or impossible to determine		Pedestrians only
Feature association				
41	Name	Above–under condition		
42	Inverse relationship	Other features below the bridge		
43	Definition	Guarantees that the bridge is always above the other features		
44	Code	3001		
45	Feature types included	Stream		
46	Order indicator	0 (*not ordered*)		
47	Cardinality	1 : ? = *One or more*		
48	Constraints			
49	Role name			

take all details into account without necessarily thoroughly knowing the structure of the whole ISO 19100 family.

A minor change of the standard has taken place recently in that the treatment of coverages has been modified. The change document is named ISO 19131:2007 *Amd. 1, Geographic information – Data product specification, Amendment 1* [13.93].

Simple Features (ISO 19125)

ISO 19125 consists of two parts, named ISO 19125-1 *Simple feature access – Part 1: Common architecture* and ISO 19125-2 *Simple feature access – Part 2: SQL option*. ISO 19125 is implementation oriented.

Both parts deal with simple features. These are geometries restricted to two dimensions with linear interpolation between the vertices and may have spatial and nonspatial attributes. The simple features model consists of points, curves, and surfaces. The elements may be combined to geometry collections that include multi point, multi curve, and multi surface.

Part 1 of the standard defines the simple features model. It is an abstract model in the sense that is independent from a specific computer platform. Part 2 defines database access of simple features through a SQL interface. The OGC proposed the basic documents of ISO 19125.

The more comprehensive standards such as ISO 19107 *Spatial schema* and ISO 19123 *Schema for coverage geometry and functions* have used some elements of ISO 19125-1.

Section 13.5.4 contains a detailed description of ISO 19125-x.

Metadata Implementation

Metadata – XML Schema Implementation (ISO/TS 19139). ISO/TS 19139 *Metadata – XML schema implementation* aims at defining an XML encoding for the metadata elements defined in ISO 19115 *Metadata*. Because of the abstract nature of the ISO 19115 specification, the actual execution of geographic information metadata could vary based on the interpretation of the metadata producers. ISO 19139 is meant to enhance interoperability by providing a common specification for describing, validating, and exchanging metadata about geographic datasets [13.94].

13.4.6 Web: Mapping and Sensors

Web Map Server Interface (ISO 19128)

There are currently many mediums for communication being used, but the Internet admittedly is the most important. If we use the Internet, we rarely think of the software running in the background. We take it as is. Our interface to the net is a browser. A great variety of maps or other visual representations of geodata have already become available on the Internet. A Web Map Server produces maps of georeferenced data. In this context, a map is a visual representation of geodata, but it is not the data themselves. ISO 19128 *Web Map Server interface* is a specification that standardizes the way maps are requested by clients via the Internet and the way that servers describe their data holdings. ISO 19128 is a web interface specification for mapping data [13.95].

Originally, the ISO standard Web Map Server interface was a development of the Open Geospatial Consortium (OGC) [13.96].

Operations. The ISO standard Web Map Server interface defines three operations, the first two of which are required of every web map server. All of those requests are sent from the client to the server.

- GetCapabilities (required): Obtain service-level metadata that is a machine-readable (and human-readable) description of the Web Map Server's information content and acceptable request parameters.
- GetMap (required): Obtain a map image for which the geospatial and dimensional parameters are well defined.
- GetFeatureInfo (optional): Ask for information about particular features shown on a map.

Processing. A standard web browser can ask a web map server to perform these operations by simply submitting requests in the form of uniform resource locators (URLs). When invoking the operation GetMap, a Web Map Server client can specify the information to be shown on the map. Some of the information that could be specified would include the number of layers, the *styles* of those layers, what portion of the Earth is to be mapped (a *bounding box*), the projected or CRS to be used, the desired output format, the output size (width and height), and the background transparency and color. When invoking GetFeatureInfo the client indicates what map is being queried and which location on the map is of interest.

According to the philosophy of the Internet, no main server is responsible for collecting the data requested by the client. The display data commonly reside only at the client's computer. A particular Web Map Server provider in a distributed Web Map Server network only need be the steward of its own data collection.

Because each Web Map Server is independent, a Web Map Server must be able to provide a machine-readable description of its capabilities. The *service metadata* enables clients to formulate valid requests and enables the construction of searchable catalogues that can direct clients to particular Web Map Servers.

A Web Map Server may optionally allow the GetFeatureInfo operation. If it does, its maps are said to be *queryable*, and a client can request information about features on the map by adding a position around which nearby features are sought.

Cascading Web Map Server. A *cascading Web Map Server* is a Web Map Server that receives a map layer from another web map server and as such behaves like a client, and forwards this map layer to a client and as such behaves like a Web Map Server to this client; for example, a cascading Web Map Server can aggregate the contents of several distinct map servers into one service. Furthermore, a cascading Web Map Server can perform additional functions such as output format conservation of coordinate transformation on behalf of other servers.

Web Feature Service (ISO 19142)

The purpose of ISO 19142 is to establish a web mapping interface that supports streaming geographic information, primarily GML, across the Internet. WFS also supports the modification of features across the Internet; this additional capability is referred to as transactional or WFS-T in short. The interface includes raster as well as vector data and works on the feature and feature property levels. This essentially implements a client–server structure with which a geographic dataset can be fully maintained, i. e., where features can be created, modified, or deleted.

XML is the extensible markup language and is discussed in Chap. 4.

The method of noting information by key–value pairs (KVP) is often used in information technology. An example is the GetCapabilities request of the Web Feature Service, such as http://hostname:port/path?service=WFS&request=GetCapabilities, where, e.g., *request* is the key and GetCapabilities is the value.

ISO 19142 defines an XML and a KVP encoding of a system-neutral syntax for 11 operations. Because of complexity, the definition of a KVP encoding is not feasible for two of the operations (Table 13.25).

Table 13.25 Operations and their request encoding in ISO 19142 (after [13.97])

Operation	Request encoding
GetCapabilities	XML & KVP
DescribeFeatureType	XML & KVP
GetPropertyValue	XML & KVP
GetFeature	XML & KVP
LockFeature	XML & KVP
GetFeatureWithLock	XML & KVP
CreateStoredQuery	XML
DropStoredQuery	XML & KVP
ListStoredQueries	XML & KVP
DescribeStoredQueries	XML & KVP
Transaction	XML

GetCapabilities. The GetCapabilities operation generates a metadata document describing a WFS service provided by a server similar to the web map server. At the beginning of a session, this document is requested by the client.

DescribeFeatureType. The DescribeFeatureType operation returns a schema description of feature types offered by a Web Feature Service (WFS). The schema descriptions define how the WFS expects feature instances to be encoded on input (via insert, update, and replace actions) and how feature instances shall be encoded on output (in response to a GetPropertyValue, GetFeature, or GetFeatureWithLock operation). This operation is also invoked at the beginning of a session to align the client's with the server's capabilities.

GetPropertyValue. The GetPropertyValue operation allows the retrieval of the value of a feature property from the data store for a set of features identified by a query expression.

GetFeature. The GetFeature operation returns a selection of features from a data store to the client. The document contains zero or more feature instances that satisfy the query expressions specified in the request. The standard representation of features uses GML.

LockFeature. Locking of features is a necessary operation as soon as two or more editing processes work on the same geospatial database, as otherwise it may happen that a feature is worked on by two editors at the same time, which would lead to undetermined results.

The purpose of the LockFeature operation is to expose *a long-term feature locking* mechanism to ensure consistency. The lock is considered long term because network latency would make feature locks last relatively longer than native commercial database locks.

GetFeatureWithLock. The GetFeatureWithLock operation provides functionally similar to the GetFeature operation except that, in response to a GetFeatureWithLock operation, a WFS shall not only generate a response document similar to that of the GetFeature operation but shall also lock the features in the result set, presumably to update the features in a subsequent transaction operation.

Stored Queries. A stored query is a named, persistent, parameterized query that can be invoked numerous times with different values bound to the query parameters. Thus, this simplifies repeated queries of the same type. Like all WFS queries, it returns a number of features that satisfy the stored query for the specified parameter values. Stored queries allow the simplification of complex temporal and spatial queries.

ISO 19142 defines four operations related to stored queries: CreateStoredQuery, DropStoredQuery, ListStoredQueries, and DescribeStoredQueries

A stored query may be created using the CreateStoredQuery operation.

The DropStoredQuery operation allows previously created stored queries to be dropped from the system.

The ListStoredQueries operation lists the stored queries available at a server.

The DescribeStoredQueries operation provides detailed metadata about each stored query expression that a server offers.

Transaction. Using the transaction operation, clients can *create*, *modify*, *replace*, and *delete* features in the WFS data store. The transaction is therefore the most comprehensive operation of the WFS. However, this operation is optional.

Filter Encoding (ISO 19143)

The term "filter" as used in ISO 19143 *Filter encoding* denotes an encoding of predicates that are typically used in query operations to specify how data instances in a source dataset should be filtered to produce a result set. Originally, the content of this standard was a part of OGC's WFS specification but has been separated from ISO 19142 *Web Feature Service* because that type of filtering is not limited to the application of ISO 19142.

XML is the extensible markup language and is discussed in Chap. 4.

Like ISO 19142, the ISO 19143 also defines an XML and keyword–value pair (KVP) encoding of a system-neutral syntax for query expressions, and an XML encoding for the listed predicates; for example, an XML-encoded query could be transformed into a SQL SELECT … FROM … WHERE … ORDER BY … statement to fetch data stored in a SQL-based relational database. Similarly, the same XML-encoded query expression could be transformed into an XQuery expression in order to retrieve data from an XML document. These queries could be expressed with a KVP encoding in a similar manner.

ISO 19143 defines only the XML encoding for the predicates [13.98].

1. Logical predicates: and, or, and not.
2. Comparison predicates: equal to, not equal to, less than, less than or equal to, greater than, greater than or equal to, like, is null, and between.
3. Spatial predicates: equal, disjoint, touches, within, overlaps, crosses, intersects, contains, within a specified distance, beyond a specified distance, and BBOX (bounding box).
4. Temporal predicates: after, before, begins, begun by, contains, during, ends, equals, meets, met by, overlaps, and overlapped by.
5. A predicate to test whether the identifier of an object matches the specified value.

Observations and Measurements (ISO 19156)

Sensor Web Enablement (SWE), an activity of the OGC, was one important reason for the development of ISO 19156 *Observations and measurements*. SWE is concerned with establishing interfaces and protocols that will create a sensor web through which applications and services will be able to access sensors of all types, and observations generated by them, over the Internet.

ISO 19156 provides a very general approach to the nature of observations as they are defined as an act associated with a discrete time instant or period through which a result – a number, a term, or another symbol – is assigned to a phenomenon. The phenomenon is a property of the feature being observed [13.99].

The observation may involve the application of a specified procedure, such as a sensor, an instrument, an algorithm, or a process chain. This procedure may be applied in situ, remotely, or ex situ (such as in a laboratory) with respect to the sampling location.

The respective ISO/IEC guide [13.100] relates the term "measurement" to any operation that aims at determining a value of a quantity. However, ISO 19156 uses the term "observation" for the general concept. "Measurement" is reserved for cases where the result is a numeric quantity.

Metrology is the science of measurements and has its origins in mechanical engineering. The measurement tasks in spatial sciences differ slightly from typical tasks in metrology in that they are related to space and time, and – more important – often only allow for indirect measurements or include mass data.

A typical example for an indirect measurement is the analysis of a remotely sensed imagery that is applied for land use mapping. This remotely sensed image is an intermediate product, a proximate, from which the ultimate feature of interest, the map, is derived.

A huge number of data is often involved in the geometry of a cartographic measurement; for instance, a road network consists of the spatially sampled points and curves. Other mass data may also include surfaces and solids.

The observation model of ISO 19156 emphasizes the semantics of the feature of interest and its properties.

Its viewpoint may be characterized as *data-user*-centric. This contrasts with sensor-oriented models, which are often more technical and take a process-centric or provider-centric viewpoint.

13.4.7 Location-Based Services

Since the advent of Global Navigation Satellite Systems (GNSS), people have been inventing new applications that combine online positioning data with other digital geographic information. The largest family of these products is called location-based services (LBS). This term is meant in the broadest possible sense, because the sources of locations are not restricted to satellite navigation systems. The term includes any technology that delivers the position of a receiver online; for example, today it could be a cellular phone that derives its position from the geographic cell it is momentarily operated in. In one of the simplest applications, the received positions are shown as a red moving dot on a digital map displayed on some handheld computer. The positions might be used for further processing on the geographic data. The development of ideas and applications has just started.

The ISO is addressing the growing field of location-based services very carefully. This is in order to direct the developments towards compliance with the existing 19100 family of standards while at the same time avoiding any restrictions imposed by early standardization, as many new ideas are still emerging that could change the scope. ISO covers the field with five standards. These are ISO 19132 *Location-based services – Reference model*, ISO 19133 *Location-based services – Tracking and navigation*, and ISO 19134 *Location-based services – Multimodal routing and navigation*, with newer developments addressed in terms of *linear referencing* (ISO 19148) and the *schema for moving features* (ISO 19141) (Chap. 21).

Location Based Services – Reference Model (ISO 19132)

ISO 19132 defines a reference model for location-based services (LBS). This reference models consists of a so-called conceptual framework, a frame of concepts, ideas, terms, definitions, and the interdependence between those. It also addresses the interfaces for data access while roaming and areas where further standards are required.

Fig. 13.46 Relation between the reference models of LBS and GIS (after [13.101])

The role that ISO 19132 plays for LBSs is identical to the role that ISO 19101 *Reference model* plays for GIS, as illustrated in Fig. 13.46.

ISO 19132 builds upon the viewpoints as defined in the Reference model for Open distributed processing (RM-ODP; ISO/IEC 10746) but limits their application for an LBS system to the first three

1. the enterprise viewpoint, detailing the purpose, scope, and policies of the system;
2. the information viewpoint, detailing the semantics of information and processing within the system;
3. the computational viewpoint, detailing the functional decomposition of the system.

The other two, the engineering and technology viewpoints, play a subordinate role in this standard.

In general, the enterprise viewpoint details the policies of the system. Regarding location-based services this addresses the roles that the stakeholders in location-based services can play with respect to a service: user, broker, or provider. The role of a service provider may be subdivided into an application provider and a data provider, which again may be a content provider and a feature data provider. Another important topic of LBS is digital rights management.

The information viewpoint addresses the semantics of information and the processing within the system. This perspective can best be related to the data model. It defines almost 30 LBS data types that serve to build a LBS-application. Examples for those data types are an instruction sent to a user, a definition of display parameters, or the selection of a cost function.

The computational viewpoint looks at the functional decomposition of the system, which can best be related to the service model of ISO 19132. A service taxonomy distinguishes location, geomatics, and information services as well as system and user management. Tracking, routing, and navigation are location services. Examples for geomatics services are address parsing (read an address) and geoparsing (find the coordinates for a given location or phone number). The information service includes queries regarding the network or moving object such as parcels.

Location-Based Services – Tracking and Navigation (ISO 19133)

Tracking and navigation are the core applications of location-based mobile services. They are covered by ISO 19133 *Location-based services – Tracking and navigation*. Tracking is the process of following and reporting the position of a vehicle in a network. In some cases, it may be the position of a handheld computer only. Routing is the finding of optimal routes between positions in a network. Route traversal is the execution of a route, usually through the use of instructions at each node in the path, and a start and stop instruction, at the first and last position of the route. The combination of routing, route transversal, and tracking is navigation. The optimal route is the one with minimal costs in terms of money, time, or other parameters such as pleasure along scenic routes.

The basic assumption is that services made available on the Internet will be accessed by mobile devices in a manner similar to on-web clients, with the exception that the mobile client can update its own position during the process. For this purpose on-web proxy applications for the mobile client are required. These applications act as a device transformer for messages and data flowing between the web service and the mobile client. The interface between the mobile client and the on-web programs is out of scope for this standard and is covered by standards written by and within ISO/TC 204 *Intelligent transport systems*.

Tracking. The tracked positions are defined by coordinates or other types of positional descriptions. A tracking service (class TK_TrackingService) delivers the positions, either one by one or as a sequential list.

The positions may be one of the types coordinate, place name, feature, linear reference, network, address, or phone.

A trigger defines the moment or the location for delivering positional information. Triggers are generally of two types: triggered by an event, or triggered by the passage of time.

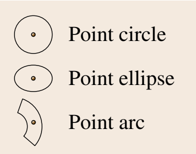


Fig. 13.47 Geometry of the point estimates circle, ellipse, and arc (after [13.102])

A transitional trigger delivers a new position dependent on the movement of the vehicle being tracked. Usually, events take place after the completion of a distance, or after a change of direction. The periodic trigger is used to control location sequences by setting temporal limits on how far apart in time tracking samples are taken.

The tracking location metadata include the mobile subscriber and the quality of positions. The mobile subscriber is the item being tracked such as a car with a navigation system. The quality of positions is shown as a buffer around them and may be expressed in five different ways.

1. Point estimate circle
2. Point estimate ellipse
3. Point estimate arc
4. Point estimate sphere
5. Point estimate ellipsoid.

For position-type coordinates the tracking service uses linear reference systems that are in wide use in transportation. They allow for the specification of positions along curvilinear features by using measured distances from known positions, usually represented by physical markers along the right-of-way of the transportation feature. ISO 19133 includes the description of positions close to but not on the path. The distance from a reference line to the path is called an offset. Figure 13.48 depicts a feature to the left of the berm of a road.

Element is a part of the road's centerline that serves as the angular reference for the offset.

Linear reference systems are an extension to the coordinate reference systems standardized in ISO 19111.

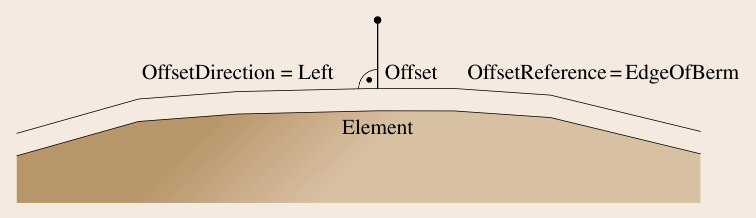


Fig. 13.48 Offset to a linear reference system (after [13.102])

Table 13.26 Elements of the address model of ISO 19133

Addressee	Phone number	Municipality quadrant
StreetIntersection	Named place	Region code (country)
Street	Street address	Number range
Postal code	Named place classification	List named places
Street location	Building	

To deal with address-type positions, ISO 19133 describes an address model with reference to existing standards. Table 13.26 lists the elements provided by ISO 19133 to specify an address.

Currently there is no fully applicable international address standard. However, the project ISO 19160 *Addressing* has started and will lead to a comprehensive solution that will fulfill the requirements of location-based services.

Navigation. Navigational computation is based on an underlying network. The network comprises the elements

- the nodes represent important points in the network, such as intersections,
- the links represent uninterrupted paths between nodes with an orientation that indicates which direction the link is to be traversed,
- the turns associate a node to an entry link and exit link to a node,
- the stops consist of either nodes or positions on links within the network. The start and the end of the route are a so-called type of stop.

According to ISO 19133, a network has two different topologies. Its geometric topology refers only to nodes and edges as shown in Fig. 13.49. The second topology is the graph of links, junctions, and turns that is shown in Fig. 13.50. Although the links, junctions, and turns have the same underlying geometry, they have their own connectivity based on usable *vehicle* routes. If a link comes to a cross-roads and U-turns are allowed, then there are up to four turns which exit that link and enter into one of the links leaving that node, including the one that reverses the incoming link.

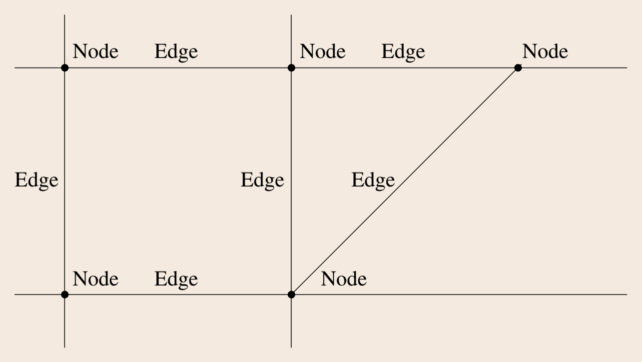


Fig. 13.49 Geometric topology of a road network

The description of a network includes constraints such as vehicle constraints, temporal constraints, and lane constraints.

A navigation service delivers the optimal route between two positions within a network and guides the vehicle along that route.

A navigation service requests a route from the navigation system and receives a proposed route based on the given parameters. Table 13.27 presents the most important attributes for a route request.

According to their complexity, navigation services are categorized into five types.

1. A *basic navigation service* must support at least cost functions based on distance and expected average time.
2. A *predictive navigation service* is a basic service that must be able to take the chosen time of day and date into account for predicting travel time.
3. A *real-time navigation service* is a predictive service that must be able to monitor traffic and road conditions and to reroute based on current information.

Table 13.27 Attributes of a route request

Route request type	Basic, predictive, etc.
Vehicle	Type, such as car or truck
Way point list	Start point, end point, other stopping points
Avoid list	Links in the network to be avoided
Departure time	Planned period of the beginning of navigation
Arrival time	Planned period of the end of navigation
Cost function	Type, default is minimum distance
Preferences	Specific user demands such as most scenic route
Advisories	Text to be displayed during navigation
Refresh interval	Maximum time before a recalculation of the route

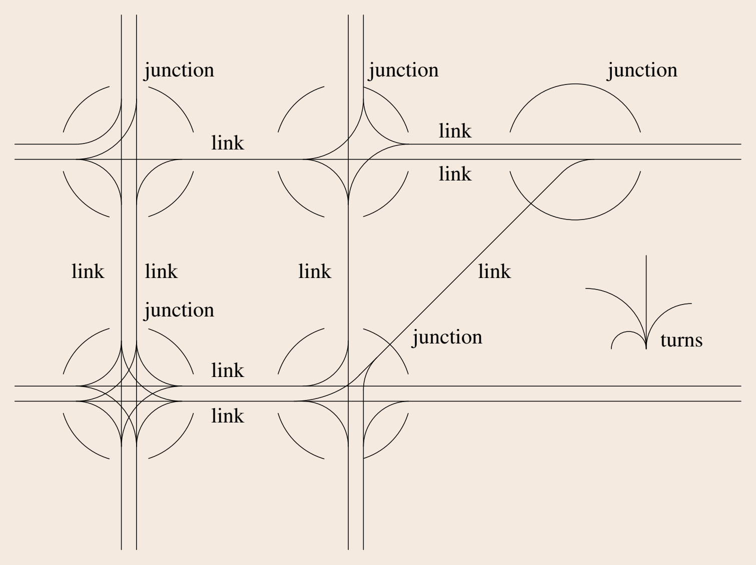


Fig. 13.50 Topology of a road network with links (edges), junctions (nodes), and turns

4. A *multiple-stop service* is a basic, predictive or real-time service that must be able to handle multiple stops (uncosted) along the route.
5. A *complex navigation service* is a multiple-stop, real-time services that must be able to include cost based on activities associated with traversal of the route, such as costing stops based on the price of activities at those stops (see the description of cost functions below).

The cost function calculates the optimal route based on minimum costs. ISO 19133 recommends the algorithms of *Dijkstra* [13.103] (Sect. 9.6) and *Bellman–Ford* [13.104, 105]. Table 13.28 summarizes the typical variables used to control a cost function for car navigation.

Table 13.28 Cost function variables for route calculation

• Distance
• Time
• Stopping time (traffic lights)
• Speed
• Speed limits
• Slope (affects mostly freight vehicles)
• Link capacity (capacity of an intersection)
• Link volume (current amount of traffic at an intersection)
• Stopping time (expected stopping time at turns)
• Conditions (weather)
• Tolls

Multimodal Operation

Location-Based Services – Multimodal Routing and Navigation (ISO 19134). ISO 19134 *Location-based services – Multimodal routing and navigation* extends ISO 19133 *Location-based services – Tracking and navigation* in that is adds the case of a multimodal network. This type of network is the typical setup of urban public transport.

A multimodal network is a network that is composed of edges which belong to more than one traveling mode, e.g., bus and light rail. If a network consists of one means of traveling, it has only single-mode junctions.

Figure 13.51 illustrates two typical cases for traveling in a multimodal network.

A NT_Link is a network link according to ISO 19133.

Movement Along Linear Features (ISO 19148, ISO 19141)

Linear Referencing (ISO 19148). ISO 19148 *Linear referencing* defines a model for relating attributes and locations to linear geographic features such as roads and pipelines, or said in a more general way, transportation and utilities. This standard is a specialization of ISO 19133 *Location-based services – Tracking and navigation*. It is also based on the family of standards that has been developed by ISO/TC 204 *Intelligent transport systems*.

Worldwide, there are numerous methods used for relating events such as road accidents and leakages

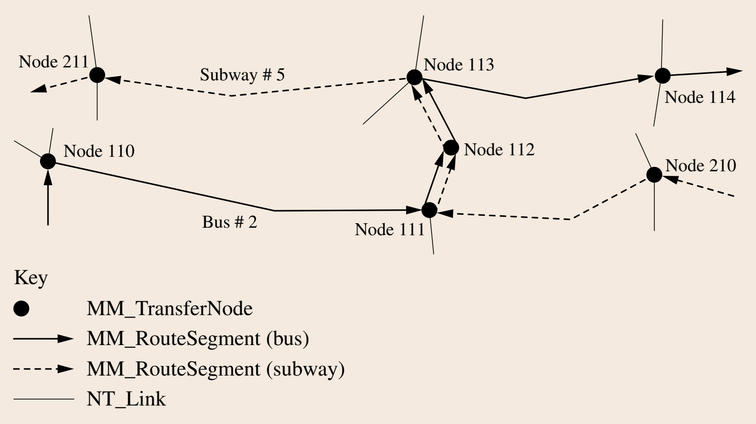


Fig. 13.51 Traveling across route segments in a multimodal network (after [13.106])

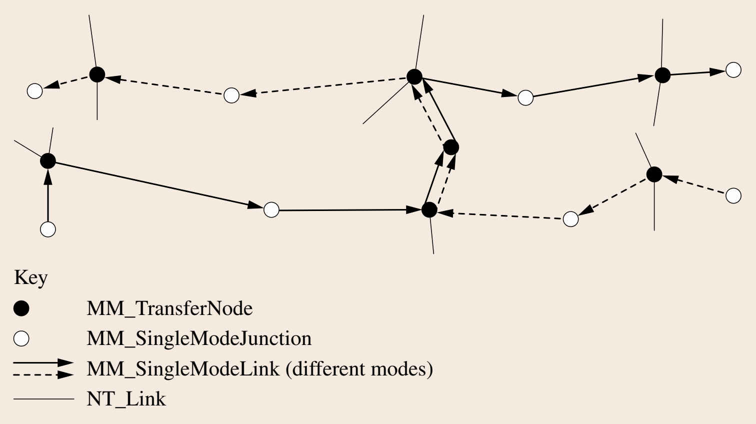


Fig. 13.52 Traveling across transfer nodes in a multimodal network (after [13.106])

to a linear feature, and thus no single best method. Therefore, ISO 19133 can only provide a generalized model.

The model has a number of characteristics

- The features do not need to be a linear geometry, but must allow for measurements in a one-dimensional, linear sense. This refers to the abstraction of a road network as used in navigation systems and to the fact that a road is never one-dimensional, as it has a width different from zero.
- The feature may have no geometry but only a reference to one. Maintenance activities such as snow plowing may be an example of this.

Point positions may be referenced (the standard says "projected") to the linear feature.

A linear element may be a feature as defined in this standard, a curve which is a geometry primitive defined in ISO 19107, or a directed edge which is a topological primitive defined in ISO 19107.

The underlying geometry of linear features is often fragmented into small straight lines to model curved features. To avoid an overhead of attribute values, this standard allows one attribute to be defined for many segments.

Figure 13.53 depicts the fundamental methods of relating events to linear features.

Figure 13.54 explains the concepts of describing offset location regarding the linear feature.

Figure 13.55 demonstrates equivocal geometries and their solution by defining a general vector offset.

Schema for Moving Features (ISO 19141). ISO 19141 *Schema for moving features* defines a model for the description of features in motion. Such a feature may be a car, an airplane, a ship, or something alike. While moving along the trajectory of the feature, the feature's

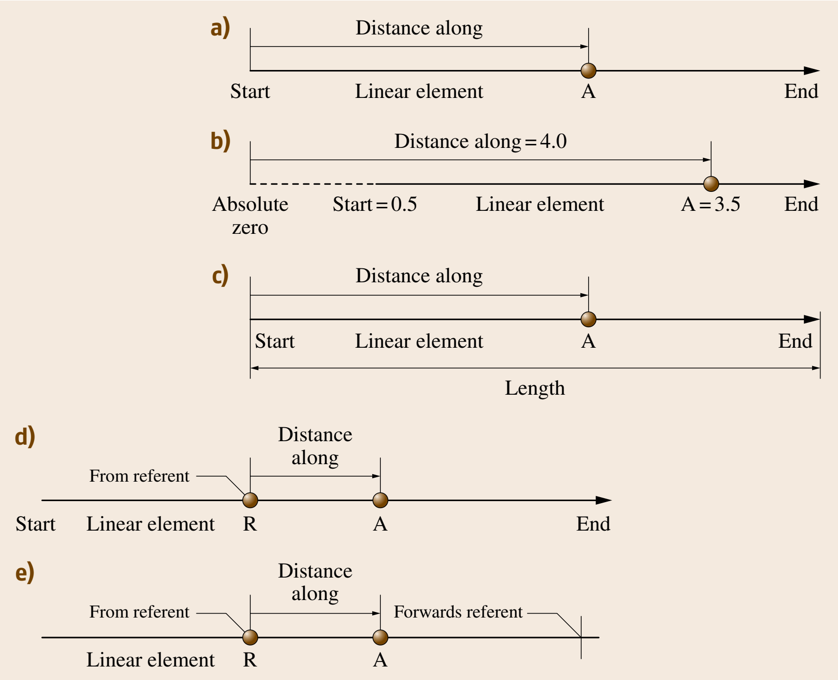


Fig. 13.53a–e A linear element and its attribute *distance along* with five different geometric references (after [13.107]). **(a)** Beginning from start of the element, absolute distance, **(b)** beginning from point zero, absolute distance, **(c)** beginning from start, relative distance, **(d)** beginning from a referent, absolute distance, **(e)** beginning from a referent, relative distance

orientation/rotation, and the clearance gauge are of interest. ISO 19141 addresses those elements.

Figure 13.56 illustrates how the concepts of foliation, prism, trajectory, and leaf relate to one another. In this illustration, a 2-D rectangle moves and rotates, and represents such a moving feature. Each representation of the rectangle at a given time is a leaf. The path traced by each corner point of the rectangle (and by each of its other points) is a trajectory. The set of points contained in all of the leaves, and in all of the trajectories, forms a prism. The set of leaves also forms a foliation.

13.4.8 Classification

Classification Systems – Part 1: Classification System Structure (ISO 19144-1)

Classification is the grouping of things or terms according to features that they have in common [13.108], and a basic step in most sciences. In geography, the classification of regions based on thematic phenomena has always been an important research topic. The Troll–Paffen map of the classification of the Earth's climate zones is a prominent example for the outcome [13.109].

Classification in geographic information sciences faces the challenge of defining and applying classification schemas in the Internet era. The ISO 19144-x group of standards entitled classification systems sets basic rules for structuring those schemas and defines a so-called land cover metalanguage that shall be used for writing such a schema.

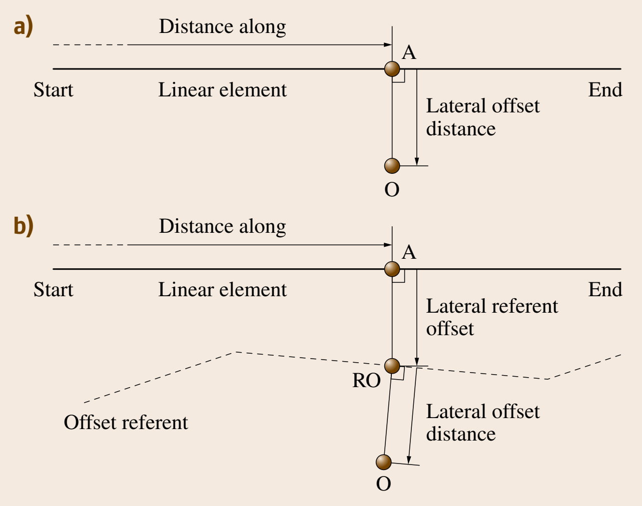


Fig. 13.54a,b Offsets. **(a)** Referenced to the linear element, **(b)** referenced to an offset referent (after [13.107])

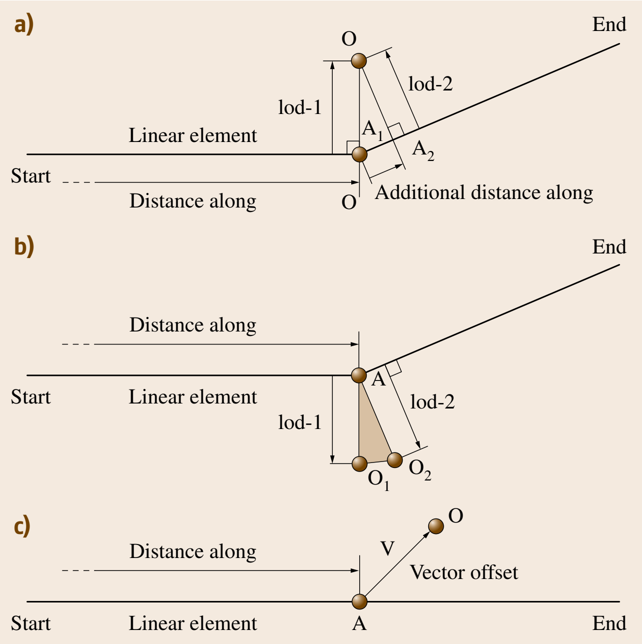


Fig. 13.55a–c Equivocal offset geometries. **(a)** Ambiguous offset locations, **(b)** unsatisfiable offset location, **(c)** vector offset for the solution of any nonstandard offset location (after [13.107]) ◀

ISO 19144-1 does not define a single classification system as the *standard one* but rather sets rules for creating such a system. ISO 19135 *Procedures for item registration* is to deliver the rules for those systems to allow for a well-organized and easy-to-maintain system.

The classification system subdivides an area into small units, each of which carry an identification code. Using the terminology of ISO 19123 *Schema for coverage and functions* (*coverage* in short), this partitioning is called a *discrete coverage*. Therefore, most of the classification methods result in discrete coverages.

A number of classification characteristics are worth mentioning.

A geographic feature according to ISO 19101 *Reference model* is different from a classified object according to ISO 19144-1 *Classification Systems – Part 1: Classification system structure* in that a geographic

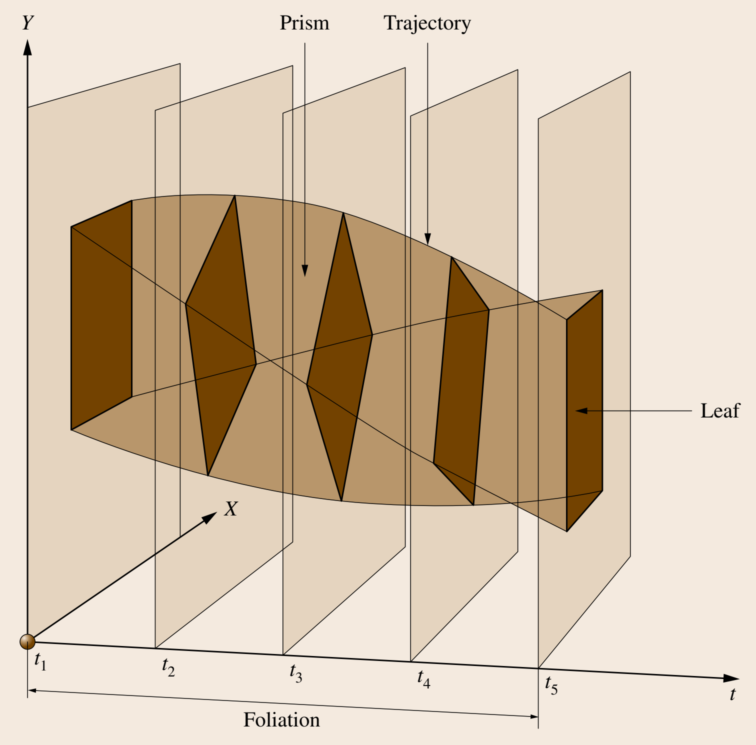


Fig. 13.56 Graphical explanation of the terms foliation, prism, trajectory, and leaf (after [13.110])

feature is atomic while a classified object is part of a whole and thus necessarily related to the others by the classifiers that decompose the whole. The standard gives the example of classifying the Earth's surface into land and water. The total of land and water is the complete surface.

As a classification is an abstract representation of real-world phenomena, a classification system shall be

- scale independent, meaning that the classes at all levels of the system shall be applicable at any scale or level of detail, and
- source independent, implying that it is independent of the means used to collect information.

Classification systems come in two basic forms: hierarchical and nonhierarchical.

The requirements are

- for nonhierarchical classification systems
  - classifiers shall be defined so that all classes are mutually exclusive.
- for hierarchical classification systems
  - Classifiers shall be defined so that all classes at a specific level of the hierarchy are mutually exclusive.
  - Criteria used to define a classifier at one level of a hierarchical classification shall not be repeated at another level (e.g., criteria used to define a classifier at a lower level shall not be duplicated at a higher level of the hierarchy).

Classification Systems – Part 2: Land Cover Metalanguage (LCML) (ISO 19144-2)

Land cover is the (bio)physical cover on the Earth's surface. This definition is provided by ISO 19144-2 *Classification systems – Part 2: Land cover metalanguage (LCML)*. Land cover is considered to be a geographically explicit feature that other disciplines may use as a geographical reference, e.g., for land use, climatic, or ecological studies.

Several land cover classification systems (LCCSs) have evolved in the past, are being used today, and will stay in the future because they often serve specific needs, and investments have been made to exploit their data. Well-known international LCCSs are the UN/Food and Agriculture Organization (FAO) LCCS, coordination of information on the environment (CORINE, European Union), Africover (United Nations), Anderson (United States Geological Survey (USGS)), and Global Map (Japan), as well as many national developments.

ISO 19144-2 provides a metalanguage expressed as a UML model that allows different land cover classification systems to be described. This metalanguage allows the description of land cover features based on physiognomy, i. e., the general appearance of an object or terrain, without reference to its underlying or scientific characteristics. Those features may be part of different land cover legends (nomenclature), thus providing a framework for comparing different systems.

The aim of ISO 19144-2 is to enable the ability to compare information from existing classification systems in a meaningful way without replacing them. The aim is to complement the development of future classification systems that may offer more reliable collection methods for particular national or regional purposes by allowing them to be described in a consistent manner. It provides a common reference structure for comparison and integration of data for any generic land cover classification system, but is not intended to replace those classification systems.

Figure 13.57 depicts the high-level model of ISO 19144-2.

13.4.9 Qualifications and Certification of Personnel (ISO/TR 19122)

Beyond the scope of ISO/TC 211, the ISO/technical report 19122 *Qualifications and certification of personnel* reviews education and training for geomatics. The report primarily presents the result of a survey on the educational systems in 18 countries that responded to a questionnaire sent out to all members of ISO/TC 211. A long-term goal of the effort is a plan for accreditation of candidate institutions and programs and for certification of individuals in the workforce. Within the geomatics community, there is an ongoing discussion regarding the extent to which educational topics should be subject to worldwide standardization [13.111].

Qualification is the knowledge, skills, training, and experience required to properly perform geomatics tasks that are normally achieved through formal education.

Certification is the procedure leading to a written testimony regarding the qualification of an individual's professional competence and can be provided by a range of public, private, and professional institutions.

The intention of this informative ISO (type 3) report can be summarized in four statements [13.112].

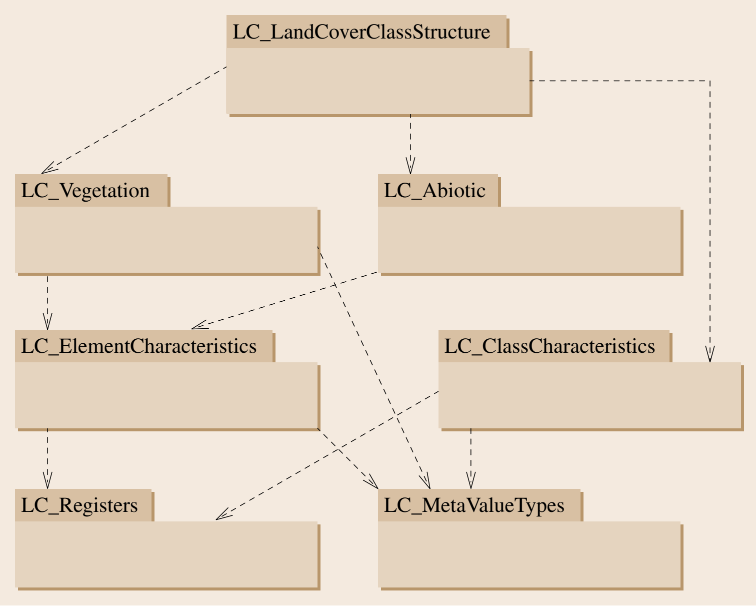


Fig. 13.57 Land cover metalanguage packages (after [13.113])

1. Define the boundaries between geomatics and other related disciplines and professions.
2. Specify technologies and tasks pertaining to geomatics.
3. Establish skill sets and competency levels for technologists, professional staff, and management in the field.
4. Research the relationship between this initiative and other similar certification processes performed by existing professional associations.

The survey questionnaire asked for the following information.

1. Does your country have a set of guidelines for the qualification and certification of personnel in the field of geographic information/geomatics?
2. If NO to question 1, are you planning to initiate this activity in the near future?
3. Do you have national legislation for certification of personnel?
4. Do you have legislation for certification at the regional level?
5. Do you have industry standards?
6. Is there a group that has defined a model curriculum?
7. Do you have a mechanism for program accreditation?
8. How many higher education institutions teach geographic information/geomatics?
9. What geographic information/geomatics professional associations exist in your country?

Eighteen countries responded to the questionnaire. In addition, 13 of them delivered a detailed case study on their national education in geomatics, namely Australia, Austria, Canada, Finland, Germany, Japan, South Korea, New Zealand, Portugal, Saudi Arabia, South Africa, the UK, and the USA. The Fédération Internationale des Géomètres (FIG) also provided a detailed report.

In a very general sense, the results of the case studies may be summarized as follows:

Japan and South Korea have established national government bodies that have responsibility for certification of personnel. Germany has a strong educational structure that has certain similarities to these Far East countries. In the UK, a number of professional organizations are linked to the Association of Geographic Information (AGI), which is a consortium of private and public interests. Canada and the USA have academic consortia [e.g., the University Consortium for Geographic Information Science (UCGIS)] and also active professional bodies. In South Africa, a strong national association has formed to bring together regional GIS organizations.

13.5 Geometry Standards

Traditionally, graphic data falls into the two categories of vector and raster. This approach is reflected in the way the ISO 19100 standards are partitioned. The ISO 19100 standards use the more general term *gridded data* instead of raster.

ISO 19107 *Spatial schema* depicts a fairly complete world of vector data. ISO 19125-1 *Simple features access – Part 1: Common architecture* is a subset of ISO 19107 using different terminology because of historic reasons.

ISO 19123 *Schema for coverage geometry and functions* describes coverage data in a general sense. Coverages are often considered to be a way of integrating the worlds of vector and raster data, thus overcoming the dichotomy originally imposed by hardware restrictions. However, coverages are restricted to three spatial and one temporal dimension. Later they shall handle n-dimensional space. ISO/TS 19130 *Imagery sensor models for geopositioning* describes the models needed to relate remotely sensed imagery data to the Earth. ISO 19129/TS *Imagery, gridded and coverage data framework* is a framework standard that describes the concepts of gridded data, lists all required elements, and fills some gaps left by the other standards.

13.5.1 Relations Between Geometry Standards

The following diagram (Fig. 13.58) shows the relations between the six geometry and imagery standards.

Although a less abstract way of describing the structures may be desirable in some cases, the terminology of the conceptual schema language UML will be used in order to be consistent with the UML models of the ISO 19100 standards. In most cases, the models consist of a hierarchy of classes. A high-level class describes a graphical element in a very general sense; for example, a GM_Object can be any geometry object of the dataset such as a point, a curve, a surface, or a solid. A low-level class describes a specific geometry such as an arc or a spline. The whole model contains an abstract view of the real world, and its only purpose is to address the classes that could possibly be present in a dataset. If a real dataset is created, it uses the classes supplied by the standard. The elements which form the real dataset are the instances of the abstract classes; for example, the instances of the class GM_Surface may be the property parcels 1, 2, . . . , n in the dataset.

13.5.2 Positions

ISO 19107, ISO 19123, and possibly others in the future have an integrated concept for dealing with positions in n-dimensional space. ISO 19125-1 supports only two dimensions and uses a different method.

The concept based on ISO 19107 will be described first. An n-dimensional set of coordinates is called a DirectPosition, such as (x, y, z). Obviously, a point object (class GM_Point) has one set of coordinates and thus one DirectPosition. Curves, surfaces, and solids have more than one set of coordinates and consequently more than one DirectPosition.

The name DirectPosition is derived from the *direct* identification of the position. Alternatively, a position can be defined by the position of another *point object* (class GM_Point). This is called an *indirect* identification of a position. An example would be a parcel boundary which is mostly a line string. The positions of the line string are the corner stones of the parcel, which

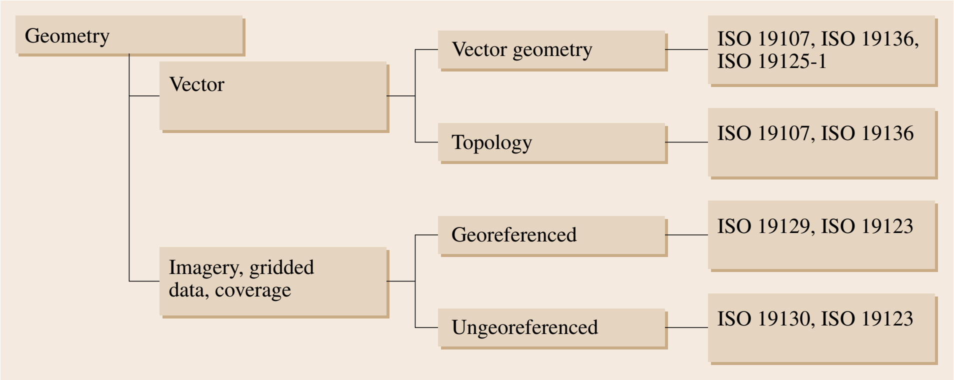


Fig. 13.58 Relation of the vector data and imagery standards of ISO 19100

are point objects themselves. Thus, the coordinates of the line string are the coordinates of the point objects.

To better handle numerous DirectPositions in a dataset, the positions of a curve, a surface, or a solid are collected in an ordered manner that is called a point array (class GM_PointArray). To avoid redundancy and unnecessary use of storage volumes, the point array only stores pointers and no coordinates. The pointers may point to DirectPositions or point objects.

The pointers within a point array (class GM_PointArray) are alternatively called controlPoints.

The class storing the flag with direct or indirect reference is called GM_Position.

The ISO 19123 concept of a coverage relates a set of attributes to a position within a bounded space. From this perspective, the basic element of a coverage is a pair of data collections; one data collection denotes a position such as (x, y) and the other data collection denotes the attributes at this position such as temperature and soil type. ISO 19123 refers to ISO 19107 for the details of positions.

This pair of data collections at one point is called a point–value pair (class CV_PointValuePair). According to ISO 19107, the position of a point–value pair is always a point object. In other words, the DirectPosition of ISO 19107 contains the coordinates of a position such as (x, y), and the point object (class GM_Point) uses this DirectPosition. The point–value pair of ISO 19123 (class CV_PointValuePair) uses the point object of ISO 19107 for position information.

A common pattern of points is a quadrilateral grid. Examples of this would be a digital image and a simple type of digital elevation matrix. For reasons of storage and computational efficiency, the quadrilateral pattern of points has some special terminology and structure. The grid addressed as a whole is called a *grid values matrix* (class CV_GridValuesMatrix). The intersections of the grid lines are called *grid points* (class CV_GridPoint). According to ISO 19107, the position of each grid point is always a *point object*.

ISO 19107 states that a grid can also be defined as a quadrilateral pattern of simple point positions or point objects (class GM_PointObject), as in ISO 19123. The grid is called a *point grid* (class GM_PointGrid) and consists of a number of parallel-placed point arrays (class GM_PointArray).

A knot is a special type of point that is only used for the description of some types of splines; for example, a Bézier spline is defined by four or more points where the curve passes through the first and last point and is

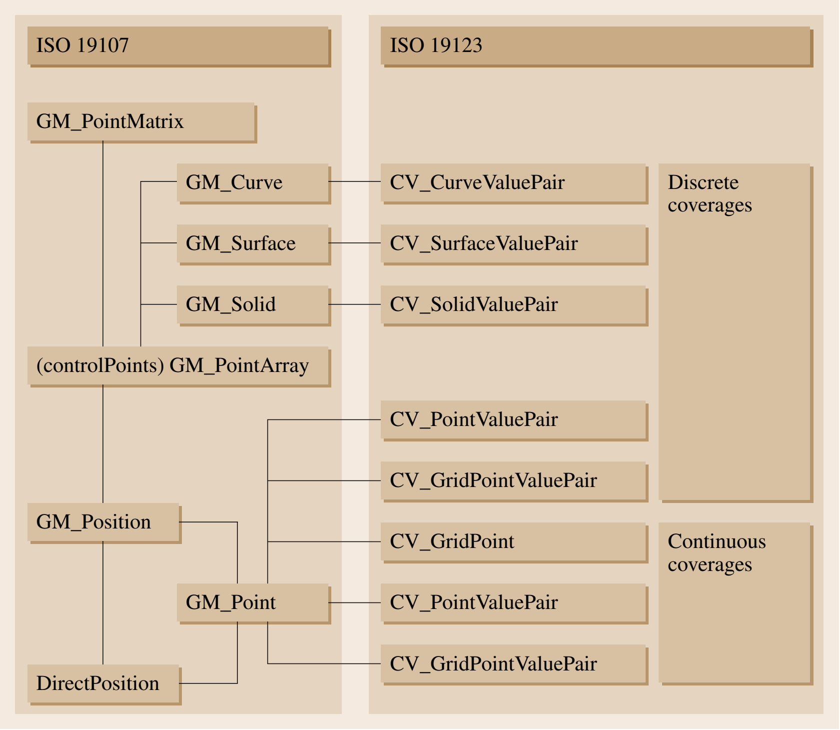


Fig. 13.59 Relations of position descriptions

only controlled in shape by the points in between. Those points are the knots of the Bézier spline.

Each dimension requires its own sequence of knots. Thus, a spline curve has one sequence, and a spline surface has two sequences.

13.5.3 Spatial Schema (ISO 19107)

ISO 19107 covers a fairly complete world of vector data and has the characteristics

- three-dimensional space, in theory *n*-dimensional,
- primitives and complexes,
- topological relations,
- based on set theory.

Set theory is the mathematical science of the infinite. It is the study of the properties of sets, abstract objects that pervade the whole of modern mathematics. The language of set theory, in its simplicity, is sufficiently universal to formalize all mathematical concepts, and thus set theory, along with a few other theories, constitutes the true foundations of mathematics [13.114] (Sect. 3.2).

ISO 19107 applies the axioms of set theory throughout the standard. An example is a geometric object that is defined as a set of geometric points.

ISO 19107 has two important design criteria: the boundary criterion and the complexes. The boundary criterion means that high-level elements are composed of a collection of low-level elements; for example, a surface consists of its boundary curves, and the curves are bounded by their start and end points. The complexes, both geometrical and topological, consist of geometries, which do not overlap.

Overview of ISO 19107

The following diagram (Fig. 13.60) shows the logical tree of the important geometry classes of ISO 19107.

General Description of the Geometry Classes of ISO 19107

A geometry object (class GM_Object) is the most general concept for all objects that a geometrical dataset may consist of. At the top level, a geometry object may be a primitive (class GM_Primitive), a complex (class GM_Complex), or an aggregate (class GM_Aggregate). In each of the three cases, the vector geometry of a geographic dataset can be completely described based on the fundamental geometries of point, curve, surface, and solid (classes GM_Point, GM_Curve, GM_Surface, and GM_Solid).

What is the difference between primitives, complexes, and aggregates? Primitives are the graphic elements that form the complete graphic of a geographic dataset. Primitives exist on their own and have no geometric relations to their neighborhood apart from the common frame of a CRS. A typical map built on primitives and perhaps showing houses, roads, and rivers is primarily designed for visual information.

Complexes (class GM_Complex) allow the introduction of certain constraints among the graphic elements and are widely used in cadastral applications. In this prominent example, the parcels of a region have to cover the area without allowing any overlaps between neighboring parcels and without leaving any gaps between them. The components of a complex can be both a composite curve (class GM_CompositeCurve) and a composite surface (class GM_CompositeSurface). An example of a composite curve could be the boundary around a parcel. The term "composite" refers to the fact that a parcel usually has more than one neighbor, and thus the parcel boundary is composed of a number of single curves.

Aggregates (class GM_Aggregate) allow the grouping of geometric elements without any constraints. A typical example is a set of elevation points. Without aggregates being available, the points could only be described as a number of individual points; the aggregate allows them to be addressed as a single dataset like a named list of points. Aggregations are named *multi primitives* such as multi points, multi curve, multi surface, and multi solid (classes GM_MultiPoint, GM_MultiCurve, GM_MultiSurface, and GM_MultiSolid).

Curves and Surfaces are orientable primitives (class GM_OrientablePrimitive), while points and solids are not. A curve is an orientable primitive because it has a defining point sequence that may have a forward or a backward order. This property is important if two or more curves form a closed polygon or a composite curve. A consecutive order of the points is required to correctly define the area as well as to draw a correct line pattern without interruptions along the curve where the individual curves meet.

A surface is an orientable primitive because either side may be the upside or downside (class GM_OrientableSurface).

A curve (class GM_Curve) consists of one or more curve segments (class GM_CurveSegment). A curve segment may have one of the following geometries: arc string, arc string by bulge, spline curve, clothoid, geodesic string, conic, and offset curve (Fig. 13.60).

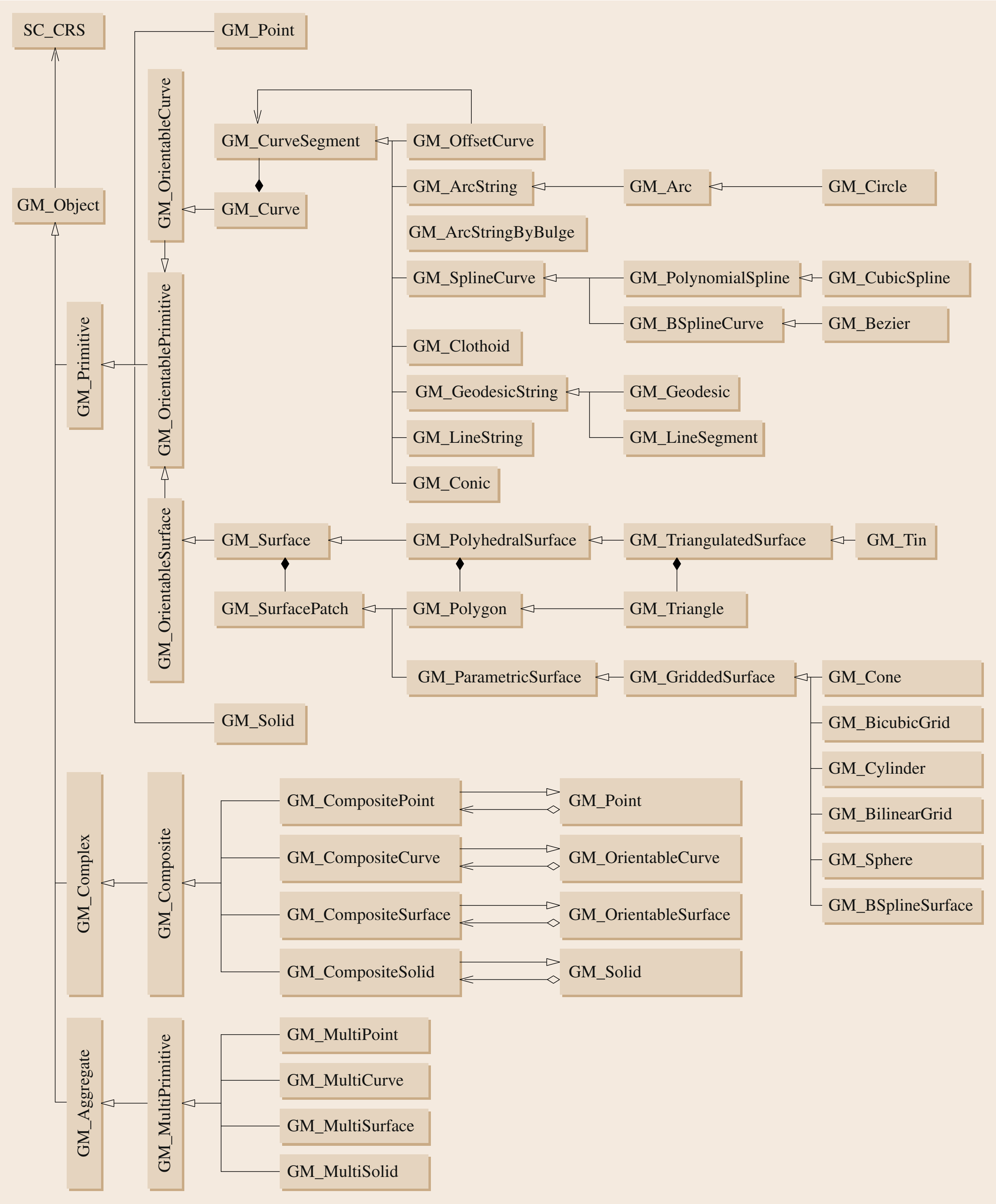

SC_CRS
GM_Point
GM_OrientableCurve
GM_CurveSegment
GM_OffsetCurve
GM_Object
GM_Curve
GM_ArcString
GM_Arc
GM_Circle
GM_ArcStringByBulge
GM_SplineCurve
GM_PolynomialSpline
GM_CubicSpline
GM_BSplineCurve
GM_Bezier
GM_Primitive
GM_OrientablePrimitive
GM_Clothoid
GM_GeodesicString
GM_Geodesic
GM_LineString
GM_LineSegment
GM_Conic
GM_OrientableSurface
GM_Surface
GM_PolyhedralSurface
GM_TriangulatedSurface
GM_Tin
GM_SurfacePatch
GM_Polygon
GM_Triangle
GM_ParametricSurface
GM_GriddedSurface
GM_Cone
GM_Solid
GM_BicubicGrid
GM_Cylinder
GM_BilinearGrid
GM_Sphere
GM_BSplineSurface
GM_Complex
GM_Composite
GM_CompositePoint
GM_Point
GM_CompositeCurve
GM_OrientableCurve
GM_CompositeSurface
GM_OrientableSurface
GM_CompositeSolid
GM_Solid
GM_Aggregate
GM_MultiPrimitive
GM_MultiPoint
GM_MultiCurve
GM_MultiSurface
GM_MultiSolid

Fig. 13.60 UML class diagram of GM_Object (after [13.55]) ◀

The surface (class GM_Surface) is either defined by a mosaic of surface patches with a great number of different shapes or by a simpler pattern of joint polygons. Surface patches might be parcels, areas of homogeneous land use, or local functional descriptions of the shape of a terrain. The perspective on surface patches focuses on every individual patch of the surface, while the perspective on the pattern of joint polygons instead focuses on the surface as a whole. The most prominent example is a triangulated irregular network (TIN) which results after processing a given set of elevation points. If one point of the dataset is changed, then the whole TIN will change according to modifications of the triangles associated to the changed point.

The description of a complete surface with only one function such as $z = 100\,\mathrm{m}$ is a rare case in geographic applications.

Under the restriction that every surface patch must be neatly linked to its neighbors in order to form a continuous surface without gaps, each patch (class GM_SurfacePatch) in a mosaic may have an individual functional description.

A simple case of a surface patch is a closed planar polygon (class GM_Polygon). A typical example is a parcel or a two-dimensional feature in a land use dataset.

In ISO 19107, polygons are always planar. This means that all curves belonging to the polygon are part of the same plane. Geometrically, this is always true for triangles only. Quadrangles and other polygons of higher order may have a 3-D shape. Those polygon are not valid polygons according to ISO 19107. If all surface patches are triangles, being a special case of polygons, the result might look the same as a TIN. However, a pattern of triangles is a TIN only if the Delaunay criterion is valid, as explained below.

The most sophisticated type of surface patch is a parametric curve surface (class GM_ParametricCurveSurface). A simple example is a semisphere. For practical reasons the defining points of a parametric curve surface often lie in a square pattern and thus form a quadrilateral grid. The resulting surface is called a gridded surface (class GM_GriddedSurface). ISO 19107 standardizes six types of gridded surface: cone, cylinder, sphere, bilinear grid, bicubic grid, and B-spline surface (classes GM_Cone, GM_Cylinder, GM_Sphere, GM_BilinearGrid, GM_BicubicGrid, and GM_BSplineSurface, respectively). A bilinear grid uses line strings as horizontal and vertical curves, while a bicubic grid uses cubic polynomial splines as horizontal and vertical curves.

A surface with only polygon surface patches is called a polyhedral surface (class GM_PolyhedralSurface). If the polygons are triangles, it is called a triangulated surface (GM_TriangulatedSurface), with no restriction on how the triangulation is derived.

A TIN (class GM_Tin) is a triangulated surface that uses the Delaunay or a similar algorithm complemented with consideration for breaklines, stoplines, and maximum length of triangle sides. These networks satisfy the Delaunay criterion away from the modifications. For each triangle in the network, the circle passing through its vertexes does not contain the vertex of any other triangle in its interior.

The TIN is also covered by ISO 19123 *Schema for coverage geometry and functions*. ISO 19107 standardizes the description of an existing TIN. ISO 19123 addresses the computation of a TIN and the interpolation of elevations.

Detailed Description of the Geometry Classes of ISO 19107

Until the end of this section an exhaustive list of the geometric elements of ISO 19107 is given.

Dimensions and Map Projection. ISO 19107 standardizes geometries in three-dimensional space as a basis for all ISO 19100 standards. The theory of ISO 19107 also allows its use in an n-dimensional space. However, the application of ISO 19107 leads to some inconsistencies.

Dimensions. The base geometries are points, curves, surfaces, and solids. Not all geometries are well defined in a three-dimensional space.

Arcs and circles have their shape on one plane only. Any projection to a coordinate plane changes them to an elliptic arc or an ellipse, other than the exceptional case when the plane of the geometry is parallel to a coordinate plane.

Cones keep their properties as cones but change their shape.

The mathematics of splines and clothoids are defined in two dimensions only. In the case where they are used in three dimensions, the formulas are usually expressed in parameterized form. This simply means that an additional dimension t is introduced. The origin of t is at the beginning of the curve, and the value of t is the length of the curve from the beginning. Us-

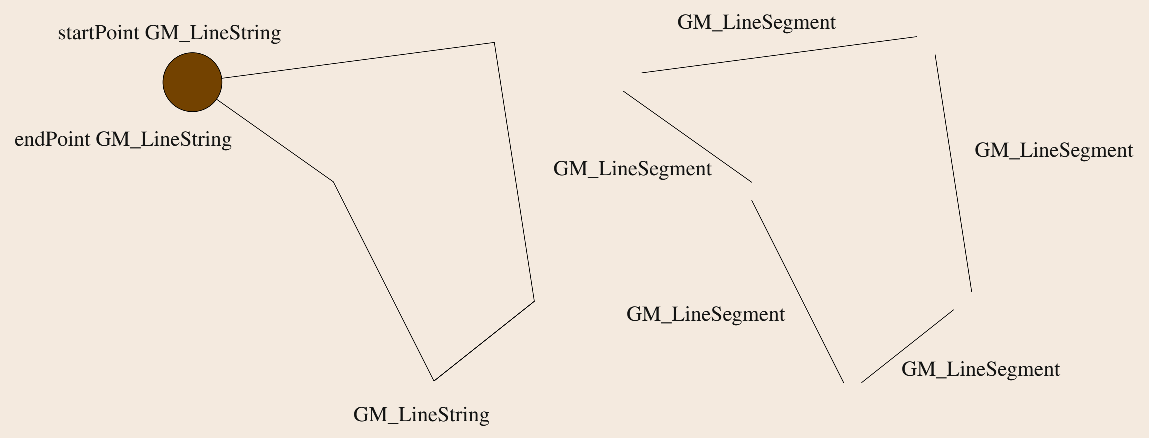


Fig. 13.61 GM_LineString

ing t, splines and clothoids can be expressed on the three separate planes x–t, y–t, and z–t [13.115].

An offset curve requires the additional information of which spatial direction the offset should be counted towards. This information is beyond ISO 19107.

There are only a few geometries (such as lines and geodesics) that can be applied to n-dimensional space without mathematics that are beyond the scope of ISO 19107.

Map Projections. The geometries of ISO 19107 are built on Euclidean space. ISO 19111 standardizes the coordinate transformations and conversions, including map projections. They usually change coordinates from Euclidean space to some other space, such as a sphere. With the exception of points, the map projection changes the shape of all geometries, because the modified geometries do not have the characteristics of the original geometries; for example, a line becomes an arc after projection from a plane to a sphere.

Curves.

GM_LineString. A line string (class GM_LineString) consists of a sequence of line segments.

GM_LineSegment. A line segment (class GM_LineSegment) is a line between two given positions. This line will either be straight or some other shape depending on the map projection.

GM_GeodesicString. A geodesic string (class GM_GeodesicString) consists of a sequence of positions interpolated using a geodesic (class GM_Geodesic) defined from the geoid or ellipsoid of the coordinate reference system being used.

GM_Geodesic. A geodesic is the shortest line between two points on an arbitrary surface. In the trivial case of a plane, the geodesic is the straight line between two points. In navigation, the geodesic on an ellipsoid is called the orthodrome.

GM_ArcString. An arc string (class GM_ArcString) consists of a sequence of arcs. Since it requires three points to determine a circular arc, the controlPoints are treated as a sequence of overlapping sets of three positions, the start of each arc, some point between the start and end, and the end of each arc. Since the end of each arc is the start of the next, this position is not repeated in the controlPoint sequence.

GM_Arc. An arc (class GM_Arc) that consists of an arc of the circle is determined by three points and is therefore

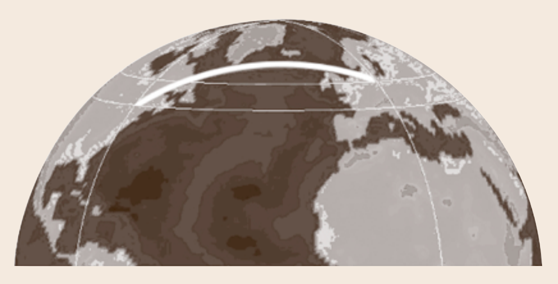


Fig. 13.62 GM_Geodesic: orthodrome between Ottawa and Neubrandenburg (after [13.116])

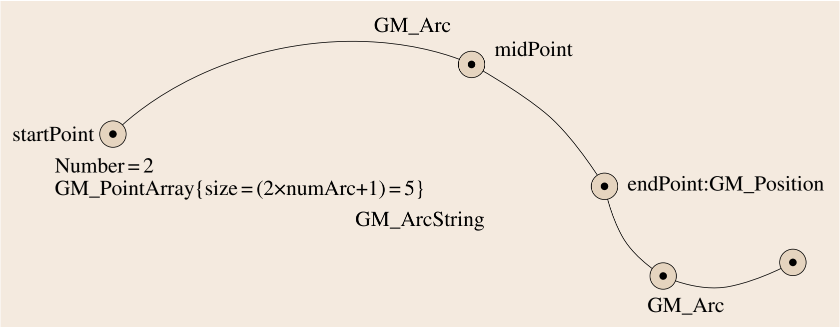


Fig. 13.63 GM_ArcString: two arc strings with a total of five control points

defined by the starting point, a point somewhere between the beginning and the end, and the point of termination. If the three points are collinear, then the arc shall be a three-point line string, and will not be able to return values for center, radius, start angle, and end angle.

GM_Circle. A circle (class GM_Circle) is defined by three points that close to form a full circle.

GM_ArcStringByBulge. An arc string by bulge (class GM_ArcStringByBulge) consists of a sequence of arcs where each arc is controlled by its startPoint, its endPoint, and a value determining its bulge. The bulge controls the offset of each arc's midpoint. The controlPoint sequence consists of the start and the end points of each arc. The bulge sequence consists of the bulge values, which is exactly one less than the length of the controlPoint array.

GM_Conic. A conic (class GM_Conic) may be an ellipse, a parabola, or a hyperbola, depending on the eccentricity parameter. The given formula in Fig. 13.65 represents a conic in polar coordinates. The diagram shows four cases of different eccentricity.

GM_Placement and GM_AffinePlacement. Placements are meant to take a standard geometric construction such as a circle, and place it as a symbol in a geographic dataset. In most cases, a placement involves a shift of dimension from 2-D to 3-D space.

The placement (class GM_Placement) allows any type of geometric transformation to be applied during the output to the target system. With the transformation involved, a circle may be changed to any type of conic.

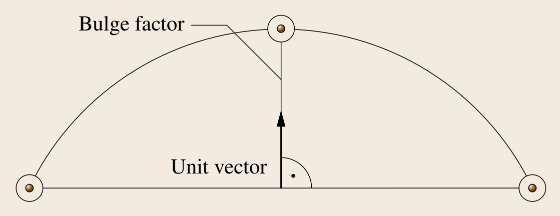


Fig. 13.64 GM_ArcStringByBulge

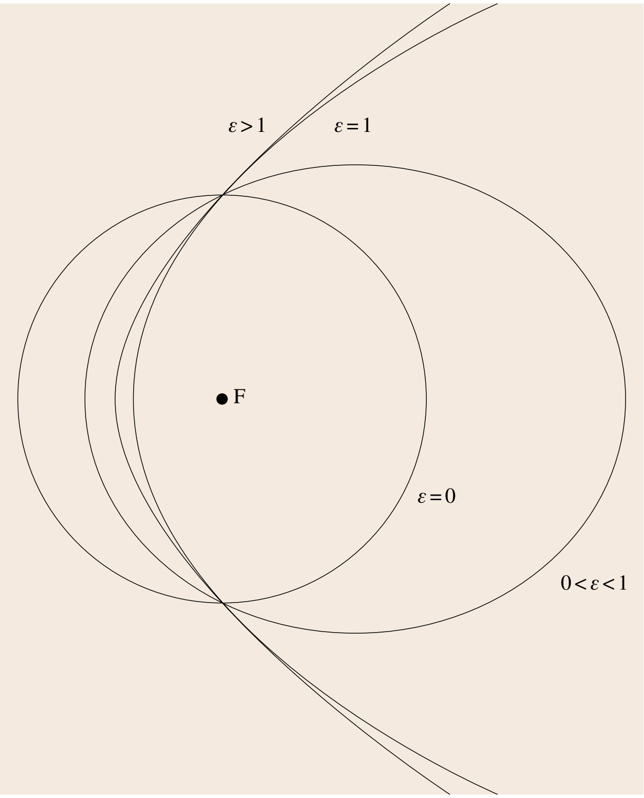


Fig. 13.65 GM_Conic (after [13.116]). Polar coordinates: (ρ, φ) with $\rho = P/(1 + \varepsilon \cdot \cos\varphi)$. $P = 1$. Eccentricity: $\varepsilon = 0$ (*circle*), $0 < \varepsilon < 1$ (*ellipse*), $\varepsilon = 1$ (*parabola*), $\varepsilon > 1$ (*hyperbola*)

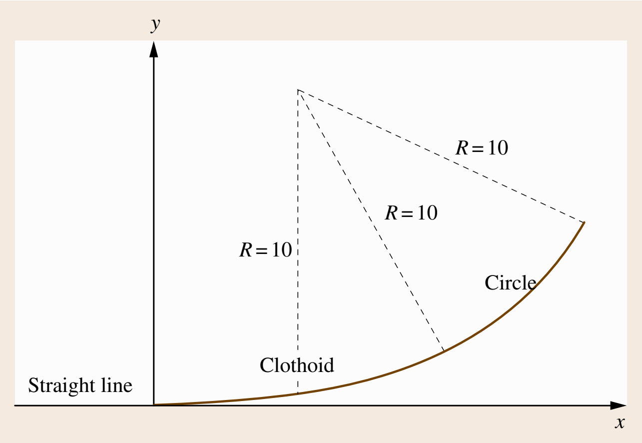


Fig. 13.66 GM_Clothoid (after [13.117])

The affine placement (class GM_AffinePlacement) allows a linear transformation only (six parameters).

GM_Clothoid. A clothoid (class GM_Clothoid) is a plane curve whose curvature is a fixed function of its length. The following equation is valid at any position along the clothoid:

$$\text{length} \times \text{radius} = \text{constant} .$$

The clothoid is used to lay out roads and railroad lines.

GM_OffsetCurve. An offset curve (class GM_OffsetCurve) is a curve at a constant distance from the basis curve. They can be useful as a cheap and simple alternative to constructing curves that are offset by definition.

GM_SplineCurve. Spline curves (class GM_SplineCurve) may be polynomial splines or B-splines.

GM_PolynomialSpline. An n-degree polynomial spline is defined piecewise as an n-degree polynomial, with up to C^{n-1} continuity at the control points where the defining polynomial changes. C^{n-1} continuity means that the original curves as well as the 1st, 2nd, ..., and $(n-1)$-th derivatives match at the control points. Parameters shall include directions for as many as $(\text{degree} - 2)$ deriva-

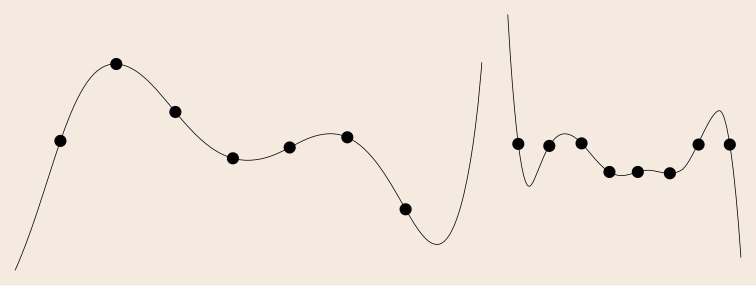


Fig. 13.67 GM_PolynomialSpline

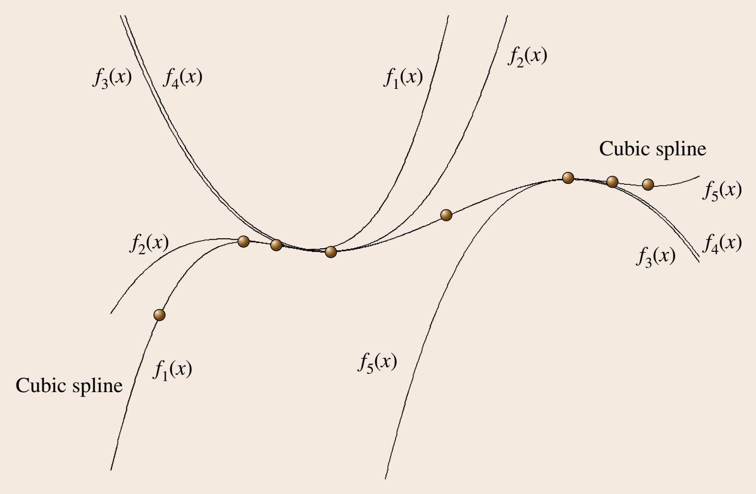


Fig. 13.68 GM_CubicSpline. Function 1: $f_1(x) = a_{01} + a_{11} \cdot x + a_{21} \cdot x^2 + a_{31} \cdot x^3$; Function 2: $f_2(x) = a_{02} + a_{12} \cdot x + a_{22} \cdot x^2 + a_{32} \cdot x^3$; ...; Function 5: $f_5(x) = a_{05} + a_{15} \cdot x + a_{25} \cdot x^2 + a_{35} \cdot x^3$. The first and the last segment are a part of the functions f_1 and f_5, respectively (after [13.116])

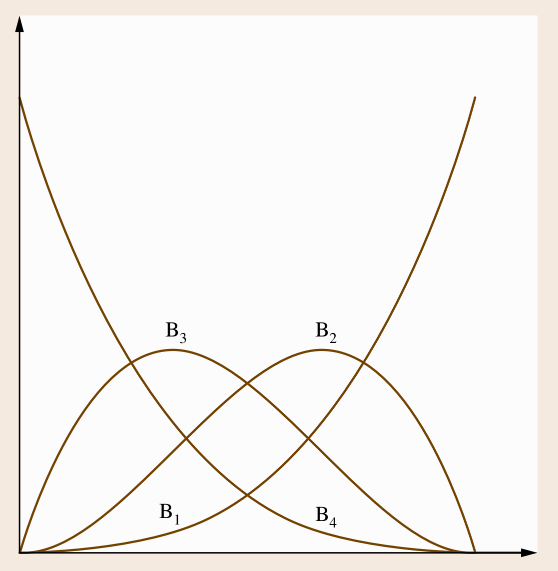


Fig. 13.69 Bernstein polynomials (after [13.116])

tives of the polynomial at the start and end point of the piece.

The left example of Fig. 13.67 has the same points as the front profile in Figs. 13.75–13.77, sixth grade. The right example demonstrates strong oscillations that are typical for polynomials, seventh grade [13.118].

GM_CubicSpline. A cubic spline (class GM_CubicSpline) consists of a sequence of segments, each with its own defining function. A cubic spline uses the control points and a set of derivative parameters to define a piecewise third-degree polynomial interpolation.

The function describing the curve must have continuous first and second derivatives at all points and pass through the controlPoints in the order given. Between each pair of control points, a curve segment is defined by a cubic polynomial. At each control point, the polynomial changes in such a manner that the first and second derivative vectors are the same for both sides.

Special provision must be made for the first and last point of the spline, because the tangent at these points remains undefined. The control parameters record must contain a vectorAtStart and a vectorAtEnd as the unit tangent vectors at controlPoint[1] and controlPoint[n], where $n =$ controlPoint.count.

GM_BSpline. A B-spline (class GM_BSpline) consists of a sequence of segments, each with its own defining function, similar to the cubic spline. The shape of each segment is controlled by a weighted influence of the four control points next to the segment. The influence is described through four polynomials, one for each control point. The definition range of the polynomials is zero to one, referring to the length of the segment. The polynomials are called basis or blending functions. A typical set of basis functions is the Bernstein polynomials shown in Fig. 13.69.

The control points of a B-spline are called knots. If the knots are spaced in equal intervals, the B-spline is uniform; if not, it is considered nonuniform.

If a B-spline is a polynomial, then it is nonrational. However, if the B-spline is a ratio of polynomials it is then considered rational.

GM_Bezier. A Bézier-spline (class GM_Bezier) is a B-spline using Bernstein polynomials to weight the influence of the control points (knots).

Surfaces.

GM_Polygon. A polygon (class GM_Polygon) is a surface patch that is defined by a set of boundary curves and an underlying surface to which these curves adhere. The default is that the curves are coplanar and that the polygon uses planar interpolation in its interior.

GM_Triangle. A triangle (class GM_Triangle) is a planar polygon defined by three corners.

GM_ParametricCurveSurface. The surface patches that make up the parametric curve surfaces are all continuous families of curves. A parametric curve surface can be expressed by a mathematical function.

GM_GriddedSurface. A gridded surface (class GM_GriddedSurface) is a GM_ParametricCurveSurface

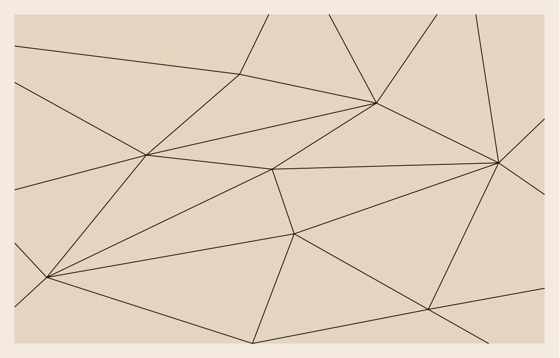


Fig. 13.70 GM_Triangle

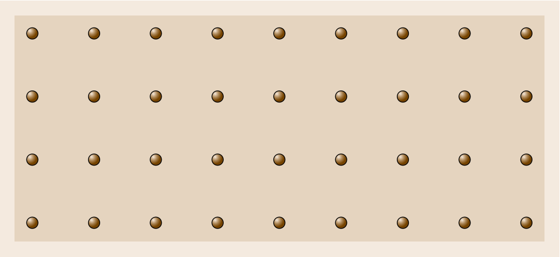


Fig. 13.71 GM_GriddedSurface

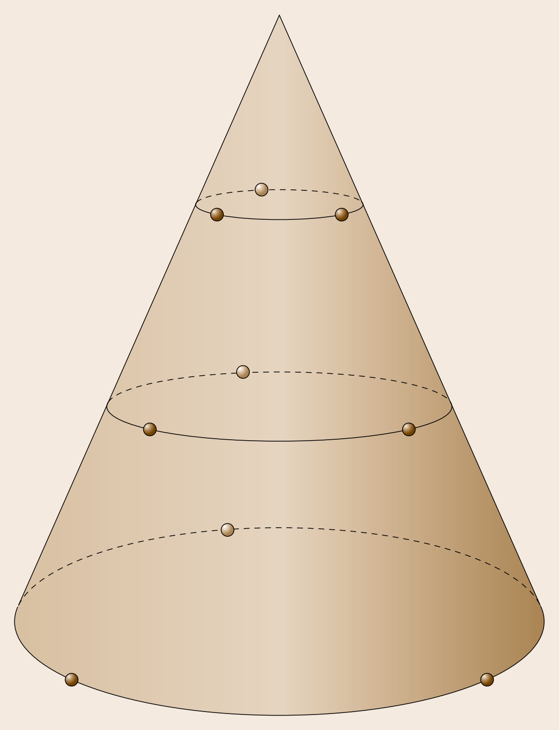


Fig. 13.72 GM_Cone

defined from a rectangular grid in the parameter space. The rows from this grid are control points for horizontal surface curves; the columns are control points for vertical surface curves.

GM_Cone. A cone (class GM_Cone) is a gridded surface given as a family of conic sections whose controlPoints vary linearly. This means that the control points defining the cone in Fig. 13.72 lie on three straight lines.

GM_Cylinder. A cylinder (class GM_Cylinder) is a gridded surface given as a family of circles whose positions vary along a set of parallel lines, keeping the cross-sectional horizontal curves with constant shape.

GM_Sphere. A sphere (class GM_Sphere) is a gridded surface given as a family of circles whose positions vary linearly along the axis of the sphere, and whose radius varies in proportion to the cosine function of the central angle. The horizontal circles resemble lines of constant latitude, and the vertical arcs resemble lines of constant longitude.

GM_BilinearGrid. A bilinear grid (class GM_BilinearGrid) is a gridded surface that uses line strings as the horizontal and vertical curves.

GM_BicubicGrid. A bicubic grid (class GM_BicubicGrid) is a gridded surface that uses cubic polynomial splines as the horizontal and vertical curves.

GM_BSplineSurface. A B-spline surface (class GM_BSplineSurface) is a rational or polynomial parametric surface that is represented by control points, basis func-

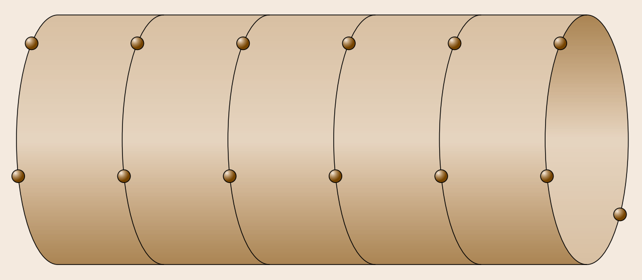


Fig. 13.73 GM_Cylinder

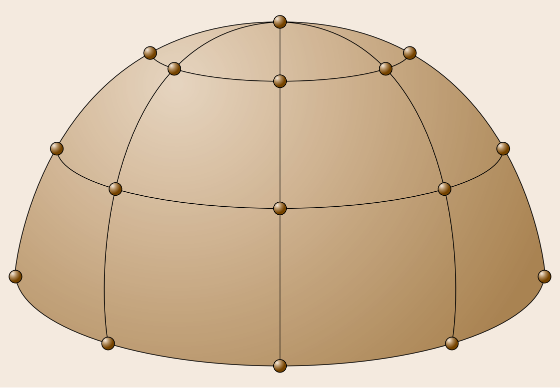


Fig. 13.74 GM_Sphere

tions, and possibly weights. If the weights are all equal, then the spline is piecewise polynomial. If they are not equal, then the spline is piecewise rational.

GM_PolyhedralSurface. A polyhedral surface (class GM_PolyhedralSurface) is a surface composed of polygon surfaces (class GM_Polygon) connected along their common boundary curves. This differs from the generic surface (class GM_Surface) only in the restriction on the types of surface patches acceptable.

GM_TriangulatedSurface. A triangulated surface (class GM_TriangulatedSurface) is a polyhedral surface that is composed only of triangles (class GM_Triangle). There is no restriction on how the triangulation is derived.

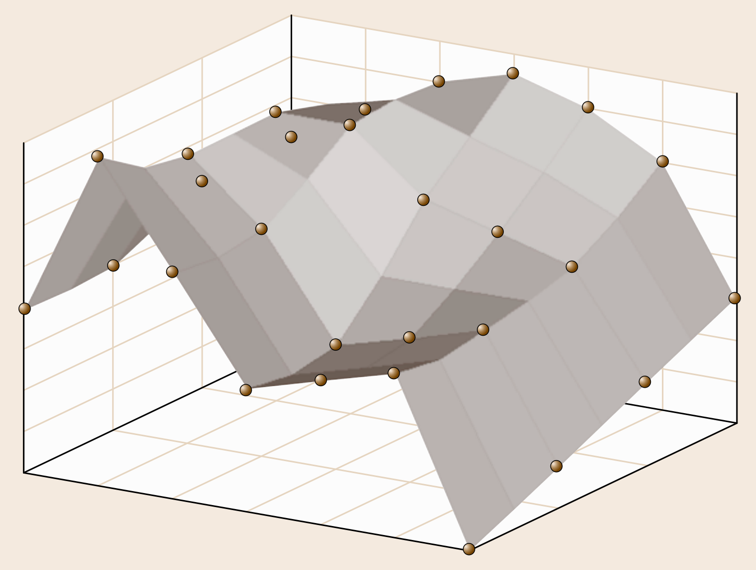


Fig. 13.75 Bilinear grid (after [13.119])

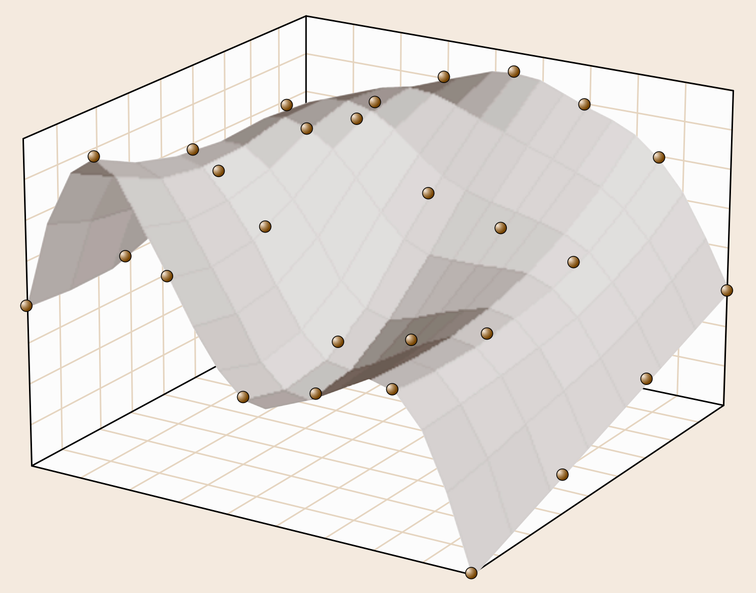


Fig. 13.76 Bicubic grid (after [13.119])

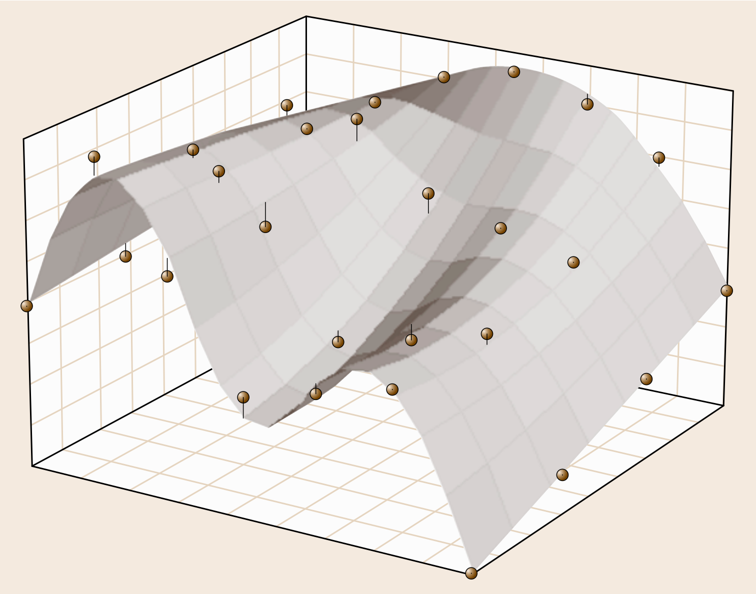


Fig. 13.77 B-spline surface (after [13.119])

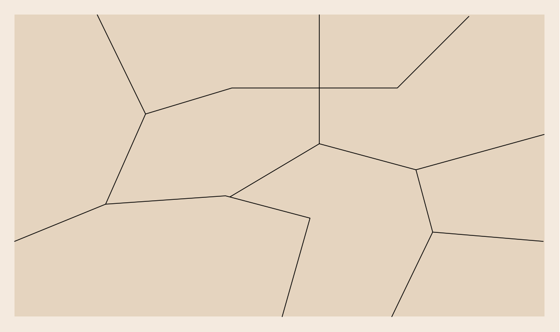


Fig. 13.78 GM_PolyhedralSurface

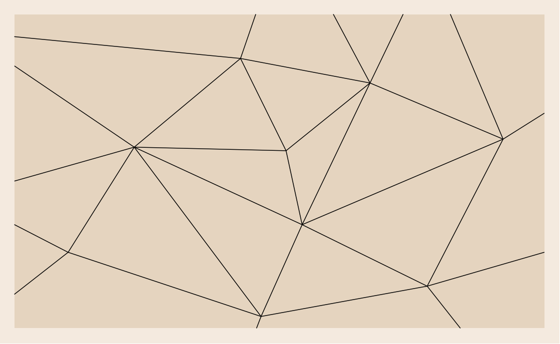


Fig. 13.79 GM_Tin

GM_Tin. A TIN (class GM_Tin) is a triangulated surface that uses the Delaunay or a similar algorithm complemented with consideration for breaklines, stoplines, and maximum length of triangle sides. The Delaunay criterion means that the circumsphere of any of the triangles must not include other points of the point set. The Delaunay triangulation method is commonly used to produce TIN tesselations with triangles that are optimally equiangular in shape. The length of their edges is a minimum. Thiessen polygons, also called Voronoi polygons or Dirichlet tesselation, are most commonly used to optimize the search for the Delaunay criterion.

Operations.

mbRegion. The operation *mbRegion* returns a region in the coordinate reference system that contains this GM_Object. The most common use of mbRegion will be to support indexing methods that use extents other than minimum bounding rectangles (MBR or envelopes).

representativePoint. The operation *representativePoint* returns a point value (DirectPosition) that is guaranteed to be on this GM_Object.

boundary. Applied to an object, the operation *boundary* returns the object's boundary, which is of one dimension lower than the dimension of the object itself. In the case of a surface, the boundary operator returns the curves around the surface. The object may have a further internal structure.

closure. The operation *closure* combines an object with its boundary. Applied to a GM_LineString, the operation *closure* returns the GM_LineString and its start and end point.

isSimple. The operation *isSimple* shall return TRUE if this GM_Object has no interior point of self-intersection or self-tangency.

isCycle. The operation *isCycle* shall return TRUE if this GM_Object has an empty boundary after topological simplification. A closed curve or a sphere has empty boundaries. This condition is alternatively referred to as being *closed*, as in a *closed curve*. This creates some confusion, since there are two distinct and incompatible definitions for the word "closed." The use of the word "cycle" is rarer but leads to less confusion. Essentially, an object is a cycle if it is isomorphic to a geometric object that is the boundary of a region in some Euclidean space. Thus, a curve is a cycle if it is isomorphic to a circle (has the same start and end point). A surface is a cycle if it is isomorphic to the surface of a sphere, or some torus.

distance. The operation *distance* shall return the distance between this GM_Object and another GM_Object. This distance is defined to be the greatest lower bound of the set of distances between all pairs of points that include one each from each of the two GM_Objects.

transform. The operation *transform* shall return a new GM_Object that is the coordinate transformation of this GM_Object into the passed coordinate reference system within the accuracy of the transformation.

envelope. The operation *envelope* returns the minimum bounding box for this GM_Object. The minimum bounding rectangle is the two-dimensional case. This is the coordinate region spanning the minimum and maximum value for each ordinate taken on by DirectPositions in this GM_Object. The simplest representation for an envelope consists of two DirectPositions, the first one containing all the minimums for each ordinate and the second one containing all the maximums.

centroid. The operation *centroid* shall return the mathematical centroid for this GM_Object. The result is not guaranteed to be on the object. For heterogeneous collections of primitives, the centroid only takes into account those of largest dimension; for example, when

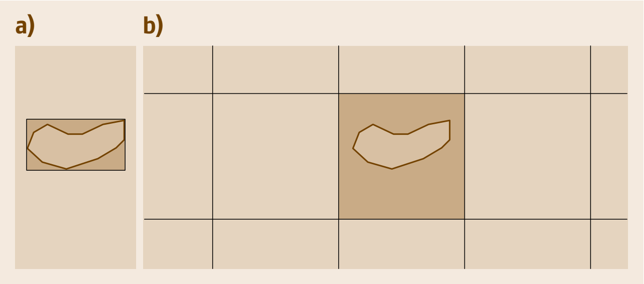


Fig. 13.80a,b Operation mbRegion; **(a)** minimum bounding rectangle, **(b)** region

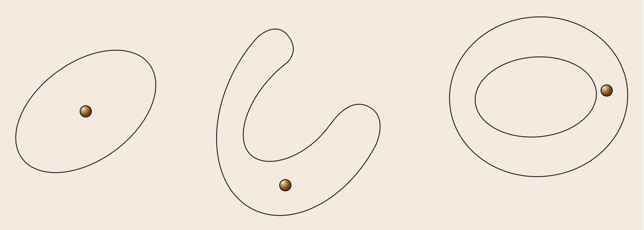


Fig. 13.81 Operation representativePoint

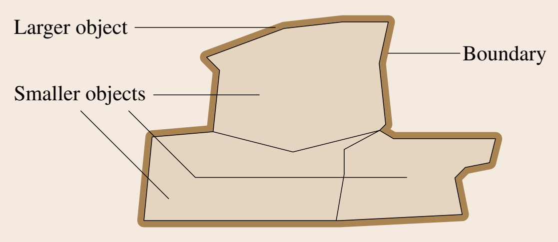


Fig. 13.82 Operation boundary

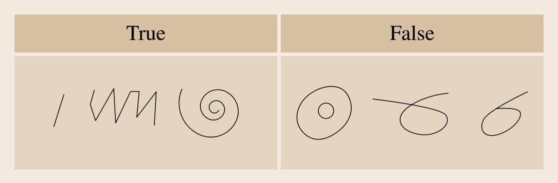


Fig. 13.83 Operation isSimple

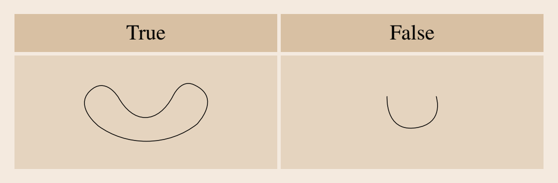


Fig. 13.84 Operation isCycle

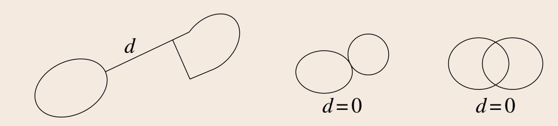


Fig. 13.85 Operation distance

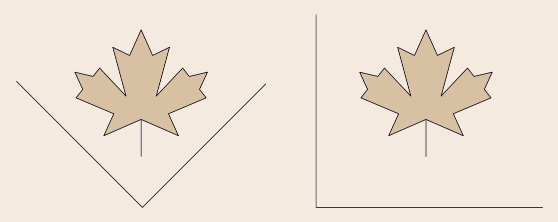


Fig. 13.86 Operation transform

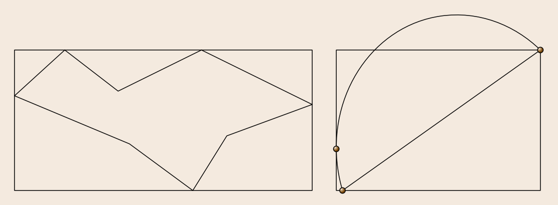


Fig. 13.87 Operation envelope

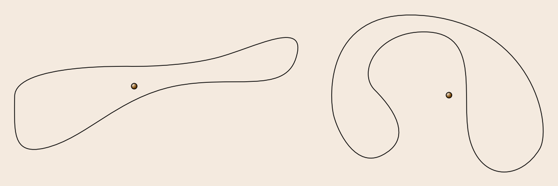


Fig. 13.88 Operation centroid

calculating the centroid of surfaces, an average is taken weighted by area. Since curves have no area, they do not contribute to the average.

convexHull. The operation *convexHull* shall return a GM_Object that represents the convex hull of this GM_Object.

buffer. The operation *buffer* shall return a GM_Object containing all points whose distance from this GM_Object is less than or equal to the *distance* passed as a parameter.

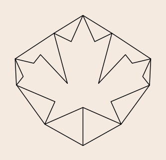


Fig. 13.89 Operation convexHull

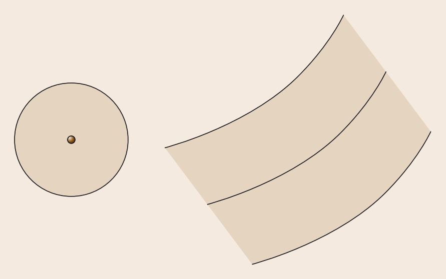


Fig. 13.90 Operation buffer

contains. The Boolean-valued operation *contains* returns TRUE if this GM_Object contains another GM_Object, or a single point given by a coordinate (DirectPosition).

intersects. The Boolean-valued operation *intersects* returns TRUE if this GM_Object intersects another GM_Object.

equals. The Boolean-valued operation *equals* returns TRUE if this GM_Object is equal to another GM_Object.

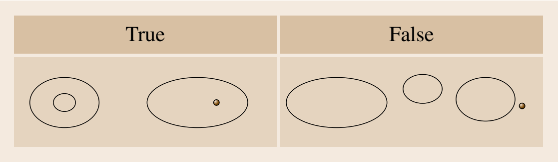


Fig. 13.91 Operation contains

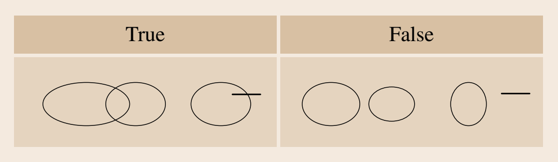


Fig. 13.92 Operation intersects

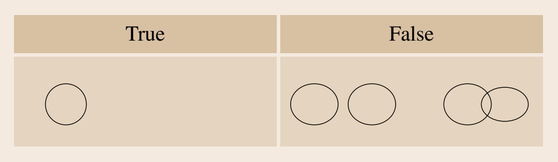


Fig. 13.93 Operation equals. Both objects on the *left* are congruent

intersection. The *intersection* operation returns the set-theoretic intersection of this GM_Object and the passed GM_Object.

union. The *union* operation shall return the set-theoretic union of this GM_Object and the passed GM_Object.

difference. The *difference* operation returns the set-theoretic difference of this GM_Object and the passed GM_Object.

symmetricDifference. The *symmetricDifference* operation returns the set-theoretic symmetricDifference of this GM_Object and the passed GM_Object.

bearing. The operation *bearing* returns the bearing, as a unit vector, of the tangent (at this GM_Point) to the curve between this GM_Point and a passed GM_Position.

area. The operation *area* shall return the sum of the surface areas of all of the boundary components of a solid.

volume. The operation *volume* shall return the volume of this solid (class GM_Solid). Holes in the volume do not count towards the volume.

startPoint, endPoint. The operations *startPoint* and *endPoint* return the direct positions of the first point and the last point, respectively, on a generic curve. This differs from the boundary operator in primitives (class GM_Primitive), since it returns only the values of these two points, not representative objects.

tangent. The operation *tangent* shall return the tangent vector along this generic curve (class GM_GenericCurve) at the passed parameter value. This vector approximates the derivative of the parameterization of the curve. The tangent shall be a unit vector (have length 1.0).

length. The operation *length* returns the distance between the two points along the curve.

samplePoint. The operation *samplePoint* returns an ordered array of points (class GM_PointArray) that lie on the curve segment. In most cases, these will be related to control points used in the construction of the segment.

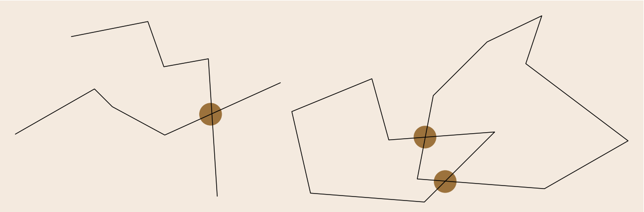


Fig. 13.94 Intersection

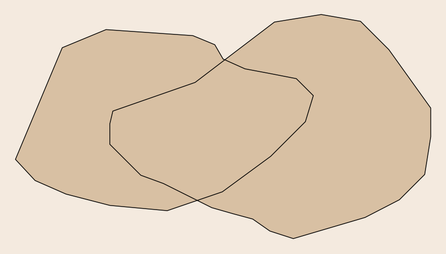


Fig. 13.95 Union

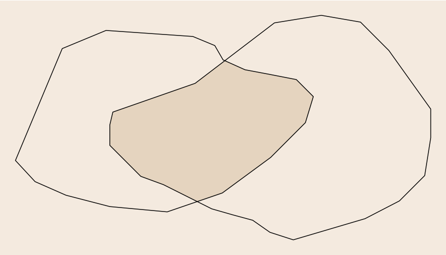


Fig. 13.96 Difference

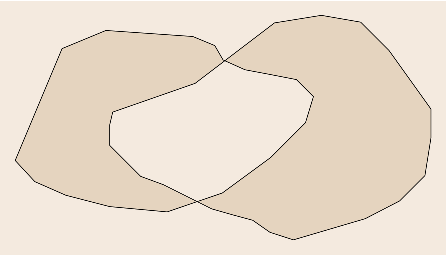


Fig. 13.97 Symmetric difference

asGM_LineSegment. The operation *asGM_LineSegment* decomposes a line string into an equivalent sequence of line segments.

Fig. 13.98 Operations startPoint, endPoint

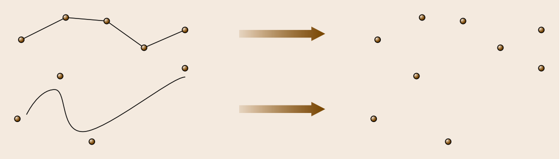


Fig. 13.99 Operation samplePoint

Fig. 13.100 Operation asGM_LineSegment

Fig. 13.101 Operation asGM_Geodesic

asGM_Geodesic. The operation *asGM_Geodesic* decomposes a geodesic string into an equivalent sequence of geodesic segments.

center. The operation *center* calculates the center of the circle of which this arc has a direct position. The coordinate reference system of the returned DirectPosition will be the same as that for the arc.

radius. The operation *radius* calculates the radius of the circle of which this arc is a portion.

startOfArc. The operation *startOfArc* calculates the bearing of the line from the center of the circle of which this arc is a portion to the start point of the arc. In the two-dimensional case, this will be a start angle. In the three-dimensional case, the normal bearing angle implies that the arc is parallel to the reference circle. If this is not the case, then the bearing must include altitude information.

endOfArc. The operation *endOfArc* calculates the bearing of the line from the center of the circle of which this arc is a portion to the end point of the arc. In the two-dimensional case, this will be an end angle. In the three-dimensional case, the normal bearing angle implies that the arc is parallel to the reference circle. If this is not the case, then the bearing must include altitude information.

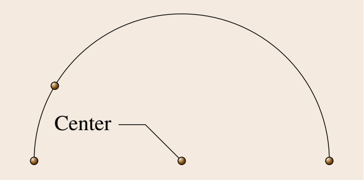


Fig. 13.102 Operation center

upNormal. The operation *upNormal* returns a vector perpendicular to the generic surface (class GM_GenericSurface) at the DirectPosition passed, which must be on the generic surface.

perimeter. The operation *perimeter* shall return the sum of the lengths of all the boundary components of this generic surface. Since perimeter, like length, is an accumulation of distance, its return value shall be in a reference system appropriate for measuring distances.

area. The area of a two-dimensional geometric object is a numeric measure of its surface area (in a square unit of distance). The operation *area* returns the area of the requested generic surface.

horizontalCurve. The operation *horizontalCurve* constructs a curve that traverses the surface horizontally.

verticalCurve. The operation *verticalCurve* constructs a curve that traverses the surface vertically.

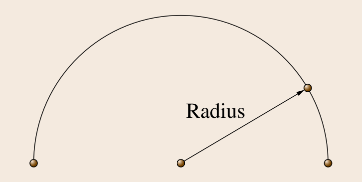


Fig. 13.103 Operation radius

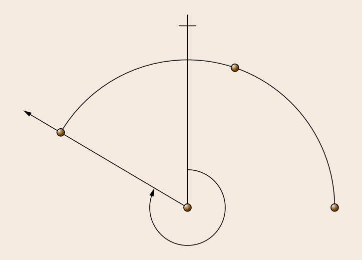


Fig. 13.104 Operation startOfArc

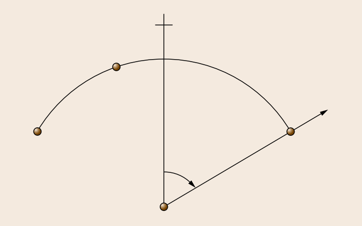


Fig. 13.105 Operation endOfArc

surface. The operation *surface* traverses the surface both vertically and horizontally.

Aggregation. Arbitrary aggregations of geometric objects are possible. These are not assumed to have any additional internal structure. Aggregations of points are called multi points, multi curves, multi surfaces, and multi solids (classes GM_MultiPoint, GM_MultiCurve, GM_MultiSurface, and GM_MultiSolid, respectively).

Topology

Topology describes the neighborhood relations of geometric data and is mostly used to accelerate computational geometry. Topology is an abstraction of the underlying geometry. Points where two or more curves meet are called nodes. The curves between pairs of nodes are geometrically simplified to straight lines and called edges. The surfaces surrounded by edges are called faces. The term to describe three-dimensional bodies defined by nodes, edges, and faces is "topological solid."

The root class of topology is TP_Object. It has the subclasses TP_Primitive and TP_Complex. The class TP_Primitive is specialized to its subclasses TP_Node, TP_Edge, TP_Face, and TP_Solid.

A topological complex (class TP_Complex) is a complete network of topological elements (node, edge, face, solid). A topological complex is used to describe that two or more topological networks are disjunct. If they are disjunct, then more than one topological complex exists.

Two topological complexes may be overlaid without being linked. This may occur if a dataset has two or more thematic layers with different topologies.

13.5.4 Simple Features (ISO 19125-1, ISO 19125-2)

ISO 19125-1 *Simple features access – Part 1: Common architecture* covers two-dimensional geometries with linear interpolation between vertices. The simple features model consists of the root class geometry and its subclasses Point, Curve, Surface, and GeometryCollection.

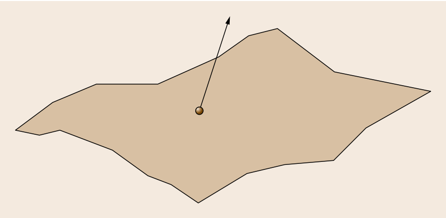


Fig. 13.106 Operation upNormal

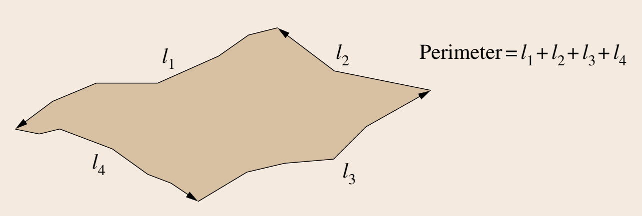


Fig. 13.107 Operation perimeter

The class Surface has the subclasses Polygon and PolyhedralSurface, and the class GeometryCollection has the subclasses MultiPoint, MultiCurve, and MultiSurface.

The class Geometry is the equivalent to the class GM_Object in ISO 19107. The class GeometryCollection is the equivalent to the class GM_Aggregate in ISO 19107. The model of ISO 19125-1 does not include complexes, a third dimension, nonlinear curves, or topology.

The simple features gained wide acceptance in spatial database applications because the amount of data required is much less than in the case of ISO 19107. Spatial extension to databases such as Oracle Spatial or PostGIS are applying the simple feature standard (Sect. 30.4). However, more sophisticated applications such as cadastre and cartography tend to use ISO 19107 and ISO 19136 *Geography markup language (GML)*.

ISO 19125-2 *Simple features access – Part 2: SQL option* specifies a SQL interface for most of the classes defined in ISO 19125-1, thus being the foundation for the simple feature database extensions in place.

Point and MultiPoint

A point (class Point) is a zero-dimensional geometric object and represents a single location in

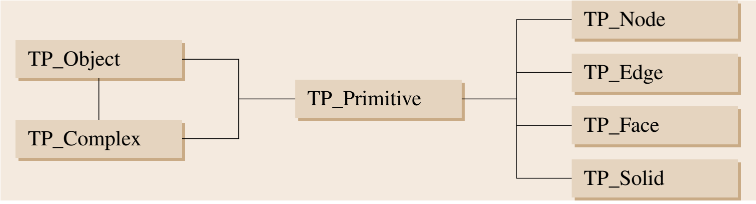


Fig. 13.108 Hierarchy of TP_Object

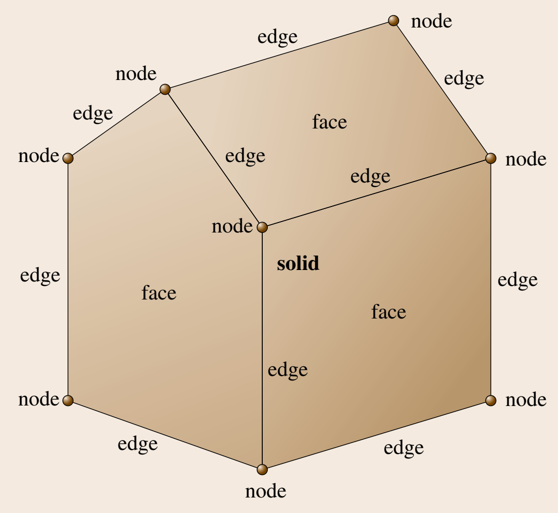


Fig. 13.109 Topology of TP_Object

the coordinate space. A multi point (class MultiPoint) is a zero-dimensional geometry collection (class GeometryCollection). The elements of a multi point are restricted to points.

Curve and MultiCurve

A curve (class Curve) is a one-dimensional geometric object that consists of one or many line strings (class LineString).

A line string has a linear interpolation between points (class Point).

A line (class Line) is a line string with exactly two points.

A linear ring (class LinearRing) is a line string that is both closed and simple.

The curve in Fig. 13.111(3) is a closed line string that is a linear ring. The curve in Fig. 13.111(4) is a closed line string that is not a linear ring.

MultiCurve. A multi curve (class MultiCurve) is a one-dimensional geometry collection (class GeometryCollection) whose elements are curves as in Fig. 13.112.

The multi curve is defined by the following most important characteristics.

- A multi curve is simple if and only if all of its elements are simple and the only intersections between any two elements occur at points that are on the boundaries of both elements.

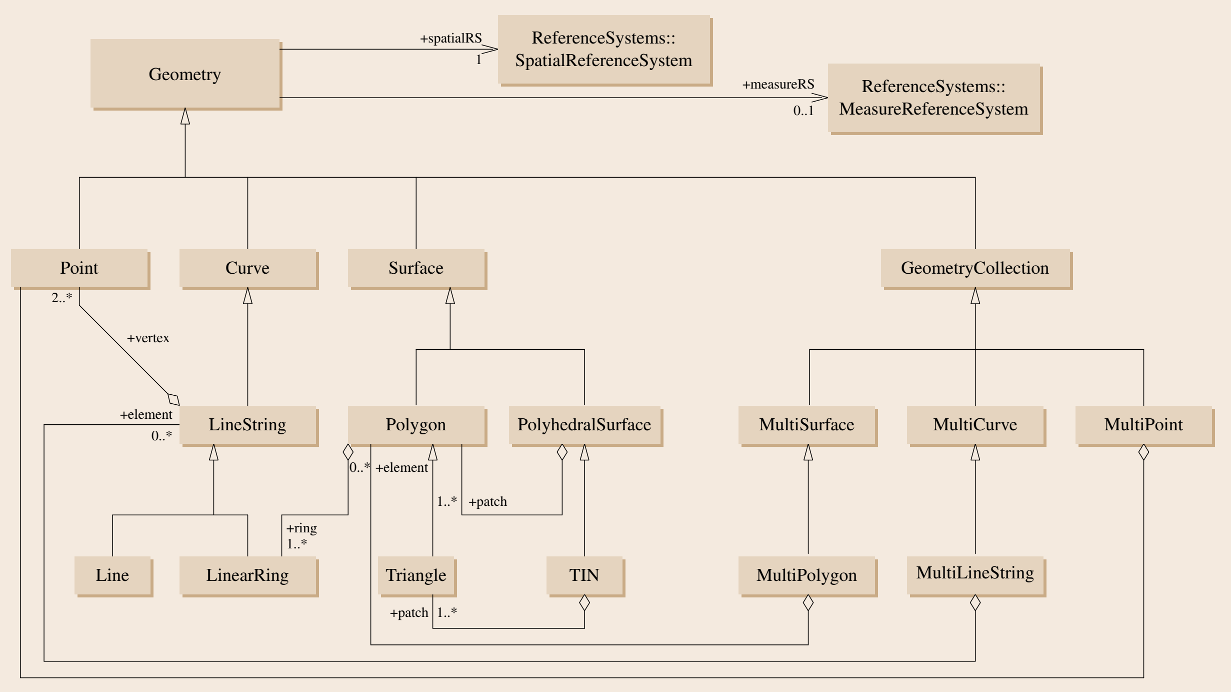


Fig. 13.110 Hierarchy of geometry of simple features (after [13.120])

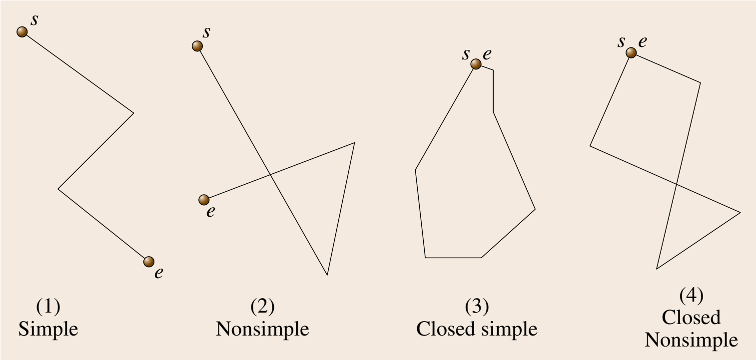


Fig. 13.111 LineString (after [13.121])

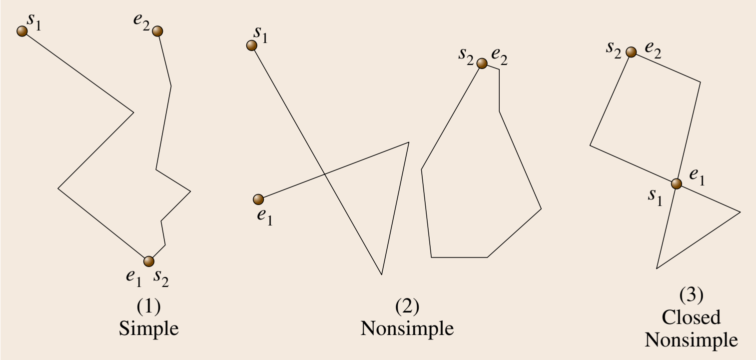


Fig. 13.112 MultiLineString (after [13.121])

- A multi curve is closed if all of its elements are closed. The boundary of a closed multi curve is always empty.

Polygon and MultiPolygon

A surface (class Surface) consists of one or many polygons (class Polygon).

A polygon (class Polygon) is a planar area defined by one exterior boundary and zero or more interior boundaries. Each interior boundary defines a hole in the polygon.

The most important rules that define valid polygons are as follows.

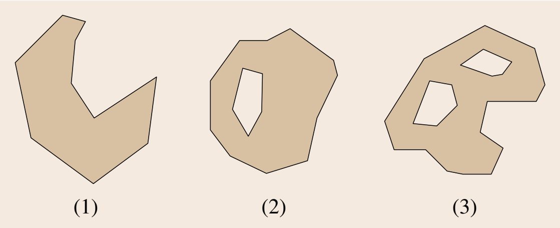


Fig. 13.113 Polygons with one, two, and three LinearRings, respectively (after [13.121])

- Polygons are topologically closed.
- The boundary of a polygon consists of a set of linear rings (class LinearRing) that make up its exterior and interior boundaries.
- The interior of every polygon is a connected point set. This is the area within the polygon.
- The exterior of a polygon with one or more holes is not connected. Each hole defines a connected component of the exterior.

MultiPolygon. A multi polygon (class MultiPolygon) is a multi surface (class MultiSurface) whose elements are polygons.

The most important rules for multi polygons are as follows.

- The interiors of two polygons that are elements of a multi polygon may not intersect.
- The boundaries of any two polygons that are elements of a multi polygon may not cross and may touch at only a finite number of points [13.122–125].

PolyhedralSurface. A PolyhedralSurface is a contiguous collection of polygons which share common

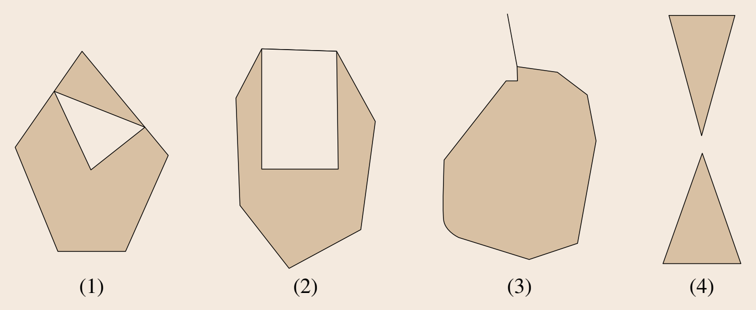


Fig. 13.114 Examples of objects not representable as a single instance of Polygon (after [13.121])

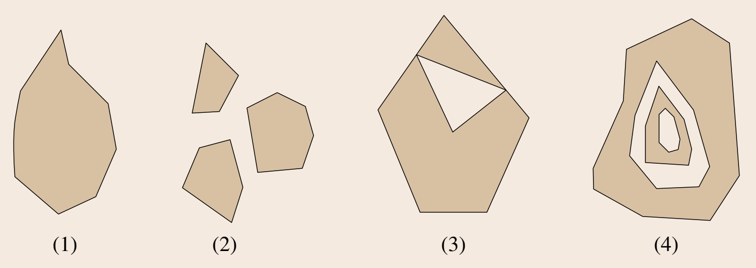


Fig. 13.115 Examples for MultiPolygon (after [13.121])

boundary segments. A triangulated irregular network (TIN) is a PolyhedralSurface consisting only of Triangle patches.

MultiSurface. A MultiSurface is a two-dimensional GeometryCollection whose elements are Surfaces, all using coordinates from the same coordinate reference system.

Example for the Topology in ISO 19107 and ISO 19125-1

Figure 13.117 explains the influence of underlying topology on a geometric dataset.

The top example displays the map as it would appear on a screen or printout. It contains roads, houses, parcel boundaries, and trees. In order to focus on the features and their relation, the graphic portrayal is kept simple. Only the trees are drawn as symbols for clarification.

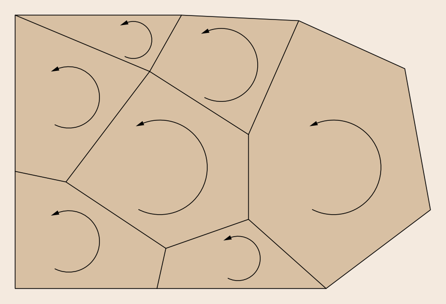


Fig. 13.116 PolyhedralSurface with consistent orientation (after [13.120])

The lower examples display the same map, exploded to reveal the underlying relations. The lower left graphic shows the geometry and the topology as standardized in ISO 19107. The two lower right graphics show the geometry as standardized in ISO 19125-1.

In ISO 19107, topology relates neighboring features. This is mostly achieved by not allowing more than one point at a given position. Consequently, two or more neighboring features that have points at the same position share the coordinates. Internally, the coordinates of the points are stored only once, while the features relate their positions to this point using a pointer technique. The topology can be used to accelerate geometric computations such as a network search, or to track gaps and overlaps in the dataset.

As ISO 19125-1 does not support topology, the features are geometrically linked by a common coordinate reference system only. A full set of coordinates is stored together with every feature. This means that, at one position, more than one point can exist. This approach is well known from computer-aided design (CAD)-type systems.

Smaller features within larger surfaces require cut-outs. As cut-outs are not supported by ISO 19125-1, features such as houses or trees have to sit on the high-

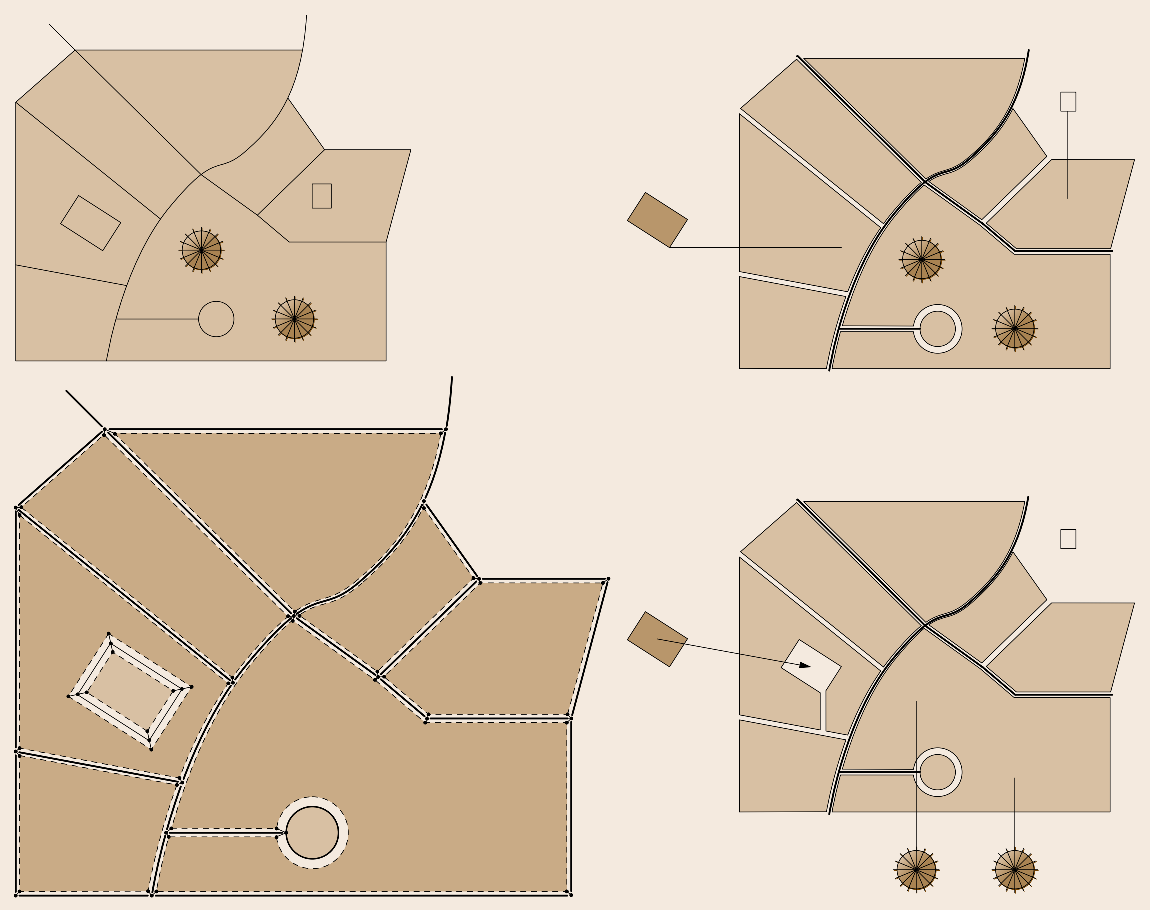


Fig. 13.117 Neighborhood relations in Spatial schema and Simple features

est display level, meaning that they have to be plotted last. This is the upper case. Alternatively, cut-outs can be simulated by introducing a cut in the surface, enabling a continuous sequence of points on a perimeter that includes the perimeter of the cut-out.

13.5.5 Schema for Coverage Geometry and Functions (ISO 19123)

Coverages are geographic information schemas that integrate discrete and continuous geographic phenomena. Discrete phenomena are recognizable objects that have relatively well-defined boundaries or spatial extent. Examples would include buildings, streams, and measurement stations. Continuous phenomena vary over space and have no specific extent. Examples of this would include temperature, soil composition, and elevation. A value or description of a continuous phenomenon is only meaningful at a particular position in space and possibly time. Temperature, for example, takes on specific values only at defined locations whether measured or interpolated from other locations.

Overview of ISO 19123

A coverage is a subtype of a geographic feature (class GF_FeatureType, ISO 19109) and is associated to a coordinate reference system according to ISO 19111.

Description of the Discrete Coverage Classes of ISO 19123

A discrete coverage consists of individual geometric objects in which an interpolation between those objects is not allowed.

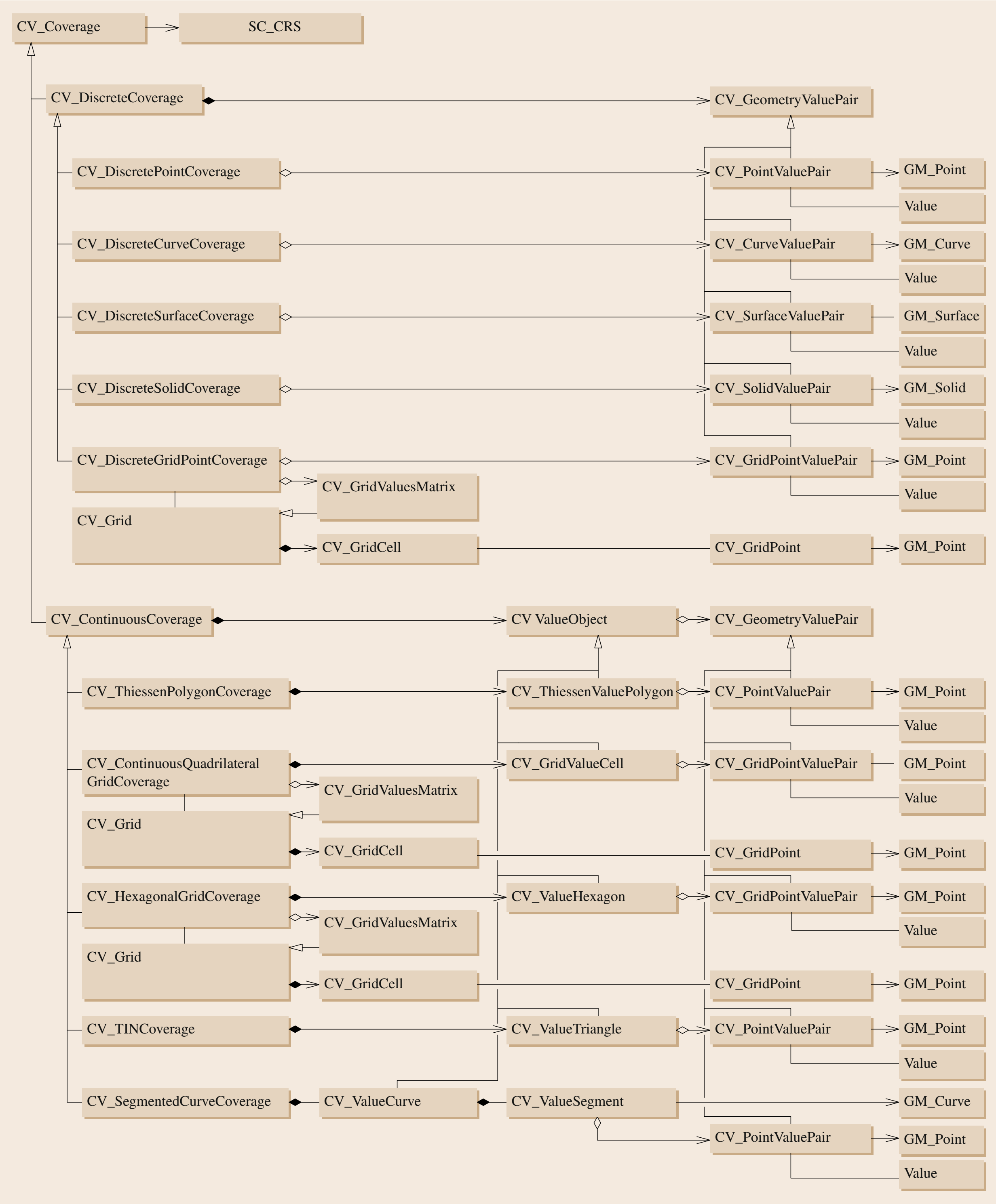

CV_Coverage
SC_CRS
CV_DiscreteCoverage
CV_GeometryValuePair
CV_DiscretePointCoverage
CV_PointValuePair
GM_Point
Value
CV_DiscreteCurveCoverage
CV_CurveValuePair
GM_Curve
Value
CV_DiscreteSurfaceCoverage
CV_SurfaceValuePair
GM_Surface
Value
CV_DiscreteSolidCoverage
CV_SolidValuePair
GM_Solid
Value
CV_DiscreteGridPointCoverage
CV_GridPointValuePair
GM_Point
CV_GridValuesMatrix
Value
CV_Grid
CV_GridCell
CV_GridPoint
GM_Point
CV_ContinuousCoverage
CV ValueObject
CV_GeometryValuePair
CV_ThiessenPolygonCoverage
CV_ThiessenValuePolygon
CV_PointValuePair
GM_Point
Value
CV_ContinuousQuadrilateral GridCoverage
CV_GridValueCell
CV_GridPointValuePair
GM_Point
CV_GridValuesMatrix
Value
CV_Grid
CV_GridCell
CV_GridPoint
GM_Point
CV_HexagonalGridCoverage
CV_ValueHexagon
CV_GridPointValuePair
GM_Point
CV_GridValuesMatrix
Value
CV_Grid
CV_GridCell
CV_GridPoint
GM_Point
CV_TINCoverage
CV_ValueTriangle
CV_PointValuePair
GM_Point
Value
CV_SegmentedCurveCoverage
CV_ValueCurve
CV_ValueSegment
GM_Curve
CV_PointValuePair
GM_Point
Value

Fig. 13.118 Hierarchy of CV_Coverage (after [13.126]) ◀

CV_DiscretePointCoverage. A discrete point coverage (class CV_DiscretePointCoverage) is a set of irregularly distributed points and their attributes. The principle use of discrete point coverages is to provide a basis for continuous coverage functions.

An example for a discrete point coverage would be a small-scale map showing cities and their population. In this case it is not feasible to interpolate between the points of the cities.

CV_DiscreteCurveCoverage. A discrete curve (class CV_DiscreteCurveCoverage) coverage is characterized by a finite spatiotemporal domain consisting of curves that may be elements of a network.

An example of a discrete curve coverage is a road network where the coverage assigns a route number, a name, a pavement width, and a pavement material type to each segment of the road system.

CV_DiscreteSurfaceCoverage. A discrete surface coverage (class CV_DiscreteSurfaceCoverage) consists of a collection of surfaces. In most cases, the surfaces that constitute the spatiotemporal domain of a coverage are mutually exclusive and exhaustively partition the extent of the coverage; for example, a coverage that represents corn fields typically has a spatial domain composed of a surface with irregular boundaries where no interpolation is feasible.

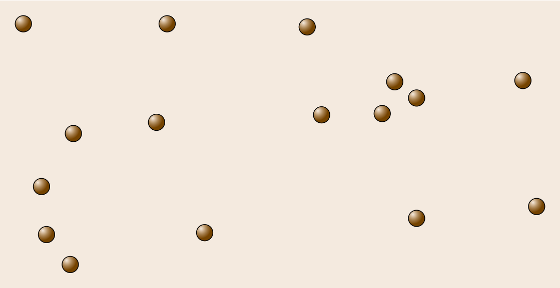


Fig. 13.119 Discrete point coverage

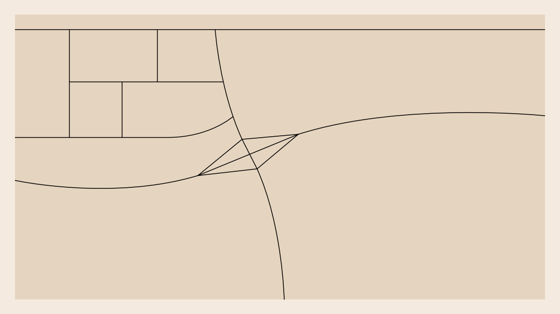


Fig. 13.120 Discrete curve coverage

CV_DiscreteSolidCoverage. A discrete solid coverage (class CV_DiscreteSolidCoverage) is a coverage whose domain consists of a collection of solids; for example, an ocean body or an atmospheric volume could be represented as a CV_DiscreteSolidCoverage with a range of attributes such as temperature and pressure at each vertex.

The 3-D grid could be a volume such as an ocean body. Every vertex may hold a range of attributes.

CV_DiscreteGridPointCoverage. A discrete grid point coverage (class CV_DiscreteGridPointCoverage) is

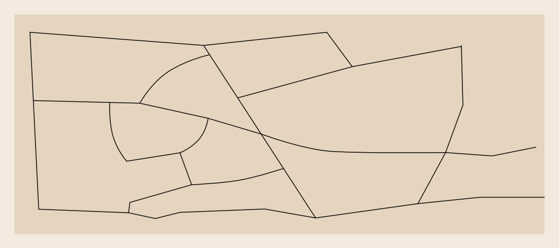


Fig. 13.121 Discrete surface coverage

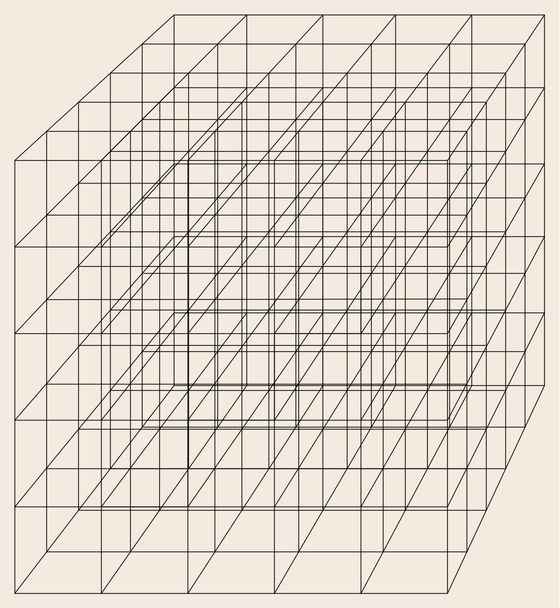


Fig. 13.122 Discrete solid coverage

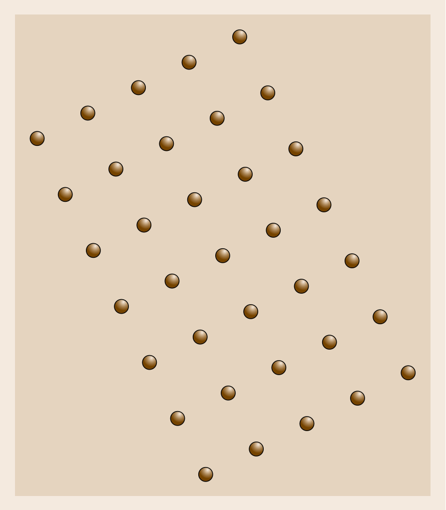


Fig. 13.123 Discrete grid point coverage

Table 13.29 Relation between interpolation methods and coverage types

Interpolation method	Type of coverage that uses this interpolation method
Nearest-neighbor interpolation	Any coverage
Linear interpolation	Segmented curve coverage
Quadratic interpolation	Segmented curve coverage
Cubic interpolation	Segmented curve coverage
Bilinear interpolation	Quadrilateral grid coverage
Biquadratic interpolation	Quadrilateral grid coverage
Bicubic interpolation	Quadrilateral grid coverage
Lost area interpolation	Discrete point coverages
Barycentric interpolation	TIN coverage

a set of regularly distributed points and their attributes. The distribution is defined in the grid values matrix (class CV_GridValuesMatrix). A discrete grid point coverage could be considered a subcase of the discrete point coverage (class CV_DiscretePointCoverage).

Description of the Continuous Coverage Classes of ISO 19123

A continuous coverage is a combination of a discrete coverage with an interpolation function that fills the space and eventually the time in between. For the interpolation, ISO 19123 defines the following methods.

CV_ThiessenPolygonCoverage. A Thiessen polygon coverage (class CV_ThiessenPolygonCoverage) partitions the space using Thiessen polygons. These are also named Voronoi polygons or Dirichlet tessellation. Thiessen polygons are closed polygons around points of an irregularly distributed point set. For any position within a Thiessen polygon, its center point is the closest of the whole point set. Thiessen polygons are defined in two-dimensional space only. They make it possible to apply lost area interpolation to a point set. They are also used for one step in the computation of a TIN for a given point set.

CV_ContinuousQuadrilateralGridCoverage. The quadrilateral grid coverage (class CV_ContinuousQuadrilateralGridCoverage) employs a systematic tessellation of the spatiotemporal domain. The principle advantage of such tessellations is that they support sequential enumeration of elements, which makes data storage and access more efficient.

A quadrilateral grid coverage may be a rectified grid or a referenceable grid. A rectified grid can be transformed into a coordinate reference system using an affine transformation. An affine transformation has six parameters: two translations (x, y), two rotations (one for each axis), and two scales (one for each axis). A referenceable grid requires a formula of higher order that transforms into a coordinate reference system. An example is the perspective transformation with eight parameters.

CV_HexagonalGridCoverage. A hexagonal grid coverage (class CV_HexagonalGridCoverage) is based on regular hexagons. That grid can be described as a rectified grid in which the two offset vectors are of equal length but differ in direction by 60°.

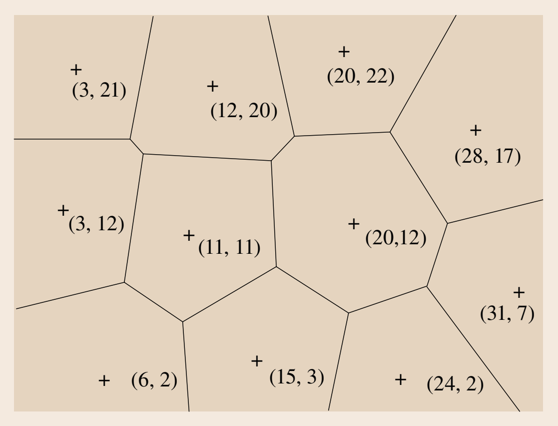


Fig. 13.124 Thiessen polygon network (after [13.126])

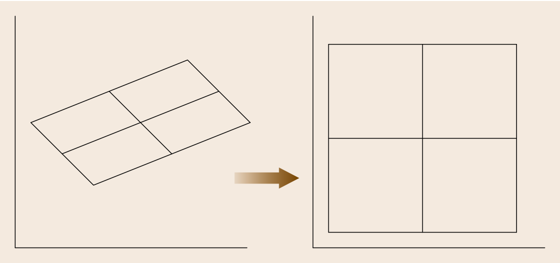


Fig. 13.125 Rectified grid (affine transformation)

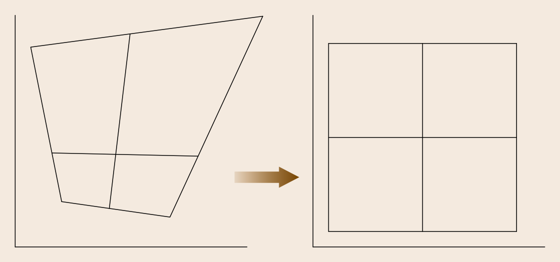


Fig. 13.126 Referenceable grid (perspective transformation)

CV_TINCoverage. A TIN coverage (class CV_TINCoverage) partitions the space in triangles that are formed according to the Delaunay criterion.

CV_SegmentedCurveCoverage. The segmented curve coverages (class CV_SegmentedCurveCoverage) are used to model phenomena that vary continuously or discontinuously along curves that may be elements of a network. An example is a road network with variable traffic intensity along the roads.

CV_DomainObject. A domain object (class CV_DomainObject) represents an element of the spatiotemporal domain of the coverage. It is an aggregation of objects that may include any combination of GM_Objects or other spatial or temporal objects defined in the ISO 19100 standards. A domain object is used to address spatial or temporal parts of the coverage such as the grid points or larger portions.

CV_ValueObject. A value object (class CV_ValueObject) represents an element of the spatiotemporal domain of a continuous coverage. A value object is used to address spatial or temporal parts of the continuous coverage such as a triangle of the TIN. A value object may be the result of an evaluation of a continuous coverage and thus data need not be persistent in the coverage.

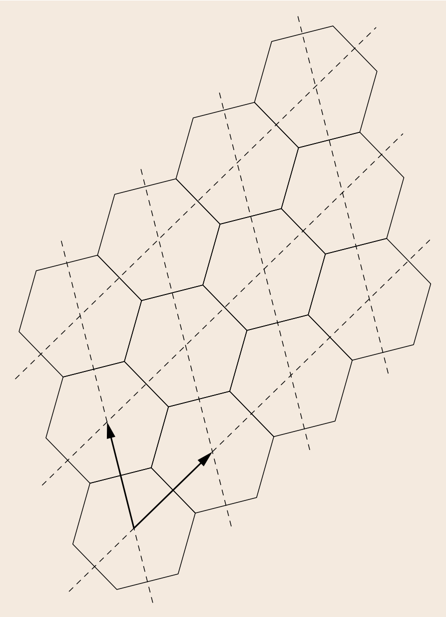


Fig. 13.127 Hexagonal grid coverage (after [13.126])

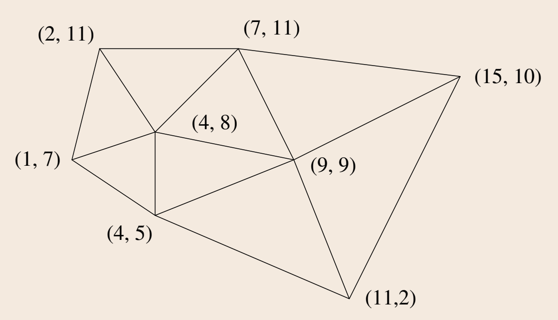


Fig. 13.128 Triangulated irregular network (TIN) (after [13.126])

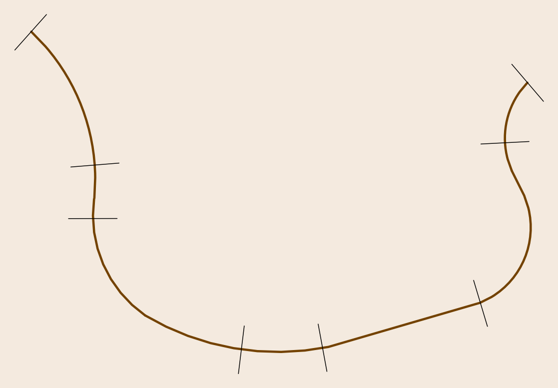


Fig. 13.129 Segmented curve coverage

CV_GeometryValuePair. A geometry–value pair (class CV_GeometryValuePair) describes an element of a coverage. As the name implies, each geometry–value pair consists of two parts: a geometric object such as a point and a record of associated feature values such as its elevation or soil type.

CV_GridPointValuePair. A grid point–value pair (class CV_GridPointValuePair) is composed of a grid point and a feature attribute value record.

CV_GridValuesMatrix. The grid values matrix (class CV_GridValuesMatrix) basically defines the attributive values at the grid points and the geometric sequence of their occurrence within the grid; for example, the grid values matrix of 100×100 elevation points contains the 10 000 elevation values and a pointer to the sequence rule.

ISO 19123 standardizes six sequence rules. The graphic examples (Figs. 13.130–13.135) all relate to a two-dimensional grid.

Operations in ISO 19123

Table 13.30 relates the important operations of coverages to the classes in ISO 19123. Some operations of the subclasses of CV_TINCoverage and CV_SegmentedCurveCoverage are not shown.

The operations *curve* and *segment* are only used with CV_SegmentedCurveCoverages. All other coverage types use the operation *locate*.

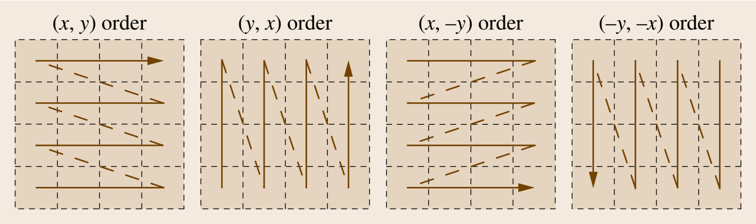


Fig. 13.130 Linear scanning (after [13.126])

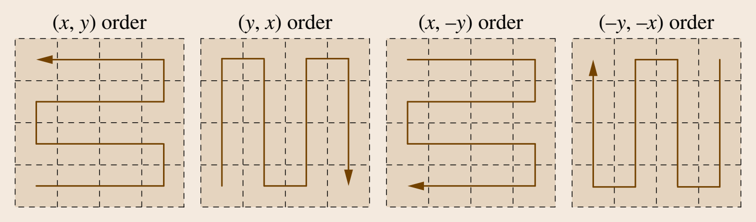


Fig. 13.131 Boustrophedonic scanning (after [13.126])

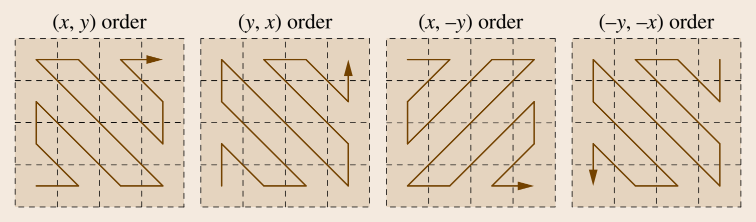


Fig. 13.132 Cantor-diagonal scanning (after [13.126])

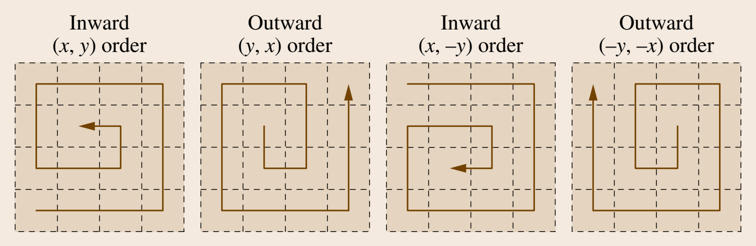


Fig. 13.133 Spiral scanning (after [13.126])

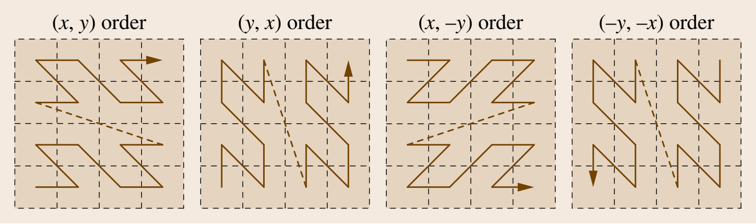


Fig. 13.134 Morton order (after [13.126])

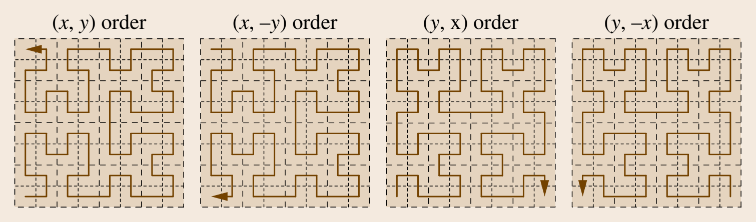


Fig. 13.135 Hilbert order (after [13.126])

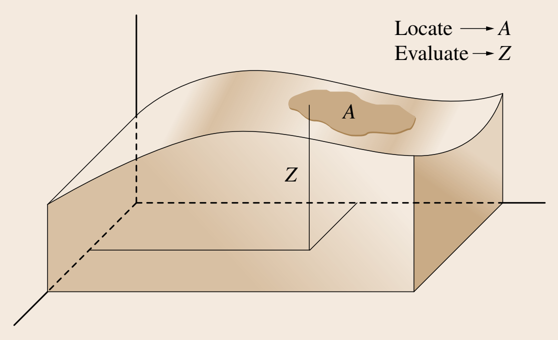


Fig. 13.136 Operations evaluate and locate

evaluation, evaluateInverse, and locate. The operation *evaluate* accepts a position as input and returns a record of attribute values for that position. Most evaluation methods involve interpolation within the neighborhood of the position.

The operation *evaluateInverse* accepts a record of feature attribute values as input and returns a set of spatiotemporal objects; for example, this operation could return a set of contour lines derived from the feature attribute values associated with the grid points.

The operation *locate* accepts a position as input and returns the set of value objects such as Thiessen polygons that contain this position. It shall return a null

Table 13.30 Operations in ISO 19123

	evaluate	evaluate inverse	locate (curve segment)	find	list
CV_Coverage	×	×			
CV_DiscreteCoverage	×	×	×	×	×
CV_DiscretePointCoverage	×	×	×	×	×
CV_DiscreteCurveCoverage	×	×	×	×	×
CV_DiscreteSurfaceCoverage	×	×	×	×	×
CV_DiscreteSolidCoverage	×	×	×	×	×
CV_DiscreteGridPointCoverage	×	×	×	×	×
CV_ContinuousCoverage	×	×	×		
CV_ThiessenPolygonCoverage	×	×	×		
CV_ContinuousQuadrilateralGridCoverage	×	×	×		
CV_HexagonalGridCoverage	×	×	×		
CV_TINCoverage	×	×	×		
CV_SegmentedCurveCoverage			×		

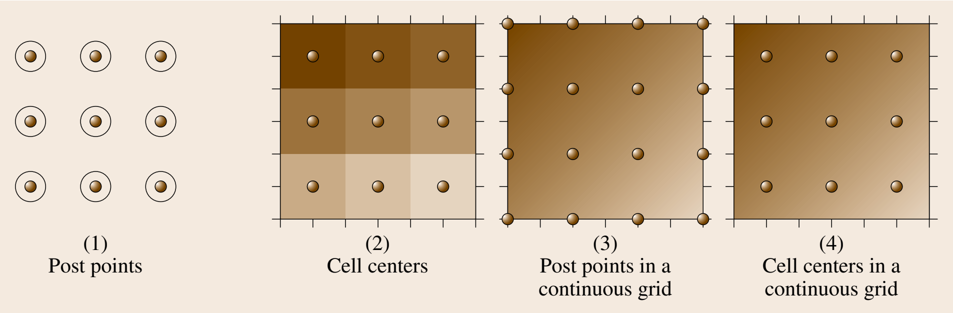


Fig. 13.137 Evaluation of a grid

value if the position is not in any of the value objects within the spatiotemporal domain of the discrete coverage.

In detail, the operation *evaluate* works differently depending on the four different kinds of coverages. Figure 13.137 shows the four cases based on a quadrilateral grid (square grid).

Cell Structures and the Operation Evaluate. The interstitial spaces between grid lines are called grid cells. Grid points viewed as lying on the cell corners are often called posts, and data composed of post points and associated feature attribute values are called matrix data. Grid points viewed as lying at the centers of the cells are called cell centers. Users of digital images sometimes take the point of view where it is assumed that each pixel value is the weighted average measurement of the scene, taken over a grid cell centered on a grid point.

There are four cases for the evaluation of the grid.

1. The grid points are considered to be the *post points in a discrete point* coverage. The coverage can only be evaluated at direct positions that fall on the grid points.
2. The grid points are considered to be at the *cell centers in a discrete surface* coverage. To evaluate the coverage at some direct position, the nearest grid points have to be identified.
3. The grid points are considered to be *post points in a continuous* grid coverage. The feature attribute values at any direct position are interpolated from those at a set of surrounding grid points.
4. The grid points are considered to be *cell centers in a continuous* grid coverage. The feature attribute values at any direct position are interpolated from those at a set of surrounding grid points.

The common point rule (class CV_CommonPointRule) provides a strategy for the operation *evaluate* to supply an unequivocal return value for all positions of the coverage. The common point rule behaves differently with discrete and continuous coverages. In discrete coverages, interpolation between the post points is not allowed. In continuous coverages, ambiguities may arise at positions that fall either on a boundary between geometric objects or within the boundaries of two or more overlapping geometric objects. In this case, the interpolation within each geometric object takes place first. The common point rule is then applied.

The common point rule offers four selection techniques: average value, lowest value, highest value, or all range values of the neighboring post points. In the case of a segmented curve coverage, the startValue or the endValue can also be selected for return.

interpolate. The operation *interpolate* accepts a position as input and returns the record of feature attribute values computed for that position.

Find, list, and curve. The operations *find* and *list* only exist for discrete coverages.

The operation *find* accepts a position as input and returns the sequence of geometry–value pairs that include the domain object nearest to the position and their distances from the position.

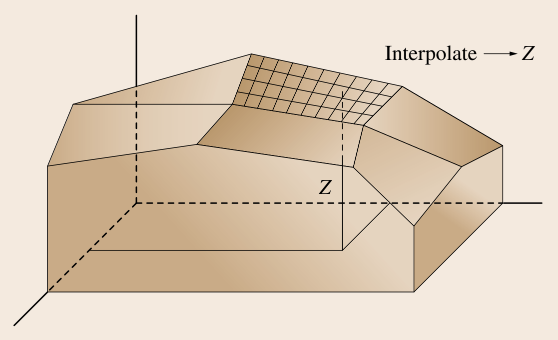


Fig. 13.138 Operation interpolate

The operation *list* returns the dictionary that contains the domain objects, such as curves of the discrete coverage, each paired with its record of feature attribute values.

The operation *curve* accepts a direct position as input and returns the value curve (class CV_ValueCurve) nearest to that position.

13.5.6 Geography Markup Language (GML) (ISO 19136)

ISO 19136 *Geography markup language (GML)* standardizes an implementation of the geometry-related standards of the 19100 family, in particular ISO 19107 *Spatial schema* and ISO 19123 *Schema for coverage geometry and functions*. However, ISO 19123 seems to deal more with interfaces, while the coverages in GML are described more from an information viewpoint [13.127]. GML is an application of XML built on XML schema. This section refers to GML version 3.x [13.128].

GML is designed for modeling, transport, and storage of geographic data. In a number of predefined schemas, GML provides a rich vocabulary that can be used to create domain-specific GML application schemas. GML serves as a foundation for the geospatial web and for interoperability of independently developed distributed applications, including location-based services.

GML Schemas

Feature and Feature Collection. A feature is an abstraction of a real-world phenomenon. It is a *geographic* feature if it is associated with a location relative to the Earth. The state of a feature is defined by a set of properties, where each property can be thought of as a {name, type, value} triple.

A feature collection is a collection of features that can itself be regarded as a feature. As a consequence, a feature collection has a feature type and thus may have distinct properties of its own, in addition to the features it contains.

Geographic features in GML include coverages and observation as subtypes.

Geometry. The geometry of a geographic feature describes its location, shape, or extent. The geometry model of GML distinguishes geometric primitives, aggregates, and complexes.

The geometric primitives are the basic elements that are used to form the geometry of a geographic dataset. Primitives are open; that is, a curve does not contain its end points, a surface does not contain its boundary curves, and a solid does not contain its bounding surface.

The geometric aggregates are arbitrary aggregations of geometry elements. They are not assumed to have any additional internal structure and are used to *collect* pieces of geometry of a specified type.

Geometric complexes are closed collections of geometric primitives. This means that they contain their boundaries.

Figure 13.139 shows the hierarchy of GML geometry types.

Coordinate Reference System. The coordinate reference system (CRS) provides the meaning for location coordinates. A CRS may be associated with any geometry of GML.

The CRS schema of GML deviates slightly from ISO 19111 *Spatial referencing by coordinates* and from topic 2 *Spatial referencing by coordinates* of the OGC's abstract specification. Appropriate change proposals will be submitted to ISO/TC 211 [13.127].

Topology. Topology describes the geometric properties of objects that are invariant under continuous deformation; for example, a square is topologically equivalent to a rectangle and a trapezoid. In geographic modeling, the foremost use of topology is in accelerating computational geometry.

The topology of a dataset is described by the topological primitives nodes, edges, faces, and topological solids. Nodes are topological points where edges meet. Edges are topological lines where faces meet. Faces are topological surfaces where solids meet.

Topological relations are described with boundaries, coboundaries, and directed topological primitives. The topological primitive *edge* is bounded by two directed topological *node* primitives. The topological primitive *edge* is also the coboundary to a pair of nodes. The other relations are formed according to Table 13.31.

Temporal Information and Dynamic Features. Time in GML allows the description of the time-dependent status of geographic features and the description of dynamic features, for example, in the domain of location-based services. The definitions of time in GML extend the model of ISO 19108 *Temporal schema*.

Time is measured on two types of scales: interval and ordinal. An interval scale offers a basis for

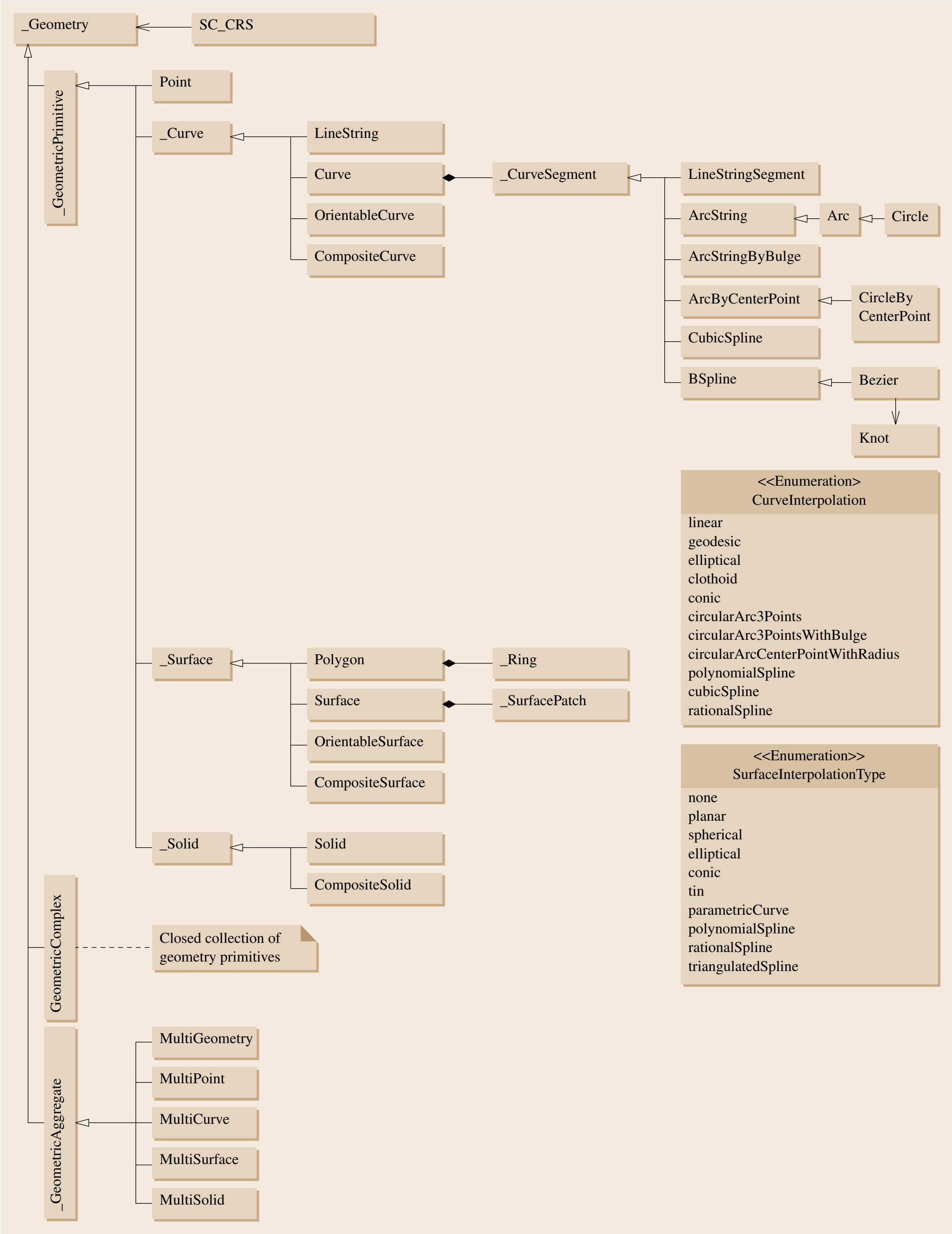

_Geometry
SC_CRS
_GeometricPrimitive
Point
_Curve
LineString
Curve
OrientableCurve
CompositeCurve
_CurveSegment
LineStringSegment
ArcString
Arc
Circle
ArcStringByBulge
ArcByCenterPoint
CircleBy CenterPoint
CubicSpline
BSpline
Bezier
Knot
<<Enumeration> CurveInterpolation
linear
geodesic
elliptical
clothoid
conic
circularArc3Points
circularArc3PointsWithBulge
circularArcCenterPointWithRadius
polynomialSpline
cubicSpline
rationalSpline
_Surface
Polygon
_Ring
Surface
_SurfacePatch
OrientableSurface
CompositeSurface
<<Enumeration>> SurfaceInterpolationType
none
planar
spherical
elliptical
conic
tin
parametricCurve
polynomialSpline
rationalSpline
triangulatedSpline
_Solid
Solid
CompositeSolid
GeometricComplex
Closed collection of geometry primitives
_GeometricAggregate
MultiGeometry
MultiPoint
MultiCurve
MultiSurface
MultiSolid

Fig. 13.139 Hierarchy of elements in ISO 19136 (GML 3.x) ◀

Table 13.31 Relation between topological primitive, directed primitive, and coboundary

Topological primitive	→	Bounded by directed primitive	
Coboundary	←	Topological primitive	
	Dimension		Dimension
Edge	1	Node	0
Face	2	Edge	1
Topological solid	3	Face	2

measuring duration. An ordinal scale provides information only about relative position in time, for example, a stratigraphic sequence or the geological time scale.

The default temporal reference system is the Gregorian calendar with universal time coordinated (UTC) [13.129].

A time instant represents a position in time. It is the equivalent to a point in space. Inexact or *fuzzy* positions may be expressed using the indeterminatePosition attribute that may have values such as *after* or *before*.

A period represents an extent in time. It is the equivalent to a curve in space. It is an interval bounded by beginning and end instants, and has a duration.

The status of dynamic features can be described by a snapshot and by a time slice. A snapshot portrays the status of a feature as a whole, whereas a time slice encapsulates the dynamic properties that reflect some change event.

Coverage. Coverages in GML are defined in accordance with ISO 19123 *Schema for coverage geometry and functions* and OGC [13.130]. However, GML implements only a subset of the functionality defined in the cited sources.

Styling. GML requires strict separation of data and presentation. Therefore, none of the GML data description constructs such as features and geometries have built-in capabilities to describe styling information. To simplify the handling of GML, a default styling mechanism was created as a separate model that can be *plugged in* to a GML dataset. The default style schema depends on the W3C Synchronized Multimedia Integration Language (SMIL) [13.131].

The GML styling mechanism distinguishes between four kinds of styling types. The feature style applies to each feature independently. The geometry style describes the style for one geometry of a feature. The topology style describes the style for one topology property. The label style describes the style for the text that is to be displayed along with the graphical representation.

The presentation consists of styling elements. The symbol element specifies a graphical symbol. It may be defined within the GML application schema. This case is called *inline*. It also may be addressed by a pointer to other GML or non-GML sources. This case is called *remote*.

The style element is the term for simple symbols.

The style variation element is used in cases where a symbol is displayed repeatedly, but with slight variations each time. In this case the geometry of the symbol has to be transmitted only once.

Animation attributes are used to describe the animation behavior of the geometry, topology, label, or graph [13.131].

XLink. XLink is an XML technique that explicitly relates two or more data objects or portions of data objects. XLink is widely used in GML. XLink components are used in GML to implement associations between objects by reference. It is currently restricted to unidirectional links between two resources in most GML applications. The associated objects may be physically as close as two elements in the same GML document or as far as any node in the World Wide Web.

Profile. A profile of GML defines a subset of the constructs of GML. GML profiles use a *copy-and-delete approach*. To create a profile, a developer might copy the applicable schema files from GML and simply delete any global types, elements, and local optional particles that he or she does not need for the application schema.

A profile can be the basis of an application schema. The building of an application schema is a two-part process. The profile acts as a restriction of GML to produce types and elements consistent with the complete GML 3 but potentially lacking in some optional particles. The application schema then uses these types as a common base, and uses them in new types and elements by extensions or inclusions.

GML 3 – (selection and restriction) → GML profile – (extension and inclusion) → application schema

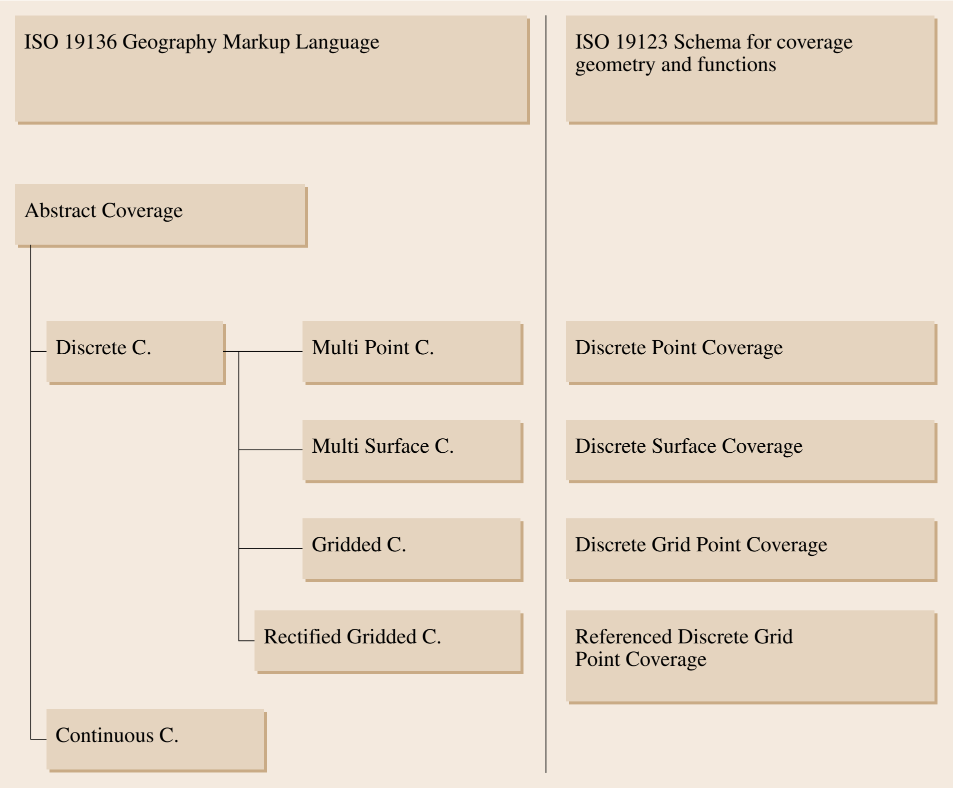


Fig. 13.140 Comparison between the coverage types in ISO 19136 and ISO 19123

ISO 19136 defines a set of rules that have to be applied for creating a profile. They can be summarized as follows.

1. A profile of GML is a logical restriction of a subset of GML.
2. A profile must not change the name, definition, or data type of mandatory GML elements or attributes.
3. The relevant schema or schemas that define a profile must use the core GML namespace.
4. An application schema may extend and use types from the profile, but must do so in its own namespace.

Other Topics of GML 3. In addition to the constructs explained above, GML offers further techniques for the description of data elements.

1. Description of observations.
2. Units, measures, and values.
3. Names for directions.
4. Definitions and dictionaries.

GML Application Schema

A GML application schema is an XML schema conforming to the rules outlined in the ISO 19136 document. The application schema is a combination of a GML profile and application-specific definitions. It describes one or more types of geographic objects, components of geographic objects, or metadata, including dictionaries and definitions, used in the definition of geographic objects.

The definition of a GML application schema must follow a number of rules. They shall guarantee the readability of and the ability to process a GML document by any GML parser and shall allow for worldwide transport and storage of GML datasets without interference with other GML datasets.

The rules have mostly three components.

1. The application schema must declare a target namespace. This is the namespace in which terms such as the application-specific feature types and coverage "live." This must not be the GML namespace. The GML namespace is defined in about 20

XML schemas such as geometryPrimitives.xsd and coverage.xsd.

2. All geographic features in the application schema must be declared as global elements in the schema. The content model for such global elements must derive either directly or indirectly from gml:AbstractFeatureType.
3. Elements representing properties of features may be declared as global elements in an application schema, or they may be declared locally within feature content models (type definitions). The type for a property element may be derived from gml:AssociationType or gml:ArrayAssociationType, or may follow the pattern of gml:AssociationType.

Relation Between GML, OGC, and the ISO 19100 Standards

GML is being maintained and developed by the GML Working Group of the Open Geospatial Consortium (OGC). GML is related to the OGC abstract specification and published as one of their implementation specifications.

ISO has adopted GML as the ISO 19136 standard.

Relation to ISO 19107 Spatial Schema. The implementation standard ISO 19136 conforms to the other standards of the ISO 19100 family. The closest relation exists to ISO 19107.

The vast majority of concepts in ISO 19107 have been implemented in GML 3.x, such as the fundamental geometries point, curve, surface, and solid, and the description of positions related to a coordinate reference system.

However, conformance with other ISO 19100 standards does not require a one-to-one implementation. The implementation of classes in GML is driven by applications and requirements. In fact, ISO 19107 states that is not expected that an implementation will implement all classes. On the other hand, GML 3 contains some elements that are beyond the range of the other ISO 19100 standards. The class GM_OffsetCurve is an example of a class in ISO 19107 that has not been implemented by GML 3. The element ArcByCenterPoint is an example of an element in GML 3 that does not exist in ISO 19107.

Relation to Other ISO 19100 Standards. ISO 19118 *Encoding* sets the encoding for the geomatics standards. The XML encoding is normative. Annex A of ISO 19118 references two other ISO/TC 211 standards that specify XML-based encoding rules: ISO 19136 (annex E) and ISO/TS 19139 *Metadata – XML schema implementation*. Although XML is strongly preferred and normative, ISO 19118 allows different encoding schemas.

ISO 19111 *Spatial referencing by coordinates* in general serves the needs of GML 3.

GML 3 contains a mechanism to include metadata, but there is no rule that only standards of the ISO/TC 211 family such as ISO 19115 *Metadata* can be used. GML is open to integrate metadata from other source such as the Dublin Core as well.

ISO 19108 *Temporal schema*, ISO 19109 *Rules for application schema*, and ISO 19117 *Portrayal* still need to be fully harmonized with GML 3.

Alignment Between ISO 19136 and GML Development

As ISO 19136 defines an implementation, it will change more rapidly than the abstract standards of the ISO 19100 family. It may happen that the version of GML that has become an international standard may be outdated, because the development of GML will go on in parallel to the process of ISO standardization. Therefore, provisions are made to sustain alignment between ISO 19136 and GML.

If possible, new versions of GML should be backward compatible or provide for an automatic mapping. The development of GML will have to take care that the conformance with the conceptual model of the ISO 19100 standards is maintained. From the perspective of the geographic information community and the marketplace, if there are good reasons for a change, the ISO 19100 conceptual model, ISO 19118 *Encoding*, or the OGC abstract specification, on which GML is based, should change.

13.6 Liaison Members of ISO/TC 211

13.6.1 Internal Liaison Members of ISO/TC 211

ISO/TC 211 *Geographic information/Geomatics* was founded in 1994 to standardize geographic information. However, various aspects of geographic information had been published as ISO, IEC, or ITU standards before the ISO/TC 211 was founded, and other relevant standards are being developed while the work of ISO/TC 211 is ongoing. Formal relations with the responsible committees, known as *internal liaisons*, have been established in order to align the existing standards and ongoing activities with the work of ISO/TC 211.

The number of internal liaisons varies according to the needs of the standardization work. The following list has been assembled from *all* technical committees and subcommittees of ISO and IEC, as well as all study groups of ITU. Groups that are presently not formal internal liaison members are marked.

In many cases, only a very specific working group or subcommittee of a technical committee will develop an internal liaison relationship with the ISO/TC 211. An example is ISO/TC 20 *Aircraft and space vehicles*. Only subcommittee 13 (ISO/TC 20/SC 13) entitled Space data and information transfer systems has an internal liaison with ISO/TC 211. The working groups and the subcommittees relevant to geographic information are titled accordingly and placed as the first paragraph of each section. In situations where the names of the working groups and subcommittees do not clearly define the subjects that they cover, a list of topics is provided for clarification. The other paragraphs in a section point to further working groups or subcommittees of the technical committee. An example is ISO/TC 204 *Intelligent transport systems* in which working group 5 *Fee and toll collection* (ISO/TC 204/WG 5) has only a minor interest in geographic information.

The internal liaison committees with ISO/TC 211 *Geographic information/Geomatics* are underlined.

As an introduction, a listing of all relevant ISO and IEC TCs and SCs as well as the ITU study groups (SGs) is given in brief.

- ISO/TC 12 *Quantities and units*
- ISO/TC 20 *Aircraft and space vehicles*
- ISO/TC 23 *Tractors and machinery for agriculture and forestry*
- ISO/TC 37 *Terminology and other language and content resources*
- ISO/TC 42 *Photography*
- ISO/TC 46 *Information and documentation*
- ISO/TC 59 *Buildings and civil engineering works*
- ISO/TC 69 *Application of statistical methods*
- ISO/TC 82 *Mining*
- ISO/TC 130 *Graphic technology*
- ISO/TC 154 *Processes, data elements and documents in commerce, industry and administration*
- ISO/TC 171 *Document management applications*
- ISO/TC 172 *Optics and photonics*
- ISO/TC 176 *Quality management and quality assurance*
- ISO/TC 184 *Automation systems and integration*
- ISO/TC 204 *Intelligent transport systems*
- ISO/TC 207 *Environmental management*
- ISO/TC 211 *Geographic information/Geomatics*
- ISO/TC 241 *Project committee: road traffic safety management system*
- SCIT *The ISO steering committee for image technology*
- IEC/TC 1 *Terminology*
- IEC/TC 80 *Maritime navigation and radio-communication equipment and systems*
- ISO/IEC JTC1/SC2 *Coded character sets*
- ISO/IEC JTC1/SC7 *Software and systems engineering*
- ISO/IEC JTC1/SC22 *Programming languages, their environments and system software interfaces*
- ISO/IEC JTC1/SC23 *Digitally recorded media for information interchange and storage*
- ISO/IEC JTC1/SC24 *Computer graphics, image processing and environmental data representation*
- ISO/IEC JTC1/SC25 *Interconnection of information technology equipment*
- ISO/IEC JTC1/SC27 *IT security techniques*
- ISO/IEC JTC1/SC29 *Coding of audio, picture, multimedia and hypermedia information*
- ISO/IEC JTC1/SC31 *Automatic identification and data capture techniques*
- ISO/IEC JTC1/SC32 *Data management and interchange*
- ISO/IEC JTC1/SC34 *Document description and processing languages*
- ISO/IEC JTC1/SC35 *User interfaces*
- ISO/IEC JTC1/SC36 *Information technology for learning, education and training*
- ISO/IEC JTC1/WG7 *Sensor networks*

- ITU-T/SG2 *Operational aspects*
- ITU-T/SG12 *Performance, QoS and QoE (quality of service, quality of experience)*
- ITU-T/SG13 *Future networks including mobile and NGN (next generation networks)*
- ITU-T/SG16 *Multimedia*
- ITU-T/SG17 *Security*
- CEN/TC 287 *Geographic information*
- CEN/TC 278 *Road transport and traffic telematics*
- CEN/ISSS *Workshop on metadata for multimedia information – Dublin Core*

ISO

ISO/TC 12: Quantities and units (presently no internal liaison with ISO/TC 211)
Working group relevant to geographic information

- Space and time (WG4).

ISO/TC 20: Aircraft and space vehicles
Subcommittee relevant to geographic information

- Space data and information transfer systems (SC13).

ISO/TC 23: Tractors and machinery for agriculture and forestry (presently no internal liaison with ISO/TC 211)
Subcommittee relevant to geographic information

- Agricultural electronics (SC19).

ISO/TC 37: Terminology and other language and content resources (presently no internal liaison with ISO/TC 211)

ISO/TC 42: Photography (presently no internal liaison with ISO/TC 211)
Working groups relevant to geographic information

- Electronic still picture imaging (WG18)
- Digital still cameras (JWG20, joint WG with IEC)
- Colour management (JWG22, joint WG with IEC/TC 100 and ISO/TC 130)
- Extended colour encoding for digital image storage, manipulation and interchange (WG23, joint with ISO/TC 130 and CIE).

Topics not mentioned in the working group names:

- Digital storage media
- Film scanners.

Other working groups and topics

- Photoflash units (WG2)
- Sensitometry, image measurement and viewing (WG3)
- Photographic chemicals and processing (WG6)
- Still projectors and transparencies (WG9)
- Photographic cameras
- Film (including aerial film).

ISO/TC 46: Information and documentation
Working groups relevant to geographic information

- Coding of country names and related entities (WG2).

ISO/TC 59: Buildings and civil engineering works
Subcommittee relevant to geographic information

- Organization of information about construction works (SC13).

ISO/TC 69: Application of statistical methods
Subcommittees relevant to geographic information

- Terminology and symbols (SC1).

Other Subcommittees

- Applications of statistical methods in process management (SC4)
- Acceptance sampling (SC5)
- Measurement methods and results (SC6)
- Applications of statistical and related techniques for the implementation of Six Sigma (SC7)
- Application of statistical and related methodology for new technology and product development (SC8).

ISO/TC 82: Mining (presently no internal liaison with ISO/TC 211)
Subcommittee relevant to geographic information

- Geological and petrographic symbols (SC1).

ISO/TC 130: Graphic technology (presently no internal liaison with ISO/TC 211)
Working groups relevant to geographic information

- Prepress data exchange (WG2)
- Process control and related metrology (WG3).

Topics not mentioned in the working group names

- TIFF/IT (TIFF for image technology)

- Color
- Proof and production prints
- Displays for color proofing
- PDF: CMYK, color managed workflows.

Other topics

- Printing ink
- Register pin systems
- Testing of prints and printing paper.

ISO/TC 154: Processes, data elements and documents in commerce, industry and administration
Working group relevant to geographic information

- Joint syntax working group (with UNECE) (joint WG1).

ISO/TC 171: Document management applications
Subcommittees relevant to geographic information

- Quality (SC1)
- Application issues (SC2)
- General issues (SC3)

ISO/TC 172: Optics and photonics
Subcommittees relevant to geographic information

- Geodetic and surveying instruments (SC6) (the only liaison member)
- Fundamental standards (SC1)
- Electrooptical systems (SC9) (laser).

Other subcommittees

- Optical materials and components (SC3)
- Telescopic systems (SC4)
- Microscopes and endoscopes (SC5)
- Ophthalmic optics and instruments (SC7).

ISO/TC 176: Quality management and quality assurance

ISO/TC 184: Automation systems and integration
Subcommittee relevant to geographic information

- Industrial data (SC4).

Topic not mentioned in the subcommittee name

- EXPRESS language.

ISO/TC 204: Intelligent transport systems
Working groups relevant to geographic information

- Architecture (WG1)
- Transport information and control system (TICS) database technology (WG3)
- General fleet management and commercial/freight (WG7)
- Public transport/emergency (WG8)
- Integrated transport information, management and control (WG9)
- Traveler information systems (WG10)
- Route guidance and navigation systems (WG11)
- Dedicated short range communication for TICS (WG15)
- Wide area communications/protocols and interfaces (WG16).

Topics not mentioned in the working group names

- Geographic Data Files (GDF)
- Onboard navigation system architecture
- Application interface definition for global navigation satellite
- Requirements for interactive centrally determined route guidance
- Intermodal goods transport.

Others working groups and topics

- Automatic vehicle and equipment identification (WG4)
- Fee and toll collection (WG5)
- Vehicle/roadway warning and control systems (WG14)
- Nomadic devices in ITS systems (WG17)
- Cooperative systems (WG18)
- Systems and cellular networks
- Lane departure warning systems
- Maneuvering aids for low-speed operation

ISO/TC 207: Environmental management
Subcommittees relevant to geographic information

- Environmental management systems (SC1)
- Environmental auditing and related environmental investigations (SC2)
- Environmental labelling (SC3)
- Environmental performance evaluation (SC4).

Others subcommittees

- Life cycle assessment (SC5)
- Greenhouse gas management and related activities (SC7).

ISO/TC 211: Geographic information/Geomatics

ISO/TC 241: Project committee: road traffic safety management system

SCIT: The ISO steering committee for image technology

The purpose of the SCIT is to coordinate activities of imaging standards projects in order to identify new work as early as possible and to optimize the use of resources for the development of new standards in image technology.

IEC
Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

IEC

IEC/TC 1: Terminology
(presently no internal liaison with ISO/TC 211)

IEC/TC 80: Maritime navigation and radiocommunication equipment and systems (presently no internal liaison with ISO/TC 211)
Working groups relevant to geographic information

- Global navigation satellite systems (GNSS) (WG4A)
- Electronic chart systems (WG7A).

Topics not mentioned in the working group names

- Decca, Omega, Loran C.

ISO JTC1 IEC
INFORMATION TECHNOLOGY STANDARDS

ISO/IEC JTC1

ISO/IEC JTC1/SC2: Coded character sets (presently no internal liaison with ISO/TC 211)

ISO/IEC JTC1/SC7: Software and systems engineering (presently no internal liaison with ISO/TC 211)
Working group relevant to geographic information

- Open distributed processing and modelling languages (WG19).

ISO/IEC JTC1/SC22: Programming languages, their environments and system software interfaces (presently no internal liaison with ISO/TC 211)
Working groups relevant to geographic information

- Fortran (WG5)
- C (WG14)
- C++ (WG21).

ISO/IEC JTC1/SC23: Digitally recorded media for information interchange and storage (presently no internal liaison with ISO/TC 211)

ISO/IEC JTC1/SC24: Computer graphics, image processing and environmental data representation
Working groups relevant to geographic information

- Multimedia presentation and interchange (WG6)
- Image processing and interchange (WG7)
- Environmental representation (WG8).

Topics not mentioned in the working group name

- Graphical Kernel System (GKS) (WG6)
- Programmer's Hierarchical Interactive Graphics System (PHIGS) (WG6)
- Portable network graphics (PNG) (WG6)
- Basic image interchange format (BIIF) (WG7).

Historical work items

- GKS-3D
- Computer graphics metafile
- Interface techniques for dialogs with graphical devices (CGI).

ISO/IEC JTC1/SC25: Interconnection of information technology equipment (presently no internal liaison with ISO/TC 211)
Working group relevant to geographic information

- Interconnection of computer systems and attached equipment (WG4).

Topics not mentioned in the working group names

- Characteristics of local area networks (LAN)
- Fiber Distributed Data Interface (FDDI)
- Small Computer System Interface (SCSI)

ISO/IEC JTC1/SC27: IT security techniques (presently no internal liaison with ISO/TC 211)

ISO/IEC JTC1/SC29: Coding of audio, picture, multimedia and hypermedia information (presently no internal liaison with ISO/TC 211)
Working groups relevant to geographic information

- Coding of still pictures (WG1)
- Coding of moving pictures and audio (WG11).

Topic not mentioned in the working group names

- JPEG 2000.

ISO/IEC JTC1/SC31: Automatic identification and data capture techniques
Working groups relevant to geographic information

- Radio frequency identification for item management (WG4)
- Real time locating systems (WG5)
- Mobile item identification and management (MIIM) (WG6)
- Security for item management (WG7).

ISO/IEC JTC1/SC32: Data management and interchange
Working group relevant to geographic information

- SQL/multimedia and application packages (WG4).

ISO/IEC JTC1/SC34: Document description and processing languages (presently no internal liaison with ISO/TC 211)
Topics not mentioned in the working group names

- Standard generalized markup language (SGML)
- HTML.

ISO/IEC JTC1/SC35: User interfaces (presently no internal liaison with ISO/TC 211)
Working groups relevant to geographic information

- Keyboards and input interfaces (WG1)
- Graphical user interface interaction (WG2)
- User interfaces for mobile devices (WG4)
- Cultural and linguistic adaptability (WG5)
- User interfaces accessibility (WG6).

ISO/IEC JTC1/SC36: Information technology for learning, education and training
Working groups relevant to geographic information

- Vocabulary (WG1)
- Supportive technology and specification integration (WG6).

ISO/IEC JTC1/WG7: Sensor networks
This new working group was approved in late 2009.

ITU

The relevant ITU-T study groups are mentioned in the brief listing at the beginning of Sect. 13.6 (presently no internal liaison with ISO/TC 211).

CEN/TC 287: Geographic information
Working group

- Spatial data infrastructure (WG5)

CEN/TC 278: Road transport and traffic telematics
Working groups relevant to geographic information

- Freight and fleet management systems (WG2)
- Public transport (WG3)
- Traffic and traveller information (WG4)
- Architecture and terminology (WG13)
- Road traffic data (WG8)
- Dedicated short range communication (WG9).

Others working groups and topics

- Electronic fee collection and access control (WG1)
- Man–machine interfaces (WG10)
- Automatic vehicle identification and automatic equipment identification (WG12)
- After theft systems for the recovery of stolen vehicles (WG14)
- eSafety (WG15)
- Cooperative systems (WG16).

CEN/ISSS: Workshop on metadata for multimedia information – Dublin Core

- Society standardization system (ISSS)

13.6.2 External Liaison Organizations to ISO/TC 211

Portrait of All (Status March 2011)

The work of standardization committees relies heavily on the expertise of organizations outside the usual standardization business. These organizations, known as *external liaison members*, are assigned to the technical committees of ISO or IEC according to the needs of a specific standards development project.

Even though the external liaison members of ISO/TC 211 are all international representatives of some kind of geographic information, they are different types of organization with different organizational structures. They might be categorized in the following way.

International organizations, representing

- Government agencies, e.g., IHO (hydrography) and the World Meteorological Organization (WMO) (weather)
- Scientific subjects, e.g., the International Association of Geodesy (IAG) (geodesy) and the International Federation of Surveyors (FIG) (surveying)
- Regional interests, e.g., the Joint Research Centre (JRC) (Europe) and the Permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIAP) (Asia, Pacific)
- Some tasks of the United Nations, e.g., the United Nations Group of Experts on Geographical Names (UNGEGN) (geographic names).

The following list is a complete summary of all current external liaison members of ISO/TC 211. Internet addresses are provided for further information.

As an introduction, a listing of all external liaison members is given in brief.

- CEOS/WGISS Committee on Earth Observation Satellites/Working Group on Information Systems and Services
- DGIWG Defence Geospatial Information Working Group

  Energistics

  EuroGeographics
- ESA European Space Agency
- EuroSDR European Spatial Data Research
- FAO/UN Food and Agriculture Organization of the United Nations
- GSDI Global Spatial Data Infrastructure
- GRSS IEEE Geoscience and Remote Sensing Society
- IAG International Association of Geodesy
- ICA International Cartographic Association
- ICAO International Civil Aviation Organization
- FIG International Federation of Surveyors
- IHO International Hydrographic Organization
- ISPRS International Society for Photogrammetry and Remote Sensing
- ISCGM International Steering Committee for Global Mapping
- JRC European Commission Joint Research Centre
- OGC Open Geospatial Consortium, Incorporated
- OGP International Association of Oil and Gas Producers
- OMG Object Management Group
- OASIS Organization for the Advancement of Structured Information Standards
- PAIGH Panamerican Institute of Geography and History
- PCGIAP Permanent Committee on GIS Infrastructure for Asia and the Pacific
- PCIDEA Permanent Committee on Spatial Data Infrastructure for the Americas
- SCAR Scientific Committee on Antarctic Research
- UN ECA United Nations Economic Commission for Africa
- UNECE United Nations Economical Commission for Europe, Statistical Division
- UNGIWG United Nations Geographic Information Working Group
- UNGEGN United Nations Group of Experts on Geographical Names
- UPU Universal Postal Union
- WMO World Meteorological Organization.

Committee on Earth Observation Satellites/Working Group on Information Systems and Services (CEOS/WGISS). CEOS is the primary international organization that provides a forum for coordination of the Earth observation (EO) programs of the world's space agencies. CEOS has also become the space component of the Global Earth Observation System of Systems

(GEOSS). WGISS is one of the three standing working groups of CEOS (the other two being the Working Groups on Calibration and Validation, and on Education, Training, and Capacity Building). WGISS aims to stimulate, coordinate, and monitor EO initiatives, thereby enabling users at global, regional, and local levels to exploit more effectively and benefit from data generated by EO satellites and other sources.

- Scope: In 1995, CEOS established the Working Group on Information Systems and Services (WGISS). It promotes collaboration in the development of systems and services that manage and supply Earth observation (EO) data to users worldwide.
- Objectives:
  - To enable EO data and information services to be more accessible and usable to data providers and data users worldwide through international coordination.
  - To enhance the complementarity, interoperability, and standardization of EO data and information management and services.
  - To foster easier exchange of EO data and information through networks and other means.
- Chair: Thailand
- Homepage: http://ceos.org/wgiss
- Members: 30 members and 20 associates
  Examples are: USGS and the National Oceanic and Atmospheric Administration (NOAA) (US), ESA (Europe), the Japan Aerospace Exploration Agency (JAXA) (Japan), the United Kingdom Space Agency (UKSA) (United Kingdom), the Centre National d'Études Spaciales (CNES) (France), the Canadian Space Agency (CSA) (Canada), Roskosmos (Russia), the Deutsches Zentrum für Luft- und Raumfahrt (DLR) (Germany), FAO (UN, Food and Agriculture Organization), ISPRS (photogrammetry and remote sensing), and the United Nations Environment Programme (UNEP).

Defence Geospatial Information Working Group (DGIWG). The DGIWG represents the experts on digital geographic information in the military agencies primarily of the NATO countries. It maintains the DIGEST geographic data exchange standard for vector data, raster data, and topological information.

ISO/TC 211 and DGIWG have signed a cooperative agreement according to which DGIWG publications or NATO standardization agreements (STANAGs) will be aligned with ISO or IEC deliverables.

- Objectives: Established in 1983, the DGIWG developed the Digital Geographic Information Exchange Standard (DIGEST) to support efficient exchange of digital geographic information among nations, data producers, and data users.
- Members: Australia, Belgium, Canada, Czech Republic, Denmark, France, Germany, Greece, Italy, The Netherlands, New Zealand, Norway, Portugal, Spain, Turkey, UK, USA
- Chair: UK
- Homepage: https://www.dgiwg.org/digest/Overview2.htm
- See also: ISO/TR 19120 *Functional standards*

Energistics. Energistics provides a noncompetitive, vendor-neutral infrastructure for the energy industry and performs the technical implementation, testing, and maintenance of all open standards.

- Objectives: The predecessor of Energistics was formed in October 1990 by five founding sponsor oil companies: BP, Chevron, Elf (since merged into Total), Mobil (since merged into ExxonMobil), and Texaco (since merged into Chevron) under the name Petrotechnical Open Software Corporation (POSC).
- Members: 111
- Chair: USA
- Homepage: http://www.energistics.org.

European Space Agency (ESA). The European Space Agency (ESA) bundles the space-related research, developments, and commercial activities of the European Union member countries.

- Objectives: Back in 1975, the ESA was founded by combining the activities of earlier and smaller organizations which had built the first European space activities since 1960. Structured as an intergovernmental organization of the European Union, the ESA is Europe's gateway to space.
- Members: Austria, Belgium, Czech Republic, Denmark, Finland, France, Germany, Greece, Ireland, Italy, Luxembourg, The Netherlands, Norway, Portugal, Romania, Spain, Sweden, Switzerland, UK
- Chair: France
- Homepage: http://www.esa.int.

EuroGeographics. Formed in 2001, EuroGeographics is an organization representing the European national mapping and cadastral agencies (NMCAs).

- Objectives:
  - promote NMCAs' national and pan-European products and services, and their role in providing the reference data for the European Spatial Data Infrastructure
  - create, maintain, and distribute harmonized, small- and medium-scale topographic reference datasets and related services to support immediate cross-border or pan-European customer requirements
- Members: 55 from 44 countries
- Chair: Belgium
- Homepage: http://www.eurogeographics.org/.

European Spatial Data Research (EuroSDR). EuroSDR is a European organization linking national mapping and cadastral agencies (NMCAs) with research institutes and universities for the purpose of applied research with a focus on photogrammetry and other image-based technologies. EuroSDR was founded in 1953 in Paris as the Organisation Européenne d'Études Photogrammétriques Expérimentales (OEEPE) in the frame of an international treaty.

- Scope: EuroSDR is active in many research fields. Some of them are: new platforms for remote sensing, camera certification, image radiometry, mobile mapping, imagery and LIDAR integration, virtual globes, data archiving, generalization, standards, INSPIRE implementation, image matching, and land cover.
- Meetings: Twice a year
- Members: 17 member states, each with a representative from an NMCA and a research organization
- Chair: France
- Homepage: http://www.eurosdr.net/.

Food and Agriculture Organization of the United Nations (FAO/UN). The Food and Agriculture Organization of the United Nations (FAO) was founded in 1945 with a mandate to raise levels of nutrition and standards of living, to improve agricultural productivity, and to improve the condition of rural populations. Today, the FAO is one of the largest specialized agencies in the United Nations system and the lead agency for agriculture, forestry, fisheries, and rural development.

- Objectives: the FAO gives practical help to developing countries; through a wide range of technical assistance, the FAO serves as a clearinghouse, providing farmers, scientists, government planners, traders, and nongovernmental organizations with the information they need to make rational decisions on planning, investment, marketing, research, and training.

  The FAO advises on national strategies for rural development, food security, and the alleviation of poverty.

- Members: 119 member countries
- Chair: Senegal; headquarters in Rome, Italy
- Homepage: http://www.fao.org.

Global Spatial Data Infrastructure (GSDI). The GSDI has members from all parts of the world, mainly organizations, companies, and universities. It focuses on communication and networking, capacity building, education, and scientific research.

- Objectives: The GSDI shall serve as a point of contact and effective voice for those in the global community involved in developing, implementing, and advancing spatial data infrastructure concepts and applications.
- Members:
  - Africa: United Nations Economic Commission for Africa
  - Australia: University of Melbourne
  - Austria: UNIGIS International Association
  - Canada: Compusult; Natural Resources Canada
  - Chile: Instituto Geográfico Militar de Chile
  - China: State Bureau of Surveying and Mapping of China
  - Croatia: State Geodetic Administration of Croatia
  - Bahrain: Central Informatics Organization of Bahrain
  - Belgium: KU Leuven
  - Europe: EuroGeographics; European Umbrella Organization for Geographic Information (EUROGI)
  - Finland: National Land Survey of Finland
  - Hungary: Hungarian Association for Geo-information
  - India: Department of Science and Technology of India; GIS Development Private Limited
  - Jamaica: Spatial Innovision Ltd.
  - Latin America: Latin America Development Bank; Pan American Institute of Geography and History (PAIGH)
  - Nepal: National Geographic Information Infrastructure Programme of Nepal
  - The Netherlands: Delft University of Technology; Dutch Kadaster, Geonovum; ITC International Institute for Geo-Information Science and Earth Observation
  - Nigeria: National Space Research and Development Agency of Nigeria
  - Poland: GISPOL – National Land Information System Users Association of Poland
  - Singapore: Singapore Land Authority
  - South Africa: EIS (Environmental Information System) AFRICA
  - Spain: Institut Cartográfic de Catalunya
  - Taiwan: Chinese Taipei GIS Center
  - United Arabic Emirates: Abu Dhabi Systems & Information Centre
  - USA: Columbia University, Environmental Systems Research Institute (Esri), Federal Geographic Data Committee; Intergraph; OpenGeo (a division of OpenPlans); OGC; Thermopylae Sciences and Technology; University of Maine
- Chair: Australia
- Homepage: http://www.gsdi.org.

IEEE Geoscience and Remote Sensing Society (GRSS). The fields of interest of the society are the theory, concepts, and techniques of science and engineering as they apply to the remote sensing of the Earth, oceans, atmosphere, and space, as well as the processing, interpretation, and dissemination of this information.

- Scope: The members of GRSS come from both engineering and scientific disciplines. Those with engineering backgrounds are often familiar with geophysics, geology, hydrology, oceanography, and/or meteorology. The fusion of geoscientific and engineering disciplines in projects of global scope give the GRSS a unique interdisciplinary character.

  The society was first known as the Geoscience Electronics Group, formed in 1962.
- Chair: Iceland
- Meetings: Since 1981 it has sponsored the annual International Geoscience and Remote Sensing Symposium (IGARSS) series.
- Homepage: http://www.grss-ieee.org/.

International Association of Geodesy

International Association of Geodesy (IAG). The International Union of Geodesy and Geophysics (IUGG) comprises eight semiautonomous associations, one of them being the International Association of Geodesy (IAG).

Geodesy supplies the reference systems for geographic information. As a science, geodesy measures the figure of the Earth, monitors the Earth's rotation, and determines the gravity field being required to build elevation reference systems.

- Members: 65
- Chair: Germany
- Homepage: http://www.iugg.org/associations/iag.php

International Cartographic Association (ICA). The ICA represents the cartographers of the world. The work of the society is presently focused on map design and dedicated maps for special user groups such as children and the blind. The ICA has about 100 national, institutional, and company members.

- Scope: The ICA is the world authoritative body for cartography, the discipline dealing with the conception, production, dissemination, and study of maps
- Objectives: The objectives are illustrated by the topics of the commissions: Cartography and Children, Digital Technologies in Cartographic Heritage, Education and Training, Generalization and Multiple Representation, Geospatial Analysis and Modeling, Geospatial Data Standards, Geovisualization, History of Cartography, Management and Economics of Map Production, Mapping from Satellite Imagery, Map Projections, Maps and Graphics for Blind and Partially Sighted People, Maps and Society, Maps and the Internet, Marine and Mountain Cartography, National and Regional Atlases, Planetary Cartography, Theoretical Cartography, Ubiquitous Mapping, Underrepresented Groups and Cartography, and Use and User Issues
- Members: National and affiliate members (institutions, companies)
- Meetings: International Cartographic Congress, every 2 years
- Chair: Australia
- Homepage: http://www.icaci.org.

International Civil Aviation Organization (ICAO). The ICAO is the organization that deals with all international civil aviation questions. The membership includes practically all the countries of the world. Aircraft navigation is the ICAO topic that generates the most interest in the standardization of geographic information.

- Scope: The ICAO sets standards and recommended practices for safe and orderly development of international civil aviation. The organization was founded in 1944 in Chicago. Its predecessor, the International Commission on Air Navigation (ICAN), was founded in 1910 in Paris.
- Members: 190 contracting states
- Meetings: Assembly meets at least once every 3 years
- Chair: Mexico; headquarters in Montreal, Canada
- Homepage: http://www.icao.int.

International Federation of Surveyors
Fédération Internationale des Géométres
Internationale Vereinigung der Vermessungsingenieure

International Federation of Surveyors (FIG). The FIG was founded in 1878 in Paris. It is a federation of national associations and is the only international body that represents all surveying disciplines.

- Scope: Surveyors are professional people who are enabled to advice on the management and use of both rural and urban land and property, whether developed or undeveloped. Surveyors understand the legislation governing land and property, markets, supporting services, and the economics of construction, management, maintenance, acquisition, and disposal. FIG aims to ensure that the disciplines of surveying and all who practice them meet the needs of the markets and communities that they serve.
  FIG is a UN-recognized nongovernment organization (NGO).
- Members: Representatives from more than 120 countries
- Meetings: Annual congresses
- Chair: Malaysia
- Homepage: http://www.fig.net.

International Hydrographic Organization (IHO). The IHO is an organization consisting of hydrographic agencies from most of the maritime countries around the world. One of their major efforts is the creation of international standards for digital hydrographical charts. For hydrographic charts, in order to promote and coordinate the development of standards, specifications and guidelines for official products and services, the International Hydrographic Organization established a Hydrographic Services and Standards Committee (HSSC), to monitor the requirements of mariners and other users of hydrographic products and information systems.

- Scope: The IHO is an intergovernmental consultative and technical organization that was established in 1921 to support safety in navigation and protection of the marine environment.
- Objectives:
  - Coordination of the activities of the national hydrographic offices
  - Greatest possible uniformity in nautical charts and documents
  - Adoption of reliable and efficient methods of carrying out hydrographic surveys
  - Development of the sciences in the field of hydrography and oceanography
- Members: 84 maritime states
- Meetings: International Hydrographic Conference every 5 years in Monaco
- Chair: Greece; International Hydrographic Bureau (IHB) in Monaco
- Homepage: http://www.iho.int/.

International Society for Photogrammetry and Remote Sensing (ISPRS). The ISPRS was the traditional international society for photogrammetry, later extending its scope to include remote sensing. The society primarily represents the engineering point of view, gathering all research on sensors (including their models) and on the mathematical models for derivation of spatial information from imagery. The ISPRS offers expertise on three-dimensional geographic information.

- Objectives: Photogrammetry and remote sensing is the art, science, and technology of obtaining reliable information from noncontact imaging and other sensor systems about the Earth and its environment. Established in 1910, the ISPRS promotes and coordinates research in the field of photogrammetry and remote sensing.
- Members: About 50 national societies and about 50 sustaining members
- Meetings: ISPRS congresses every 4 years, midterm symposia in between
- Chair: Turkey
- Homepage: http://www.isprs.org.

International Steering Committee for Global Mapping (ISCGM). The ISCGM, initiated by Japanese scientists, is a group that aims at global mapping to improve environmental protection and disaster management. The ISCGM was established in 1996 in Tsukuba, Japan.

- Objectives: The primary purpose of this committee is to examine measures to foster the development of global mapping to facilitate the implementation of global agreements and conventions for environmental protection. The ISCGM presently supports two online datasets:
  - The Global Land Cover by National Mapping Organizations (GLCNMO) contains data on a 1 km grid with 20 land cover items. The classification is based on the LCCS developed by the FAO.
  - The Global Percent Tree Cover represents the density of trees on the ground.
- Members: Participation from most countries of the world
- Chair: Japan
- Homepage: http://www.iscgm.org/cgi-bin/fswiki/wiki.cgi

Joint Research Centre of the European Union (JRC). The JRC is the research centre of the European Commission. The European Commission functions as the government of the European Union (EU). One of the seven laboratories of the JRC governs the creation of the European spatial data infrastructure (INSPIRE) and is located in Ispra, Italy.

- Scope: The JRC is the European Union's scientific and technical research laboratory and is an integral part of the European Commission. The JRC is a Directorate-General, providing the scientific advice and technical knowhow to support EU policies.
- Members: Directorate-General and 7 JRC Institutes
- Chair: France; Directorate-General in Brussels, Belgium
- Homepage: http://ec.europa.eu/dgs/jrc/.

Open Geospatial Consortium, Incorporated (OGC). The OGC is the worldwide leading consortium of GIS industries promoting the interoperability of geographic information across platforms, systems, and country borders. The main field of current activity is complete integration of the sources of geographic information based on the Internet.

- Scope: The OGC is an international industry consortium of more then 400 companies, government agencies, and universities participating in a consensus process to develop publicly available geoprocessing specifications. Open interfaces and protocols defined by open geospatial specifications support interoperable solutions that geo-enable web, wireless, and location-based services, mainstream IT, and empower technology developers to make complex spatial information and services accessible and useful with all kinds of applications. The primary goal is the provision of free and openly available standards to the market.
- Members: More than 400 companies, government agencies, and universities
- Chair: USA
- Homepage: http://www.opengeospatial.org.

A detailed discussion of the OGC follows in Sect. 13.7.

International Association of Oil and Gas Producers (OGP). The OGP is a UK-based association that works on behalf of the world's oil and gas exploration and production companies.

- Objectives:
  - To improve understanding of the oil and gas industry by being a visible, accessible, reliable, and credible source of information.
  - To undertake special projects and develop industry positions on critical issues affecting oil and gas exploration and production.
  - To represent and advocate the views of this industry
- Members: About 70 companies and national associations
- Chair: UK
- Homepage: http://www.ogp.org.uk/.

OMG

WE SET THE STANDARD

Object Management Group (OMG). Founded in 1989, the OMG is a computer industry consortium that develops standards related to many IT fields.

- Scope: OMG develops enterprise integration standards for a wide range of technologies, including: real-time, embedded and specialized systems, analysis and design, architecture-driven modernization, and middleware, business modeling and integration, finance, government, healthcare, legal compliance, life sciences research, manufacturing technology, robotics, software-based communications, and space
- Members: About 370 companies and universities, representing virtually every large organization in this field, smaller companies, and end-users
- Chair: USA
- Homepage: http://www.omg.org/.

OASIS

Advancing open standards for the information society

Organization for the Advancement of Structured Information Standards (OASIS). Founded in 1993, the OMG is a computer industry consortium that develops standards with a focus on web services.

- Scope: OASIS produces web services standards along with standards for security, e-business, and standardization efforts in the public sector and for application-specific markets.
- Members: Over 600 organizations and individual members in 100 countries
- Chair: USA
- Homepage: http://www.oasis-open.org/.

Pan American Institute of Geography and History (PAIGH). The Pan American Institute of Geography and History was created in 1928 in Havana, Cuba. It integrates cartography, geography, history, archeology, anthropology, as well as geophysics, and publishes a number of well-known journals, working mostly on behalf of Latin American countries.

- Members: Most countries in Latin America plus some overseas such as Spain
- Chair: Argentina; headquarters in Mexico
- Homepage: http://www.ipgh.org/english/.

Permanent Committee on GIS Infrastructure for Asia and the Pacific (PCGIAP). The PCGIAP is a regional organization for Asia and the Pacific that coordinates the activities of its member states in the field of geographic information. The major initiatives come from countries such as China, Australia, Japan, India, and Iran.

- Objectives: The aims of the Committee are to maximize the economic, social, and environmental benefits of geographic information by providing a forum for nations from Asia and the Pacific to:
  - cooperate in the development of a regional geographic information infrastructure,

  - contribute to the development of the global geographic information infrastructure,
  - share experiences and consult on matters of common interest, and participate in any other form of activity such as education, training, and technology transfer.
- Members: 56 nations
- Chair: China
- Homepage: http://www.pcgiap.org/.

Permanent Committee on Spatial Data Infrastructure for the Americas (PC IDEA) (Comité Permanente para la Infraestructura de Datos Geoespaciales de las Américas, CP IDEA). Initiated by Colombia, the PC IDEA is an organization of national agencies for mapping, cartography, and geographic information in Latin America including the USA and Canada. PC IDEA was established in the year 2000. The permanent committee operates within the principles of the 21st Agenda of the United Nations Conference on the Environment and Development in order to maximize the economic, social, and environmental benefits derived from the use of geospatial information, and the knowledge and exchange of experiences and technologies by the different countries, based on a common development model that permits the establishment of a geospatial data infrastructure in the region of the Americas.

- Objectives: The PC IDEA helps its member organizations to:
  - establish and coordinate the policies and technical rules for the development of a regional data infrastructure for the Americas,
  - stimulate the cooperation, investigation, complementation, and exchange of geographic information,
  - define strategies to help the member countries to build their cadastral system.
- Members: 24 national agencies for mapping, cartography, and geographic information
- Chair: Brazil
- Homepage: http://www.cp-idea.org/.

Scientific Committee on Antarctic Research (SCAR). The SCAR coordinates scientific activities regarding the Antarctic. One of their current projects is the creation of a spatial data model for the continent. The SCAR is an organization open to governmental and nongovernmental members.

- Objectives: SCAR has three standing scientific groups that are mainly responsible for:
  - Sharing information on disciplinary scientific research being conducted by national Antarctic programmes.
  - Identifying research areas or fields where current research is lacking.
- Members: 31 national polar research committees, 14 other members (associated members and international unions)
- Chair: USA
- Homepage: http://www.scar.org.

United Nations Economic Commission for Africa (UN ECA). In 1958 the United Nations (UN) established the Economic Commission for Africa (ECA) as one of the UN's five regional commissions. ECA's mandate is to promote the economic and social development of its member states, foster intraregional integration, and promote international cooperation for Africa's development.

- Objectives:
  - Regional integration, trade and infrastructure
  - Poverty reduction and growth, sustainable development, and gender
  - Promoting good governance and popular participation
  - Information and communication technology, science and technology for development
  - Statistics and statistical development
- Members: 54 member states (practically all of Africa)
- Chair: Gambia; headquarters in Addis Ababa, Ethiopia
- Homepage: http://www.uneca.org/.

UNECE

UNECE (United Nations Economical Commission for Europe) Statistical Division. UNECE's major aim is to promote pan-European economic integration, and it is one of the UN's five regional commissions.

- Scope: The area of expertise of the UNECE covers sectors such as economic cooperation and integration, energy, environment, housing and land management, gender, population, statistics, timber, trade, and transport.
- Members: 56 member states (Europe plus North America and Central Asia)
- Chair: Slovakia; headquarters in Geneva, Switzerland
- Homepage: http://www.unece.org/.

United Nations Geographic Information Working Group (UNGIWG). Formed in 2000, the UNGIWG is a working group that aims at building the UN Spatial Data Infrastructure.

- Objectives:
  - improve the efficient use of geographic information
  - promote standards for maps and other geospatial information
  - develop core maps to avoid duplication
  - build mechanisms for sharing, maintaining, and assuring the quality of geographic information
  - provide a forum for discussing common issues and emerging technological changes.
- Homepage: http://www.ungiwg.org/.

United Nations Group of Experts on Geographical Names (UNGEGN). The UNGEGN is a UN expert group that provides technical recommendations for the international spelling of geographic names.

- Scope: In 1959, the Economic and Social Council (ECOSOC) paved the way for a small group of experts to meet and provide technical recommendations on standardizing geographical names at the national and international levels.
- Chair: Canada
- Homepage: http://unstats.un.org/unsd/geoinfo/ungegn/

UPU UNIVERSAL POSTAL UNION

Universal Postal Union (UPU). Established in 1874, the Universal Postal Union (UPU), with its headquarters in Berne, Switzerland, is the second oldest international organization worldwide.

- Scope: The UPU helps to ensure a universal network of up-to-date products and services. In this way, the organization fulfills an advisory, mediating, and liaison role, and provides technical assistance where needed. It sets the rules for international mail exchanges and makes recommendations to stimulate growth in mail, parcel, and financial service volumes and improve quality of service for customers
- Member: 191 member countries
- Chair: France; headquarters in Berne, Switzerland
- Homepage: http://www.upu.int/

World Meteorological Organization (WMO). The WMO is the worldwide weather organization dealing with weather prediction, climate change, and related topics. The membership list of the WMO consists of almost all countries worldwide. The interest of the WMO in standardized digital geographic information is obvious.

- Scope: From weather prediction to air pollution research, climate change-related activities, ozone layer depletion studies, and tropical storm forecasting, the WMO coordinates global scientific activity to allow increasingly prompt and accurate weather information and other services for public, private, and commercial use, including international airline and shipping industries.
- Members: 189 member states and territories
- Chair: France; headquarters in Geneva, Switzerland
- Homepage: http://www.wmo.ch/

13.7 Open Geospatial Consortium

The Open Geospatial Consortium (OGC) is an international industry consortium dedicated to geospatial interoperability by instituting international consensus-based standards.

Its mission is

> *to serve as a global forum for the collaboration of developers and users of spatial data products and services, and to advance the development of international standards for geospatial interoperability.*

The stated goals are listed here.

- Goal 1 – Provide free and openly available standards to the market, tangible value to members, and measurable benefits to users.
- Goal 2 – Lead worldwide in the creation and establishment of standards that allow geospatial content and services to be seamlessly integrated into business and civic processes, the spatial web, and enterprise computing.
- Goal 3 – Facilitate the adoption of open, spatially enabled reference architectures in enterprise environments worldwide.
- Goal 4 – Advance standards in support of the formation of new and innovative markets and applications for geospatial technologies.
- Goal 5 – Accelerate market assimilation of interoperability research through collaborative consortium processes.

13.7.1 Background

The spirit and development process are different from the ISO approach in that the OGC primarily develops implementation specifications whereas the ISO standardizes abstract specifications at the top level.

Founded in 1994, the OGC evolved from the geographic resources analysis support system (GRASS) user community – the Open GRASS Foundation (OGF). GRASS was developed by the US Army Corps of Engineers Construction Engineering Research Laboratory (CERL) and used by several US Government agencies and universities around the world. As more and diverse GIS systems evolved, it was realized that the open data format espoused by the OGF was not providing an inclusive interoperable solution. On September 25, 1994 the OGC was founded to provide full interoperability for diverse geoprocessing systems communicating directly over networks using open interfaces based on the open geodata interoperability specification.

Today, the OGC has more than 400 members, representing the complete spectrum of players in the GIS marketplace. Their background ranges from system manufacturers across production companies and government agencies to universities and research laboratories. The membership type is split into four main categories: strategic, principle, technical, and associate (with six subcategories) (Figs. 13.141, 13.142).

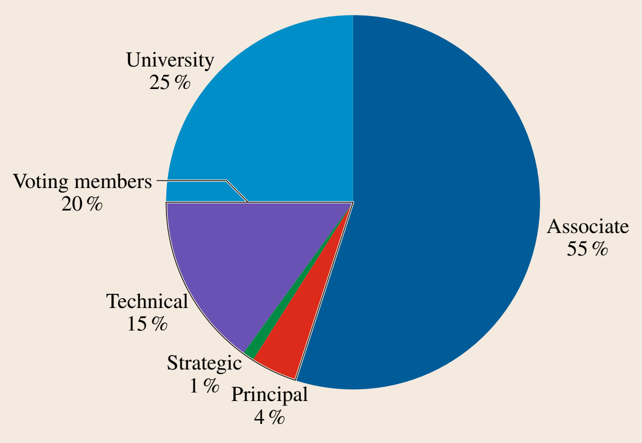


Fig. 13.141 OGC membership by level (as of April 2011)

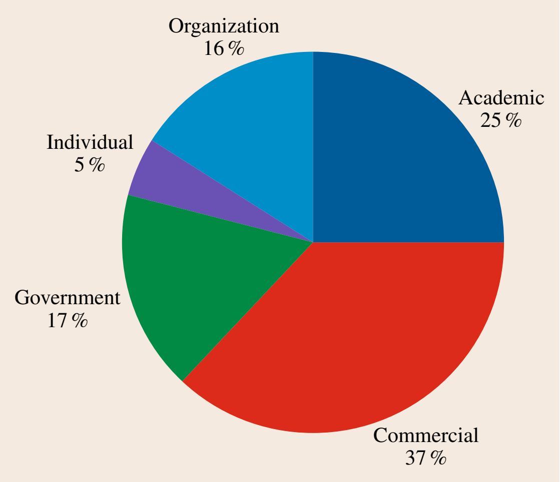


Fig. 13.142 OGC membership by sector (as of April 2011)

Table 13.32 List of strategic members of the open geospatial consortium (as of April 2011)

Company	Field of activity	Origin
Lockheed Martin	Space systems	USA
National Aeronautics and Space Administration (NASA)	Government/civilian	USA
National Geospatial-Intelligence Agency (NGA)	Government/defense	USA
Northrop Grumman	Electronics, IT, mission systems, ships, space systems	USA
United States Geological Survey (USGS)	Government/civilian	USA

Table 13.33 List of principle/principle plus members of the open geospatial consortium (as of April 2011)

Company	Field of activity	Origin
ERDAS Inc.	GIS products/services	USA, Sweden
PCI Geomatics Inc.	GIS products/services	Canada
BAE Systems – C3I Systems	GIS products/services	USA
Bentley Systems, Inc.	GIS products/services	USA
Department of Science & Technology	Government – civilian	India
EADS ASTRIUM	Imagery/services	Europe
Esri	GIS products/services	USA
Feng Chia University	University	Taiwan
GE Smallworld	GIS products/services	UK
Google	Information technology	USA
Intergraph Corporation	GIS products/services	USA
lat/lon GmbH	Open source	Germany
Oracle USA	Information technology	USA
Rolta India, Ltd.	GIS products/services	India
SAIC	Geographic services	USA
US Department of Homeland Security (DHS)	Government – civilian	USA
US National Oceanic and Atmospheric Administration (NOAA)	Government – civilian	USA

The annual fee is different for each category: strategic members US $ 250 000 (including fees and in-kind contributions), principal members US $ 55 000, technical members US $ 11 000, and associate members between US $ 4400, US $ 500, e.g., in the case of universities, to US $ 200 for municipal government members. In practice, the annual fee of strategic members is negotiable, because the fee is often paid by installing a working position at the staff level and/or by sponsoring larger implementation projects.

The OGC is registered as a not-for-profit corporation under Section 501(a) of the US Internal Revenue Code. Mark Reichardt is the President and Chief Executive Officer (CEO), and David Schell is Chairman of the Board of Directors (BOD). It has approximately 20 officers and staff. The BOD consists of 22 people, representing a variety of disciplines from around the world.

The OGC is managed by a hierarchical set of committees and boards governed by the President and CEO and the BOD (Figs. 13.141, 13.142).

1. The Strategic Member Advisory Committee consists of the strategic members and the OGC CEO. It recommends areas of strategic opportunity and resource strategies to support OGC program operations to the BOD, the OGC staff, and the membership. It also provides the Interoperability and Specification Programs with management and operational resources.
2. The planning committee is made up of strategic and principal members, the executive committee of the BOD, and two representatives of the technical committee, and is chaired by an OGC staff member. The planning committee performs strategic technology planning with regard to the geospatial standards which have the greatest chance of being adopted by the market. It ratifies specification development plans, release schedules, conformance and testing plans, and all major documents produced by the technical committee. It also elects the BOD and maintains the policy and procedures of the consortium.
3. The technical committee (TC) is made up of strategic, principal, and technical members, and is chaired by OGC staff. This is the committee where the standards are developed through a consensus process. All levels of membership can participate and provide input to developing documents, but technical committee members are the only members allowed to vote to approve standards and other major documents to be forwarded to the planning committee for final approval. The technical committee establishes the special interest groups, working groups, and subcommittees to perform the work of the consortium.
4. The OGC Architecture Board (OAB) is facilitated by the OGC Chief Technical Officer and one additional OGC staff and OGC technical committee representative, nominated and elected by the technical committee. The OAB provides guidance to the TC and PC regarding OGC lifecycle management. It reviews and recommends for adoption by the TC the OGC reference model, monitors technology trends related to the standards baseline, and identifies technology gaps and issues. It reviews all RFC submissions of candidate standards and provides guidance related to the technical content of existing OGC standards and best practices [13.132].

13.7.2 OGC Programs

The work in OGC is performed in three programs with different objectives (Fig. 13.143).

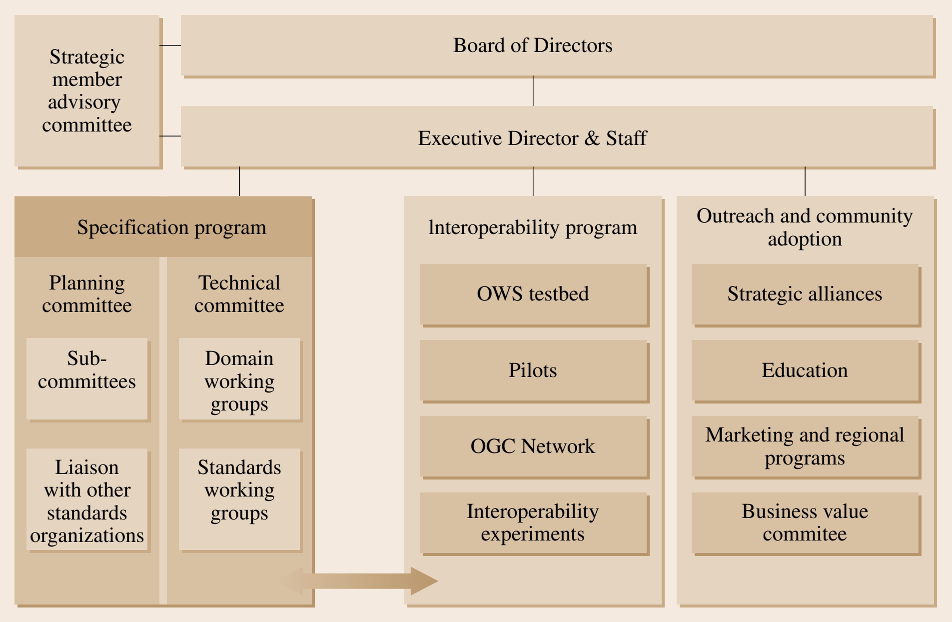


Fig. 13.143 OGC organization

The standards program is the program where the planning and technical committee and its working groups develop and approve the OGC standards and major documents. Its processes are described under the OGC standards development process below.

The interoperability program (IP) is a series of engineering initiatives, including interoperability testbeds, interoperability experiments, interoperability pilots, and the OGC network aimed at accelerating the development and acceptance of OGC specifications. The interoperability program has evolved into the OGC's main field of activity.

The OGC IP testbed [13.133] is a research and development activity to determine specification requirements and proofs of concept. Typically, sponsors with requirements work with the OGC IP team to develop a concept to determine and test specification requirements. This team develops and puts out a request for quotation/call for participation. Potential participants submit proposals, which are then reviewed, and participants are selected. Participants may be provided with partial funding, but are expected to also provide some in-kind contribution of resources. Some participants participate fully in-kind. The testbed usually follows an architecture developed by the sponsors and OGC IP team. Prototype proof-of-concept applications are developed. The outcome of these testbeds is a demonstration of concepts, what worked and what did not, and which specifications are required, as well as engineering reports (ERs), which are presented in the domain working groups (DWGs) and some of which are submitted through the request for comment (RFC)/standards working group (SWG) process to become standards. A testbed example is provided by the OGC Web Services Phase 8 (OWS-8), which consisted of four tracks.

- *Observation fusion:* refinement of a WCS Earth observation application profile and implementation of testing sensor web standards for detection, tracking, and bookmarking of moving objects in video
- *Geosynchronization:* Testing methods for the distribution of datasets and collections of datasets offline and over networks and web service components to support synchronization and updates of geospatial data across an SDI
- *Cross-community interoperability:* Testing semantic mediation approaches to query and use of data from different data models, use of style registries, services, and KML
- *Aviation:* Testing the delivery, filtering, and update of aeronautical information exchange model (AIXM) 5.1 using WFS-T/FE, use of coverage for encoding weather forecast and radar data, and reviewing and validating weather information exchange model (WXXM) schemas.

The testbed was sponsored by

- US National Geospatial-Intelligence Agency (NGA),
- US Geological Survey (USGS),
- US Army Geospatial Center (AGC),
- US Federal Aviation Administration (FAA),
- EUROCONTROL,
- US National Aeronautics and Space Administration (NASA),
- European Space Agency (ESA),
- UK Defence Science and Technology Laboratory (DSTL),
- Lockheed Martin, Corporation.

It involved 30 participating organizations, involving 160 individuals representing the sponsors and participants.

Interoperability experiments [13.134] (IEs) are an activity to further improve existing OGC standards, led and executed by OGC members and usually focusing on a specific domain, being facilitated by OGC staff. OGC charges US $ 2000 for this service. Any member of OGC can participate; all participation is in-kind there are no sponsored activities. These are usually short-duration activities, narrowly focusing on a single interoperability issue. An example of an IE is the geo-interface for atmosphere, land, Earth, and ocean netCDF (GALEON), which experimented with providing a geo-interface to netCDF datasets using the OGC WCS specification to provide open access to atmospheric and oceanographic modeling and simulation outputs. It also provided a test and comments/suggestions for future versions of the WCS specification. The initiators of the interoperability experiment were: Unidata/University Corporation for Atmospheric Research (UCAR), Institute of Methodologies for Environmental Analysis of the Italian National Research Council (IMAA-CNR), George Mason University, and the NASA Geospatial Interoperability Office.

Pilots [13.135] are run much like testbeds, except instead of developing and testing technology for new standards, they stress-test and perfect existing OGC standards or sets of standards, working toward improving the standard. Like testbeds, pilots have sponsors and issue Request for Quotation/Call for Participation (RFQ/CFP) to select applicants as participants which accept partial funding for their efforts. An example OGC pilot is the Group on Earth Observation System of System (GEOSS) architecture implementation pilot (AIP), which was an interoperability program to test OGC catalogue services specifications and improve access to data and services as well as to establish and test infrastructure components and OGC services for several GEOSS societal benefit areas such as disaster management, biodiversity and climate change, air quality and health, and renewable energy. GEO members and participating organizations provided components and services relevant to SBAs. They also participated in interoperability testing of the services to validate the architecture, and in the collaborative refinement of societal benefit scenarios to guide testing, demonstrations, and operations of interoperable services. The pilot was initiated by the group on Earth observations (GEO), a voluntary partnership of 148 governments and international organizations launched in response to calls for action by the 2002 World Summit on Sustainable Development and by the G8 (Group of Eight) leading industrialized countries.

OGC network [13.136] is an Internet-accessible infrastructure of components that implement OGC standards. It is a global registry of OGC-compatible services, a collaborative environment for OGC members and the public to see OGC standards in action and links to many resources to help developers work to develop OGC-compatible technology. It also provides a configuration-controlled XML schema registry.

The Outreach and Adoption Program (OCAP)

Standards are like products; they must be fit for purpose, perform as stated, maintained, and marketed. The outreach and adoption program is OGC's marketing arm. OCAP works with OGC members and user communities around the globe to encourage uptake of OGC standards. This program manages print publication, press releases, participation in conferences, and training. OCAP pursues discussion with industry sectors not represented in OGC as well as developing partnerships with professional societies and standards and geospatial technology promotion organizations.

13.7.3 The OGC Standards Development Process

The OGC has established a formal process for the development of standards and major documents. Work is performed in the technical committee and approved by the planning committee using a defined consensus-based voting procedure and a number of formalized document types including implementation specification (IS), best practice paper (BP), engineering report (ER), discussion paper (DP), white paper (WP), and request for comment (RFC). Only IS are officially approved OGC standards to be used to specify requirements in contacts and other official documents. A BP is an official position of the OGC endorsed by the membership and should not be used for contracting purposes. An ER is the output of an OGC interoperability program testbed and does not represent the official position of the OGC. They may contain specifications and requirements which often provide the foundation for the development of an OGC IS. An ER may also contain a report on the testbed results and a summary of the outcome. DPs are used to provide opinions to create discussion around technology issues and as such do not represent the official position of the OGC. WPs however do provide official positions of the OGC, but should not be treated as standards.

The work of the TC is performed in working groups. The SWG develops draft specifications, which are then approved by the technical committee membership. The domain working groups focus on domain-specific requirements and issue and review ERs and encourage or produce RFCs for new candidate standards. Once the DWG submits a document, intended to become a standard, to the TC, a SWG is formed, where work on the standard is performed. Access to work in the SWG is limited to individuals who have *opt-in* to repudiate intellectual property right claims to the future standard [13.137]. Voting in WGs is by simple majority of OGC members present at the WG meeting, with the caveat that no OGC member organization may cast more than one vote. Once the work of the SWG is finished, the candidate standard is released to the TC for a 60 day intellectual property rights (IPR) review and vote. Once approved by the TC, it is sent to the PC for final vote and publishing as an IS. An RFC can also go through a fast-track process where an accepted practice or standard developed by other groups can become an OGC standard, going straight to the TC, bypass-

Table 13.34 Domain working groups (DWGs) and working groups (WGs) of the OGC (as of April 2011)

Title	Chair
3DIM DWG	Tim Case
Architecture DWG	US Geological Survey
Aviation DWG	US Federal Aviation Administration
Catalogue SWG	US Geological Survey
CF-NetCDF SWG	National Center for Atmospheric Research (NCAR)
Coordinate reference system DWG	Blue Marble Geographics
CityGML SWG	UK Ordnance Survey
Coverages DWG	FORWISS (Bavarian Research Centre for Knowledge-Based Systems)
Data preservation DWG	North Carolina State University
Data quality DWG	Blue Marble Geographics
Decision support DWG	Intergraph Corporation
Defense and intelligence DWG	NGA
Earth system science DWG	Ecosystem research
ebRIM AP of CSW SWG	ERDAS, Inc.
ebXML RegREp SWG	ERDAS, Inc.
Emergency & disaster management DWG	OGC
GeoAPI SWG	GEOMATYS
Geographic linkage service SWG	GeoConnections – Natural Resources Canada
GML DWG	Galdos Systems, Inc.
GML SWG	interactive instruments
Geometry DWG	Oracle
GeoSPARQL SWG	OGC
GeoSynchronization SWG	CubeWerx
Geo rights management (GeoRM) DWG	Beuth Hochschule für Technik Berlin
GeoXACML	Technische Universität München, Dept. of Informatics
GMLJP2 SWG	Galdos Systems Inc.
Geosemantics DWG	Traverse Technologies
Hydrology DWG	CSIRO
Open location services SWG	MAGIC Services Forum
Mass market geo DWG	Google
Metadata DWG	Esri
Meteorology and oceans DWG	UK Met Office
Oblique imagery DWG	Lockheed Martin
Open GeoSMS SWG	Industrial Technology Research Institute
Ordering services for Earth observation products SWG	European Space Agency
OWS common SWG	SeiCorp, Inc.
OWS context SWG	National Geospatial-Intelligence Agency
PubSub SWG	International Geospatial Services Institute GmbH
PUCK SWG	Monterey Bay Aquarium Research Institute
Security DWG	Universität der Bundeswehr
Sensor web enablement SWG	Botts Innovative Research
Sensor model language SWG	Botts Innovative Research
Sensor observation service	52 North Initiative for Geospatial Open Source Software GmbH
Simple features SWG	Oracle
Style layer descriptor and symbology encoding SWG	School of Business & Engineering Vaud
SWE common SWG	EADS ASTRIUM

Table 13.34 (continued)

Title	Chair
University DWG	Open Grid Forum
WaterML SWG	OGC
WCS SWG	Jacobs University Bremen GmbH
Web mapping service	ESRI
Web processing service SWG	Universität Münster – Institute for Geoinformatics
Web feature service DWG	Computer Aided Development Corp. Ltd
Web feature service gazetteer profile SWG	USGS
Workflow DWG	Intergraph Corporation

ing the SWG process. All standards are the property of OGC [13.138].

Presently, the OGC has the DWGs and SWGs (Table 13.34).

13.7.4 OGC Standards

The vision of the OGC is a world in which everyone benefits from geographic information and services that are made available across any network, application, or platform. Through the tremendous efforts of the OGC in the past, some of the visionary developments, such as web mapping, have made considerable progress. OGC standards fall into two categories: abstract specifications and implementation specifications. Originally, the concept of the OGC specification program was aimed at building a complete suite of GIS standards. Today, this ambitious goal has been unofficially modified towards a focus on implementations specifications. The work on the abstract specification has become the concern of ISO/TC 211 *Geographic information/Geomatics*. Some of the original OGC abstract specifications have become ISO standards.

OGC Abstract Standards

OGC abstract standards [13.139] provide the conceptual foundation for OGC standards. By basing OGC implementation standards on an architecture of abstract standards which have been harmonized with other standards in the fields of information technology and geographic information such as the W3C and ISO/TC 211 ensures proper reuse, integration, and harmonization within the OGC implementation standards and those of the other standards bodies.

Topic 1: Feature Geometry. This abstract standard [13.140] specifies conceptual schemas for describing the spatial characteristics of geographic features, and a set of spatial operations consistent with these schemas. It treats vector geometry and topology up to three dimensions. It defines standard spatial operations for use in access, query, management, processing, and data exchange of geographic information for spatial (geometric and topological) objects of up to three topological dimensions embedded in coordinate spaces of up to three axes. This topic is identical to ISO 19107 *Spatial schema*.

Topic 2: Spatial Referencing by Coordinates. This abstract specification [13.141] defines the conceptual schema for the description of spatial referencing by coordinates, optionally extended to spatiotemporal referencing. It describes the minimum data required to define one-, two-, and three-dimensional spatial coor-

Table 13.35 OGC abstract standard – ISO equivalent standards

OGC abstract standard	ISO international standard
Topic 1 Feature geometry	ISO 19107 Spatial schema
Topic 2 Spatial referencing by coordinates	ISO 19111 Spatial referencing by coordinates
Topic 6 Schema for coverage geometry and functions	ISO 19123 Schema for coverage geometry and functions
Topic 7 Earth imagery	ISO/TS 19101-2 Reference Model – Part 2 – Imagery
Topic 11 Metadata	ISO 19115 Metadata
Topic 12 The OpenGIS service architecture	ISO 19119 Services
Topic 20 Observations and measurements	ISO 19156 Observations and measurements

Table 13.36 Coordinate location system examples

Locational coordinates	Meaning of coordinates
(x, y, z)	where x, y, and (optionally) z are real numbers (abstract geometry coordinates)
(long, lat, elev)	where longitude, latitude, and (optionally) elevation are geographic coordinates (world coordinates)
(n, x)	where n is a segment ID and x is the linear offset along the segment from the origin of the segment (linear reference coordinates)
(r, c)	where r and c are (perhaps integer or real) row and column coordinates (image or raster coordinates)
(E, N)	where E and N (Easting and Northing) are real numbers (map coordinates)

dinate reference systems with an extension to merged spatiotemporal reference systems. It allows additional descriptive information to be provided. It also describes the information required to change coordinates from one coordinate reference system to another. It has been developed in collaboration with ISO 19111.

Topic 3: Locational Geometry Structures. Locational geometry [13.142] provides essential and abstract models for technology that is used widely across the GIS landscape. Its first heavy use is in support of simple feature geometry specifications and their spatial reference systems. It provides a discussion of the notion of locational geometry. The scenario of this discussion assumes that the same project world has been (or is to be) implemented (that is, abstracted into a feature collection) twice, using two different locational systems. A locational system is a mathematical construct providing coordinates for each corner of interest. The coordinates are usually scalars, but could be values from another domains. Examples are provided in Table 13.36.

Topic 4: Stored Functions and Interpolation. This topic [13.143] provides essential and abstract models in support of coverage specifications. Coverages, in general, require two stored functions. The first relates Earth coordinates to the window coordinates in the coverage extent, providing a mapping from the coordinates of a spatial reference system (SRS) to the coverage extent coordinates. The second function assigns values to points in the coverage extent. The values may be thought of as colors, as this is a common value space. However, the values could be temperatures, a scalar representing fitness of habitat for songbirds, the name of the owner of the parcel containing the point, and so on, defined by a schema and taking the schema mapping and taking values in the schema range.

Topic 5: Features. This abstract standard [13.144] introduces the concept and discusses the essential model for features that have been defined in ISO 19101 and an extensive primer on the notion of geographic information. It defines the abstract model for feature, feature identifier, identifier scope, identifier change registry, feature repository, and feature collection.

Topic 6: Schema for Coverage Geometry and Functions. This abstract standard [13.145] defines a conceptual schema for the spatial characteristics of coverages. Coverages support mapping from a spatial, temporal, or spatiotemporal domain to feature attribute values where feature attribute types are common to all geographic positions within the domain. A coverage domain consists of a collection of direct positions in a coordinate space that may be defined in terms of up to three spatial dimensions as well as a temporal dimension. This abstract standard was developed in collaboration with ISO/TC 211 and is identical to ISO 19123 *Coverages*.

Topic 7: Earth Imagery. This abstract specification [13.146] defines a reference model for standardization in the field of geographic imagery. This reference model identifies the scope of the standardization activity being undertaken and the context in which it takes place. The scope includes gridded data with an emphasis on imagery. Although structured in the context of information technology and information technology standards, this technical specification is independent of any application development method or technology implementation approach.

Topic 8: Relationships Between Features. Topic 5 of the abstract specification introduces features, an abstraction of the entities in the real world. Entities in the real world do not exist in isolation. Typically, an entity in the real world is related to other real-world entities in a variety of ways. This topic [13.147] introduces an abstraction for the relationships between entities in the real world.

Topic 10: Feature Collections. A feature collection is an abstract object consisting of feature instances, their feature schema, and project schema. This document [13.148] discusses the need (or not) for these concepts, and how feature collections can be used.

Topic 11: Metadata. This topic [13.149] refers to ISO 19115 *Metadata*, which defines a comprehensive metadata schema that is used to fully describe geographic resources. Minimum metadata may be used in resource catalogs and portals for discovery purposes, or comprehensive metadata can be used to support a complete understanding of resources, allowing them to be used properly to their full potential.

Topic 12: The OpenGIS Service Architecture. This abstract standard [13.150] identifies and defines architecture patterns for service interfaces used for geographic information and to explain the relationship to the open systems environment model. It presents a geographic services taxonomy and a list of example geographic services placed in the services taxonomy. It also prescribes how to create a platform-neutral service specification, and how to derive platform-specific service specifications that are conformant with this. The standard provides guidelines for the selection and specification of geographic services from both platform-neutral and platform-specific perspectives. It is identical to ISO 19119 *Services*.

Topic 13: Catalogue Services. This abstract standard [13.151] covers geospatial information access services, which include geospatial information retrieval services, geospatial product information services, and geospatial catalogue services. This topic thus covers OGC services for both data discovery and data access. It defines the term "catalogue" to describe the set of service interfaces which support organization, discovery, and access of geospatial information. Catalogue services help users or application software to find information that exists anywhere in a distributed computing environment. A catalogue can be thought of as a specialized database of information about geospatial resources available to a community of users. These resources are assumed to have OGC feature, feature collection, catalogue, and metadata interfaces, or they may be geoprocessing services. Catalogs assist in the organization and management of diverse geospatial data and services for discovery and access; support discovery of resource information from diverse sources and gather it into a single, searchable location; and provide a means of locating, retrieving, and storing the resources indexed by the catalogue.

Topic 14: Semantics and Information Communities. This abstract specification [13.152] provides the essential model to permit interoperability across information communities. An information community is a collection of people (a government agency or group of agencies, a profession, a group of researchers in the same discipline, corporate partners cooperating on a project, etc.) who, at least part of the time, share a common digital geographic information language and share common spatial feature definitions; for example, if each information community has a fixed vocabulary, a fixed collection of schemas, and an unambiguous set of feature instances, a difference in vocabulary, say the use of "house" versus "dwelling", will inhibit interoperability. This abstract specification provides an essential model to overcome these differences and enable each to be able to share information with the other as if they were native.

Topic 15: Image Exploitation Services. This topic volume [13.153] describes the categories and taxonomy of image exploitation services needed to support the use of images and certain related coverage types. Image exploitation services are required to support most aspects of image exploitation, including precision measurement of ground positions and of object dimensions; for example, a variety of services are needed for extracting features from images, or digital elevations from stereoscopic images. Image exploitation services are widely implemented and used in photogrammetric systems, currently using custom interfaces. Although the focus of this document is on services for using images, many of these services are also applicable to using other types of grid coverages and some nongrid coverages.

Topic 16: Image Coordinate Transformation Services. This topic [13.154] covers image coordinate conversion services; that is, this part of the abstract specification describes services for transforming image position coordinates to and from ground position coordinates. These services might alternatively be called *image geometry model services*.

Topic 17: Location-Based Services. This topic [13.155] covers location-based/mobile services; that is, this part of the abstract specification describes services that take advantage of mobility and the position or relative position of devices and points, lines, or polygons of service. Important concepts are location, route, and types of service.

Topic 18: Geospatial Digital Rights Management Reference Model. This abstract standard [13.156] is a reference model for Digital Rights Management (DRM) functionality for geospatial resources (GeoDRM). As such, it is connected to the general DRM market in that geospatial resources must be treated as nearly as possible like other digital resources, such as music, text, or services.

Topic 20: Observations and Measurements. This abstract standard [13.157] defines a conceptual schema for observations, and for features involved in sampling when making observations. It provides models for the exchange of information describing observation acts and their results, both within and between different scientific and technical communities. Observations commonly involve sampling of an ultimate feature of interest. This abstract standard defines a common set of sampling feature types classified primarily by topological dimension, as well as samples for ex situ observations. The schema includes relationships between sampling features (subsampling, derived samples).

OGC Implementation Standards [13.158]

OpenGIS Implementation Specification for Geographic information – Simple Feature Access – Part 1: Common Architecture. Simple feature application programming interfaces (APIs) [13.159] provide for publishing, storage, access, and simple operations on simple features (point, line, polygon, multi point, etc.). The purpose of these specifications is to describe interfaces to allow GIS software engineers to develop applications that expose functionality required to access and manipulate geospatial information comprising features with simple geometry using different technologies. This part of OpenGIS simple features access (SFA) describes the common architecture for simple feature geometry. It is identical to ISO 19125-1. The simple feature geometry object model is distributed computing platform neutral and is provided using UML notation. The base geometry class has subclasses for Point, Curve, Surface and GeometryCollection. Each geometric object is associated with a spatial reference system, which describes the coordinate space in which the geometric object is defined. The extended geometry model has specialized zero-, one-, and two-dimensional collection classes named MultiPoint, MultiLineString, and MultiPolygon for modeling geometries corresponding to collections of Points, LineStrings, and Polygons, respectively. MultiCurve and MultiSurface are introduced as abstract superclasses that generalize the collection interfaces to handle curves and surfaces. The object model for geometry is shown in Fig. 13.110. This part of OGC simple feature access implements a profile of the spatial schema described in ISO 19107:2003 *Geographic information – Spatial schema*. A detailed mapping of the schema in SFA to the schema described in ISO 19107:2003 is provided.

The three OpenGIS simple features implementation specifications (one each for object linking and embedding component object model (OLE/COM), Common Object Broker Architecture (CORBA), and SQL) define interfaces that enable transparent access to geographic data held in heterogeneous processing systems on distributed computing platforms.

OpenGIS Implementation Specification for Geographic Information Simple Feature Access – Part 2: SQL Option. This second part of OpenGIS simple features access (SFA) [13.160] defines a SQL schema that supports storage, retrieval, query, and update of feature collections via the SQL call-level interface (SQL/CLI) (ISO/IEC 9075-3:2003). It is identical to ISO 19125-2. A feature has both spatial and nonspatial attributes. Spatial attributes are geometry valued, and simple features are based on two or fewer dimensional geometric (point, curve, and surface) entities in two or three spatial dimensions with linear or planar interpolation between vertices. This standard is dependent on the common architectural components defined in part 1 of this standard.

In a SQL implementation, a collection of features of a single type are stored as a *feature table*, usually with some geometry-valued attributes (columns). Each feature is primarily represented as a row in this feature table, and described by that and other tables logically linked to this base feature table using standard SQL techniques. The nonspatial attributes of features are mapped onto columns whose types are drawn from the set of SQL data types, potentially including SQL3 user-defined types (UDT). The spatial attributes of features are mapped onto columns whose types are based on the geometric data types for SQL defined in this standard and its references. Feature-table schemas are described for two sorts of SQL implementations: implementations based on a more classical SQL relational model using only the SQL predefined data types, and SQL with additional types for geometry. In any case, the geometric representations have a set of SQL-accessible routines to support geometric behavior and query.

In an implementation based on predefined data types, a geometry-valued column is implemented using a *geometry ID* reference into a geometry table. A geometry value is stored using one or more rows in a single geometry table, all of which have the geometry ID as part of their primary key. The geometry table may be implemented using standard SQL numeric types or SQL binary types; schemas for both are described in this standard.

The term "SQL with geometry types" is used to refer to a SQL implementation that has been extended with a set of geometry types. In this environment, a geometry-valued column is implemented as a column whose SQL type is drawn from this set of geometry types. The mechanism for extending the type system of an SQL implementation is through the definition of user-defined types. Commercial SQL implementations with user-defined type support have been available since mid-1997, and an ISO standard is available for UDT definition. This standard does not prescribe a particular UDT mechanism, but specifies the behavior of the UDTs through a specification of interfaces that must be supported. These interfaces are described for SQL3 UDTs in ISO/IEC 13249-3.

OpenGIS Simple Features Implementation Specification for CORBA. The purpose of this specification [13.161] is to provide interfaces to allow GIS software engineers to develop applications that expose functionality required to access and manipulate geospatial information comprising features with *simple* geometry using OMG's CORBA technology.

Common object request broker architecture (CORBA) provides a specification for object-oriented distributed systems in a language, operating system, platform, and vendor independent way. It has no ISO equivalent and is not much used in recent years.

OpenGIS Simple Features Implementation Specification for OLE/COM. This specification [13.162] is based on use of the object linking and embedding, database (OLE DB) and ActiveX data objects (ADO) facilities for accessing data using Microsoft technology. As an OLE/component object model (COM)-based standard, current Microsoft technologies for database access are described with respect to geographic information processing. These technologies included open database connectivity (ODBC), data access object (DAO), remote data objects (RDO), ADO, and OLE DB. ADO specifically provides the OLE automation object-oriented standards for accessing and manipulating databases. This specification addresses the unique requirement of GIS-specific interfaces above and beyond the current interfaces available through current Microsoft data access technologies.

OpenGIS Web Map Service (WMS) Implementation Specification. This standard [13.163] defines the behavior of a service that dynamically produces spatially referenced maps from geographic information. It specifies operations to retrieve a description of the maps offered by a server to retrieve a map, and to query a server about features displayed on a map. It is applicable to pictorial renderings of maps in a graphical format; it is not applicable to retrieval of actual feature data or coverage data values.

A WMS produces maps of spatially referenced data dynamically from geographic information. It defines a *map* to be a portrayal of geographic information as a digital image file suitable for display on a computer screen. A map is not the data itself. WMS-produced maps are generally rendered in a pictorial format such as PNG, graphics interchange format (GIF), or JPEG, or occasionally as vector-based graphical elements in scalable vector graphics (SVG) or web computer graphics metafile (WebCGM) formats.

The WMS standard defines three operations: one returns metadata about the service; another returns a geographically referenced map; and an optional third operation returns information about individual features shown on the map. Web map service operations can be initiated using a standard web browser by submitting requests in the form of uniform resource locators (URLs). The content of such URLs depends on which operation is providing the request. In particular, when requesting a map, the URL indicates what information is to be shown on the map, what portion of the Earth is to be mapped, the desired coordinate reference system, and the output image width and height. When two or more maps are produced with the same geographic parameters and output size, the results can be accurately overlaid to produce a composite map. The use of image formats that support transparent backgrounds (e.g., GIF or PNG) allows overlaid maps to be rendered translucent, revealing the map below. Furthermore, individual maps can be requested from different servers. WMS thus enables the creation of a network of distributed map servers from which clients can build customized maps.

OpenGIS Styled Layer Descriptor (SLD) Profile of the WMS Implementation Specification. The styled layer

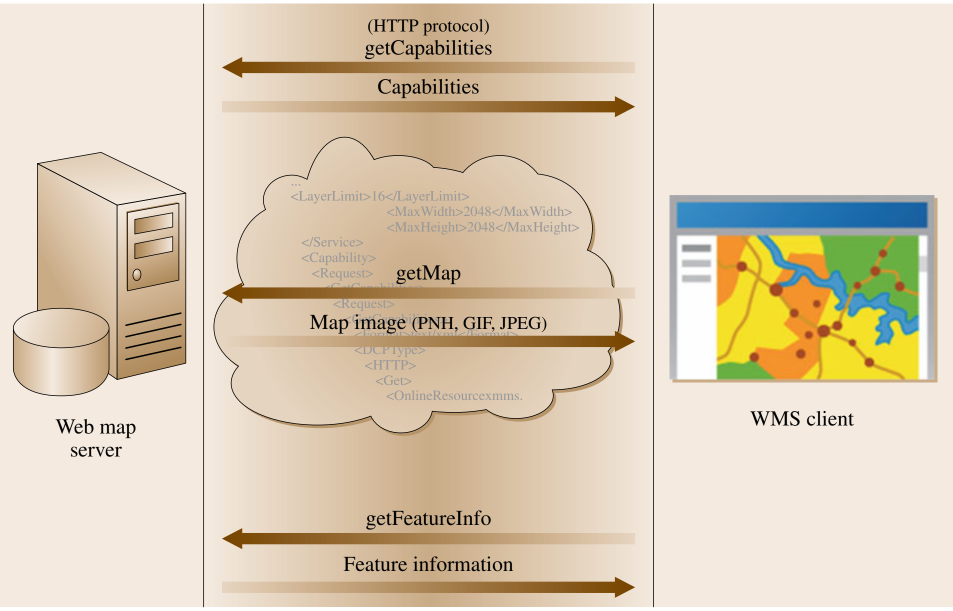


Fig. 13.144 Web map service operations

descriptor (SLD) profile of the WMS encoding standard [13.164] defines an encoding that extends the WMS standard to allow user-defined symbolization and coloring of geographic feature and coverage data. SLD addresses the need for users and software to be able to control the visual portrayal of the geospatial data. The ability to define styling rules requires a styling language that both the client and server can understand. The OpenGIS symbology encoding standard (SE) provides this language, while the SLD profile of WMS enables application of SE to WMS layers using extensions of WMS operations. Additionally, SLD defines an operation for standardized access to legend symbols.

OpenGIS Symbology Encoding (SE) Implementation Specification. This specification [13.165] specifies the format of a map styling language for producing georeferenced maps with user-defined styling. This language can be used to portray the output of WMS, WFS,

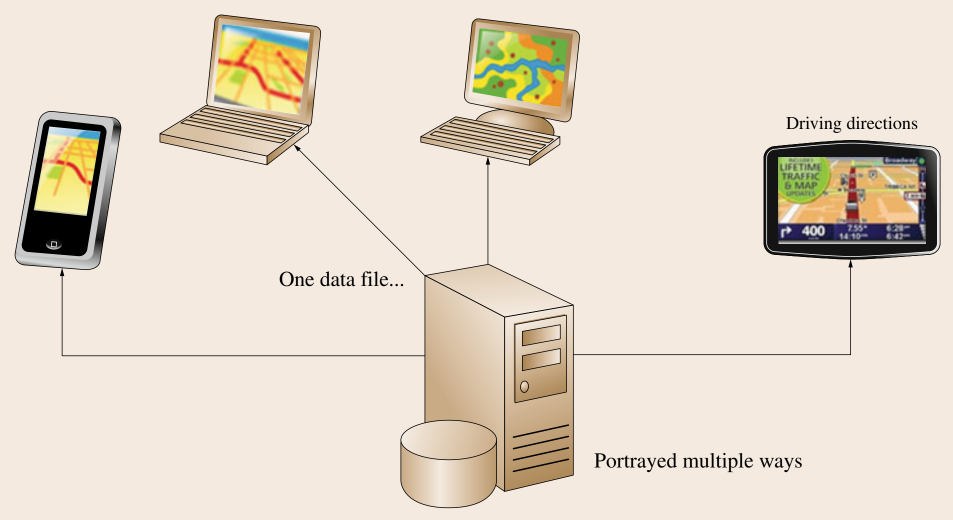


Fig. 13.145 Style layer descriptor

and web coverage servers (WCS). It defines an XML encoding that can be used for styling feature and coverage data. These styles apply either to specific feature types or coverage types, depending on the used data type. Symbology encoding includes the FeatureTypeStyle and CoverageStyle root elements. These elements include all information for styling the data such as filter and different kinds of symbolizers. As symbology encoding is a grammar for styling map data independent of any service interface specification, it can be used flexibly by a number of services that style georeferenced information or store styling information that can be used by other services.

OpenGIS Web Map Context Implementation Specification. This specification [13.166] applies to the creation and use of extensible markup language (XML)-encoded documents which unambiguously describe the state, or context, of a WMS client application in a manner that is independent of a particular client and that might be utilized by different clients to recreate the application state. The specification is a companion specification to the OGC WMS implementation specification. WMS specifies how individual map servers describe and provide their map content. The present context specification states how a specific grouping of one or more maps from one or more map servers can be described in a portable, platform-independent format for storage in a repository or for transmission between clients. This description is known as a web map context document, or simply a context. A context document includes information about the server(s) providing layer(s) in the overall map, the bounding box and map projection shared by all the maps, sufficient operational metadata for client software to reproduce the map, and ancillary metadata used to annotate or describe the maps and their provenance for the benefit of human viewers.

The specification contains an XML schema against which context XML can be validated.

There are several possible uses for context documents.

- The context document can provide default startup views for particular classes of user. Such a document would have a long lifetime and public accessibility.
- The context document can save the state of a viewer client as the user navigates and modifies map layers.
- The context document can store not only the current settings but also additional information about each layer (e.g., available styles, formats, SRS, etc.) to avoid having to query the map server again once the user has selected a layer.
- The context document could be saved from one client session and transferred to a different client application to start up with the same context.
- Contexts could be cataloged and discovered, thus providing a level of granularity broader than individual layers.

OpenGIS Web Map Tile Service (WMTS) Implementation Standard. This standard [13.167] provides digital maps using predefined image tiles. The service advertises the tiles it has available using a declaration in the service metadata. This declaration defines the tiles available in each layer in each graphical representation style, in each format, in each coordinate reference system, at each scale, and over each geographic fragment of the total covered area. The service metadata document also declares the communication protocols and encodings through which clients can interact with the server. Clients can use the service metadata document to request specific tiles. WMTS complements the existing web map service standard. The WMS standard focuses on flexibility in the client request, enabling clients to obtain exactly the final image they want. A WMS client can request that the server create a map by overlaying an arbitrary number of the map layers offered by the server, over an arbitrary geographic bound, with an arbitrary background color, at an arbitrary scale, and in any supported coordinate reference system. The client may also request that the map layers be rendered using a specific server-advertised style or even using a style provided by the client when the WMS server implements the OGC SLD standard. However, all this flexibility comes at a price: server image processing must deal with some number of connected clients, and there is only limited potential to cache images between the server and client, since most images are different.

As web service clients have become more powerful, it has become possible to consider an alternative strategy which forces the clients to perform image overlays themselves and which limits the clients to requesting map images which are not at exactly the right position, thereby forcing the clients to mosaic the tiles obtained from the server and clip the set of tiles into a final image. This restriction of image requests to a fixed, predefined set allows for servers to be limited based on communication processing abilities rather than image processing abilities, because servers can prerender some or all of their images

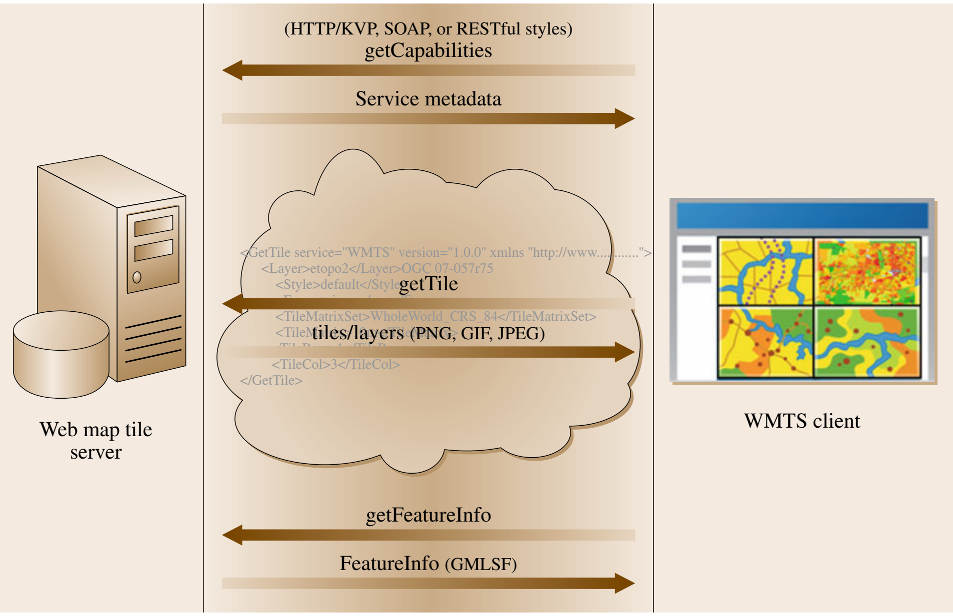


Fig. 13.146 Web map tile operations

and can use image caching strategies. The fixed set of images also enables network providers to cache images between the client and the server, reducing latency and bandwidth use. Popular, nonstandardized, commercial implementations of this approach, such as Google Maps, Microsoft Virtual Earth, and Yahoo! Maps, have already shown that there are clear performance benefits to adopting this methodology. The WMTS offers an approach to declaring the images which a client can request from a server, enabling a single type of client to be developed for all servers. The standard specifies WMTS in two stages. First, an abstract specification describes the semantics of the resources offered by the servers and requested by the client. This abstract definition specifies the semantics of the ServiceMetadata document, of the Tile images or representations, and of the optional FeatureInfo documents providing descriptions of the maps at specific locations. Second, the standard specifies several different concrete exchange mechanisms between clients and servers in two different architectural styles. The standard defines the GetCapabilities, GetTile and optional GetFeatureInfo operations for procedure-oriented architectural style-based approaches using several different message encodings, including messages encoded using key–value pairs (KVP), XML messages, or XML messages embedded in Simple Object Access Protocol (SOAP) envelopes. The standard also defines a representational state transfer (REST) request mechanisms and endpoint publishing strategy to enable a resource-oriented architectural style based on web-based URL endpoints (RESTful), allowing clients to simply request the service metadata, Tile, and FeatureInfo resources as documents.

OpenGIS WFS Implementation Specification. This standard [13.168] defines how a web service describes, queries/filters, and delivers geographic features. It specifies a service that provides transactions on and access to geographic features in a manner independent of the underlying data store. Features are described and streamed to the client using GML. The standard supports

- discovery functions which allow a service to be interrogated to determine its capabilities and to retrieve the application schema that defines the feature types that the service offers,
- query functions which allow features or values of feature properties to be retrieved from the underlying data store based upon constraints, defined by the client, on feature properties,
- locking functions which allow exclusive access to features for the purpose of modifying or deleting features,
- transaction functions which allow features to be created, changed, replaced, and deleted from the underlying data store,

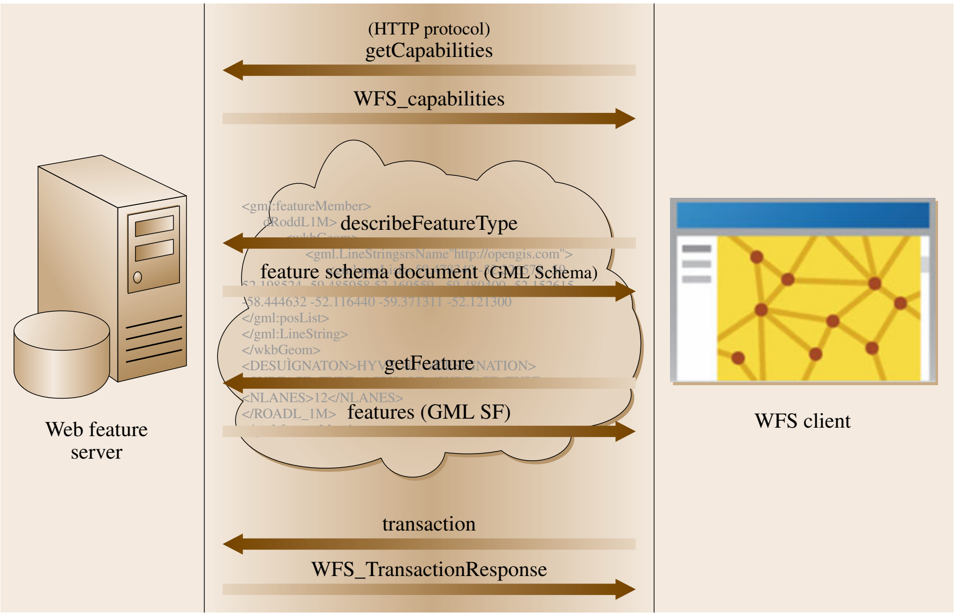


Fig. 13.147 Web Feature Service operations

- stored query functions which allow clients to create, drop, list, and describe parameterized query expressions that are stored by the server and can be repeatedly invoked using different parameter values.

The WFS standard defines the following operations.

- GetCapabilities (discovery operation)
- DescribeFeatureType (discovery operation)
- GetPropertyValue (query operation)
- GetFeature (query operation)
- GetFeatureWithLock (query and locking operation)
- LockFeature (locking operation)
- Transaction (transaction operation)
- CreateStoredQuery (stored query operation)
- DropStoredQuery (stored query operation)
- ListStoredQueries (stored query operation)
- DescribeStoredQueries (stored query operation).

OpenGIS Filter Encoding (FE) 2.0 Encoding Standard. This standard [13.169] defines the encoding of expressions which support the querying/filtering of usually large data stores to produce a subset of data that contains just the desired information. It describes an XML and key–value pair (KVP) encoding of a system-neutral syntax for expressing projections, selection, and sorting clauses collectively, called a query expression. These components are modular and intended to be used together or individually by services described in other standards. The standard defines an abstract component, named AbstractQueryExpression, from which other specifications can subclass concrete query elements to implement query operations. The XML representation is easily validated, parsed, and transformed into a server-specific language required to retrieve or modify object instances stored in an object store, e.g., a large data store of geographic features.

The FE standard defines the XML encoding for the following predicates (sets of computational *operations* applied to a data instance which evaluate to true or false).

- A standard set of logical predicates: and, or, and not.
- A standard set of comparison predicates: equal to, not equal to, less than, less than or equal to, greater than, greater than or equal to, like, is null, and between.
- A standard set of spatial predicates: equal, disjoint, touches, within, overlaps, crosses, intersects, contains, within a specified distance, beyond a specified distance, and BBOX.
- A standard set of temporal predicates: after, before, begins, begun by, contains, during, ends, equals, meets, met by, overlaps, and overlapped by.

- A predicate to test whether the identifier of an object matches the specified value (Sect. 13.4.6).

OpenGIS Web Coverage Service (WCS) Implementation Standard. This document [13.170] specifies a web service for delivering multidimensional coverage data over the World Wide Web. This version is limited to describing and requesting grid (or simple) coverages. Grid coverages provide digital geospatial information representing space-varying phenomena for regularly spaced locations along zero, one, two, or three axes of a spatial coordinate reference system. Coverages may also have a time dimension, which may be regularly or irregularly spaced. A coverage defines, at each location in the domain, a set of fields that may be scalar valued (such as elevation) or vector valued (such as brightness values for specific bands of the electromagnetic spectrum). These fields (and their values) are known as the range of the coverage. A WCS provides access to potentially detailed and rich sets of geospatial information, in forms that are useful for client-side rendering, multivalued coverages, and input into scientific models and other clients. Where the WMS provides static images, and the WFS provides streams of feature data, the web coverage service: provides detailed descriptions of the data available from a server; defines a rich syntax for requests against these data; and returns coverage data which may be interpreted, extrapolated, etc., and not just portrayed. The web coverage service provides three operations: GetCapabilities, DescribeCoverage, and GetCoverage. The GetCapabilities operation returns an XML document describing the service and brief descriptions of the available coverages that clients may request. Clients would generally run the GetCapabilities operation and cache its result for use throughout a session, or reuse it for multiple sessions. When the GetCapabilities operation does not return such descriptions, then equivalent information must be available from a separate source, such as an image catalogue. The DescribeCoverage operation lets clients request a full description of one or more coverages served by a particular WCS server. The server responds with an XML document that fully describes the identified coverages.

The GetCoverage operation is normally run after GetCapabilities and DescribeCoverage operation responses have shown what requests are allowed and what data are available. The GetCoverage operation returns a coverage (that is, values or properties of a set of geographic locations), encoded in a well-known coverage format.

OGC Web Service Common Implementation Specification. This document [13.171] specifies many of the behaviors that may be common to many OGC web service standards. The behaviors specified by OWS common currently include

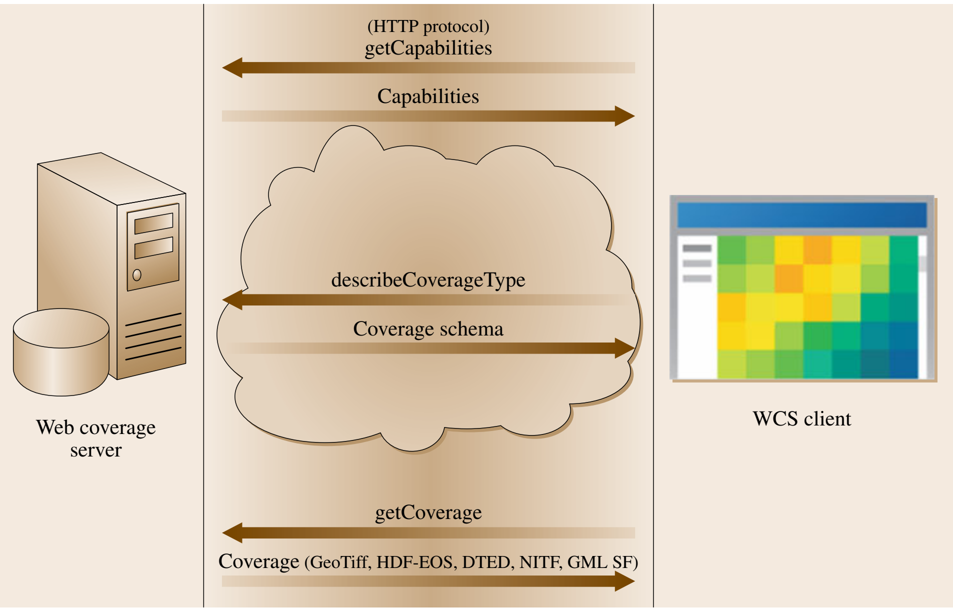


Fig. 13.148 Web coverage service operations

1. operation request and response contents,
2. parameters and data structures included in operation requests and responses,
3. XML and KVP encoding of operation requests and responses.

This standard will be used to specify common behaviors used in many versions of OGC web service standards. Rather than continuing to repeat this material, each specification should normatively reference relevant parts of OWS common. This document will serve as a normative reference for future versions of OGC web services including the WMS, WFS, and WCS. It is presently only used by the WCS (2.0) and the WMTS.

Web Processing Service (WPS). WPS [13.172] defines a standardized interface that facilitates the publishing of geospatial processes, and the discovery of and binding to the discovered processes by clients. Processes include any algorithm, calculation, or model that operates on spatially referenced data. Publishing means making available machine-readable binding information as well as human-readable metadata that allows service discovery and use. A WPS can be configured to offer any sort of GIS functionality to clients across a network, including access to preprogrammed calculations and/or computation models that operate on spatially referenced data. A WPS may offer calculations as simple as subtracting one set of spatially referenced numbers from another (e.g., determining the difference in influenza cases between two different seasons), or as complicated as a global climate change model. The data required by the WPS can be delivered across a network, or available at the server. This interface specification provides mechanisms to identify the spatially referenced data required by the calculation, initiate the calculation, and manage the output from the calculation so that the client can access it. This web processing service is targeted at processing both vector and raster data. The WPS specification is designed to allow a service provider to expose a web-accessible process, such as polygon intersection, in a way that allows clients to input data and execute the process with no specialized knowledge of the underlying physical process interface or API. The WPS interface standardizes the way processes and their inputs/outputs are described, how a client can request the execution of a process, and how the output from a process is handled. Because WPS offers a generic interface, it can be used to wrap other existing and planned OGC services that focus on providing geospatial processing services.

Instead, it specifies a generic mechanism that can be used to describe and web-enable any sort of geospatial process. To achieve interoperability, each process must be specified in a separate document, which might be called an application profile of this specification. This document does not specify any specific data required or output by the WPS. Instead, it identifies a generic mechanism to describe the data inputs required and produced by a process. This data can be delivered across the network, or available at the server. This data can include image data formats such as GeoTIFF, or data exchange standards such as GML. Data inputs can be legitimate calls to OGC web services; for example, a data input for an intersection operation could be a polygon delivered in response to a WFS request, in which case the WPS data input would be the WFS query string. This document does not address the archival, cataloguing, discovery, or retrieval of information that has been created by a WPS.

OpenGIS GML Encoding Standard. GML [13.173] is an XML grammar for expressing geographical features. GML serves as a modeling language for geographic systems as well as an open interchange format for geographic transactions on the Internet. As with most XML-based grammars, there are two parts to the grammar: the schema that describes the document and the instance document that contains the actual data. A GML document is described using a GML schema. This allows users and developers to describe generic geographic datasets that contain points, lines, and polygons. However, the developers of GML envision communities working to define community-specific application schemas that are specialized extensions of GML. Using application schemas, users can refer to roads, highways, and bridges instead of points, lines, and polygons. If everyone in a community agrees to use the same schemas, they can exchange data easily and be sure that a road is still a road when they view it. Clients and servers with interfaces that implement the WFS read and write GML data. GML is also an ISO standard (ISO 19136:2007) (Sect. 13.5.6).

OpenGIS City Geographic Markup Language (CityGML) Encoding Standard. This document [13.174] is an encoding standard for the representation, storage, and exchange of virtual 3-D city and landscape models. CityGML is implemented as an application schema of the GML version 3.1.1 (GML3). CityGML models both complex and georeferenced 3-D vector data along with the semantics associated with the data. In con-

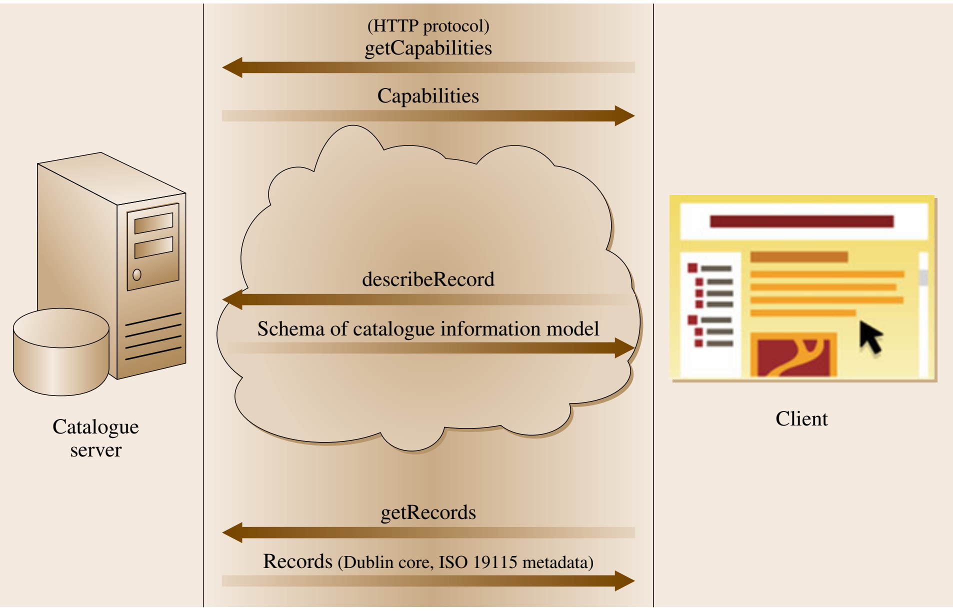


Fig. 13.149 Catalogue service web application protocol operations

trast to other 3-D vector formats, CityGML is based on a rich, general-purpose information model in addition to geometry and appearance information. For specific domain areas, CityGML also provides an extension mechanism to enrich the data with identifiable features enhancing of semantic interoperability.

OpenGIS GML in JPEG 2000 for Geographic Imagery Encoding Specification. This standard [13.175] defines the means by which the GML is used within JPEG 2000 images for geographic imagery. The standard also provides packaging mechanisms for including GML within JPEG 2000 data files and specific GML application schemas to support the encoding of images within JPEG 2000 data files. JPEG 2000 is a wavelet-based image compression standard that provides the ability to include XML data for description of the image within the JPEG 2000 data file.

OpenGIS Catalogue Service Implementation Specification. This standard [13.176] specifies the interfaces, bindings, and a framework for defining application profiles required to publish and access digital catalogues of metadata for all types of geospatial resources: imagery, raster and vector data, services, studies, etc. Metadata provides the resource properties that can be queried and returned through catalogue services for evaluation and, in many cases, direct activation or retrieval of the referenced resource. Catalogue services support the use of one of several identified query languages to find and return results using well-known content models (metadata schemas) and encodings. The standard defines a general catalogue interface model and three application protocols: Z39.50 protocol binding, CORBA/IIOP (Internet Interobject) protocol binding, and Hypertext Transfer Protocol (HTTP) binding referred to as catalogue services for the web (CS-W) (Fig. 13.149). It also specifies the concept of harvesting, in which metadata records are harvested across the web and pulled into a catalogue.

OGC maintains several application profiles of the catalogue services standard, each using a different information model: the base CSW using the Dublin Core information model; CSW-ebRIM Registry Service – Part 1: ebRIM profile of CSW; OpenGIS catalogue services specification – ISO metadata application profile; FGDC CSDGM application profile for CSW (a best practice); and OGC catalogue services standard extension package for ebRIM application profile: Earth observation products.

OGC KML. Google's KML (formerly keyhole markup language) version 2.2 [13.177] has been adopted as an OGC implementation standard. KML is an XML language focused on geographic visualization, including annotation of maps and images. Geographic visualization includes not only the presentation of graphical data on the globe, but also the control of the user's navigation in the sense of where to go and where to look.

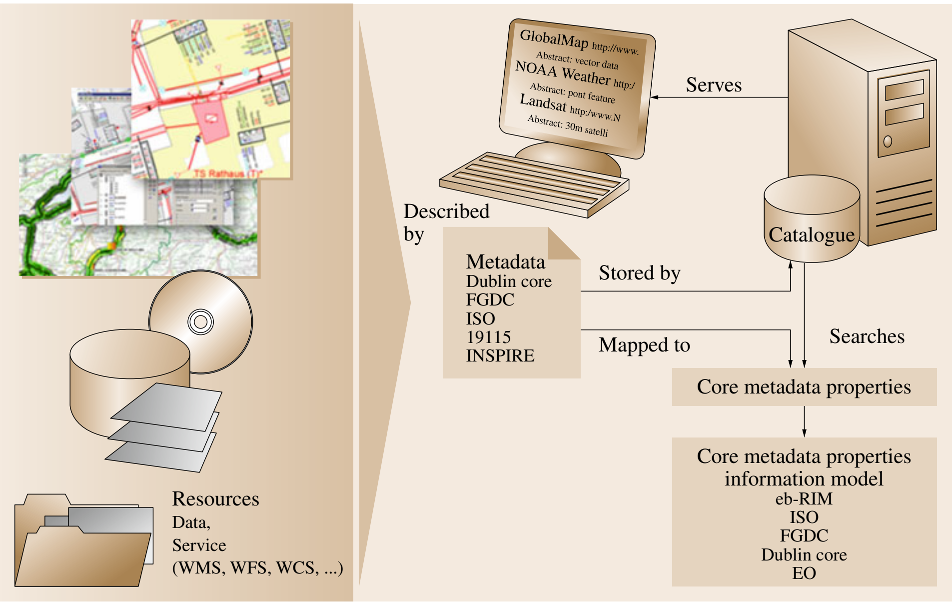


Fig. 13.150 CSW serving metadata based on different information models

Currently, KML 2.2 utilizes certain geometry elements derived from GML 2.1.2. These elements include point, line string, linear ring, and polygon.

OpenGIS Location Service (OpenLS) Implementation Specification. This standard [13.178] specifies interfaces that enable companies in the location-based services (LBS) value chain to *hook up* and provide their pieces of applications such as emergency response (E-911, for example), personal navigator, traffic information service, proximity service, location recall, mobile field service, travel directions, restaurant finder, corporate asset locator, concierge, routing, vector map portrayal and interaction, friend finder, and geography voice-graphics (spoken directions). These applications are enabled by interfaces that implement OpenLS services such as a directory service, gateway service, geocoder service, presentation (map portrayal) service, and others (Chap. 21).

OpenGIS Coordinate Transformation Service Implementation Specification. This standard [13.179] provides a way for software to specify and access coordinate transformation services for use on specified spatial data. It addresses a key requirement for overlaying views of geodata (*maps*) from diverse sources, namely the ability to perform coordinate transformation in such a way that all spatial data are defined relative to the same spatial reference system.

OpenGIS Geographic Objects Implementation Specification. This standard [13.180] provides an open set of common, lightweight, language-independent abstractions for describing, managing, rendering, and manipulating geometric and geographic objects within an application programming environment. It provides both an abstract object standard (in UML) and a programming-language-specific profile (in Java). The language-specific bindings serve as an open application program interface (API).

OpenGIS Geospatial Extensible Access Control Markup Language (GeoXACML) Encoding Standard. This standard [13.181] defines a geospatial extension to the OASIS standard extensible access control markup language (XACML) [13.182]. This extension incorporates spatial data types and spatial authorization decision functions based on the OGC simple features and GML standards. GeoXACML is a policy language that supports the declaration and enforcement of access rights across jurisdictions and that can be used to implement interoperable access control systems for geospatial applications such as spatial data infrastructures.

OGC Network Common Data Form (NetCDF) Core Encoding Standard. This document [13.183] specifies the network common data form (netCDF) core standard and extension mechanisms. The OGC netCDF encoding supports electronic encoding of geospatial data, specifically digital geospatial information representing space- and time-varying phenomena. NetCDF is a data model for array-oriented scientific data. A freely distributed collection of access libraries implementing support for that data model and a machine-independent format are available. Together, the interfaces, libraries, and format support the creation, access, and sharing of multidimensional scientific data.

Observations and Measurements – XML Implementation. This standard [13.184] specifies an XML implementation of the observations and measurements (O&M) conceptual model (OGC observations and measurements v2.0, also published as ISO/DIS 19156), including a schema for sampling features. This encoding is an essential dependency for the OGC sensor observation service (SOS) interface standard. More specifically, this standard defines XML schemas for observations, and for features involved in sampling when making observations. These provide document models for the exchange of information describing observation acts and their results, both within and between different scientific and technical communities.

OGC SWE Common Data Model Encoding Standard. This standard [13.185] defines low-level data models for exchanging sensor-related data between nodes of the OGC SWE framework. These models allow applications and/or servers to structure, encode, and transmit sensor datasets in a self-describing and semantically enabled way.

OpenGIS SWE Service Model Implementation Standard. This standard [13.186] currently defines eight packages with data types for common use across OGC (SWE) services. Five of these packages define operation request and response types. The packages are: (1) Contents – Defines data types that can be used in specific services that provide (access to) sensors; (2) Notification – Defines the data types that support provision of metadata about the notification capabilities of a service as well as the definition and encoding of SWE service events; (3) Common – Defines data types common to other packages; (4) Common codes – Defines commonly used lists of codes with special semantics; (5) DescribeSensor – Defines the request and response types of an operation used to retrieve metadata about a given sensor; (6) UpdateSensorDescription – Defines the request and response types of an operation used to modify the description of a given sensor; (7) InsertSensor – Defines the request and response types of an operation used to insert a new sensor instance at a service; (8) DeleteSensor – Defines the request and response types of an operation used to remove a sensor from a service.

OpenGIS Sensor Model Language (SensorML). This standard [13.187] specifies models and XML encoding that provide a framework within which the geometric, dynamic, and observational characteristics of sensors and sensor systems can be defined. There are many different sensor types, from simple visual thermometers to complex electron microscopes and Earth-observing satellites. These can all be supported through the definition of atomic process models and process chains. Within SensorML, all processes and components are encoded as application schema of the Feature model in the GML. This is one of the OGC SWE suite of standards.

OpenGIS Sensor Observation Service (SOS). The SOS [13.188] provides an API for managing deployed sensors and retrieving sensor data and specifically *observation* data. Whether from in situ sensors (e.g., water monitoring) or dynamic sensors (e.g., satellite imaging), measurements made from sensor systems contribute most of the geospatial data by volume used in geospatial systems today. This is one of the OGC SWE suite of standards.

OGC Sensor Planning Service Implementation Standard (SPS). This standard [13.189] defines interfaces for queries that provide information about the capabilities of a sensor and how to task the sensor. The standard is designed to support queries that have the following purposes: to determine the feasibility of a sensor planning request; to submit and reserve/commit such a request; to inquire about the status of such a request; to update or cancel such a request; and to request information about other OGC Web services that provide access to the data collected by the requested task. This is one of the OGC SWE suite of standards.

OpenGIS Georeferenced Table Joining Service (TJS) Implementation Standard. This OGC standard [13.190] defines a simple way to describe and exchange tabular data that contains information about geographic objects. It standardizes an interface definition for and applies to the creation and use of a table joining service (TJS). It includes the definition of all TJS requests and responses, including the specification of the geographic data attribute set (GDAS) encoding format using XML. This standard does not address the archival, cataloging, discovery, or retrieval of GDAS or other TJS XML documents. TJS offers a way to expose this type of data to other computers, so that it can be found and accessed, and a way to merge that data with other spatial data that provides a framework, to enable mapping or geospatial analysis. Tabular data to be exchanged via TJS must include a geographic identifier. The geographic identifier refers to a spatial feature found in a separate geospatial dataset. In order to join tabular data to another dataset, both datasets must contain the same geographic identifier (i. e., key field). An example of such tabular data is a collection of population counts by city. The table includes the city name, but does not include any other geographic identifier. The city names can be used to join the population data to a layer in a GIS that contains the spatial coordinates for each city, in order to map the information or perform some sort of geospatial analysis.

TJS includes two related sets of operations. Tabular data are served on the network by implementing the GetData and related operations. The response to a GetData operation is an XML file, in a format known as geographic data attribute set (GDAS). Tabular data is ingested at some other node on the network by a TJS configured to support the JoinData and related operations. These operations allow a computer to join tabular data in GDAS format into a local spatial framework dataset. This local dataset can then be used to provide maps via a WMS, or served up through some other mechanism that provides access to the joined data.

OpenGIS Transducer Markup Language (TML) Encoding Specification. This standard [13.191] specifies an application and presentation layer communication protocol for exchanging live streaming or archived data (i. e., control data) and/or sensor data from any sensor system. A sensor system can be one or more sensors, receivers, actuators, transmitters, and processes. A TML client can be capable of handling any TML-enabled sensor system without prior knowledge of that system. The protocol contains descriptions of both the sensor data and the sensor system itself. It is scalable, consistent, unambiguous, and usable with any sensor system incorporating any number of sensors and actuators. It supports the precise, spatial and temporal alignment of each data element. It also supports the registration, discovery, and understanding of sensor systems and data, enabling users to ignore irrelevant data. It can adapt to highly dynamic and distributed environments in distributed net-centric operations. The sensor system descriptions use common models and metadata, and they describe the physical and semantic relationships of components, thus enabling sensor fusion. This is one of the OGC SWE suite of standards.

OpenGIS Web Coverage Processing Service (WCPS) Language Interface Standard. This standard [13.192] defines a protocol-independent language for the extraction, processing, and analysis of multidimensional gridded coverages representing sensor, image, or statistics data. Services implementing this language provide access to original or derived sets of geospatial coverage information, in forms that are useful for client-side rendering, input into scientific models, and other client applications.

OGC Implementation Standards Classification

While most ISO/TC 211 and OGC abstract standards cover the basics of geographic information such as spatial and temporal schemas, features and coverages, and coordinate reference systems, OGC implementation standards currently cover five additional categories: data management, encoding, web services, location-based services, and sensor-related standards. Figure 13.151 provides a classification structure for these standards. Some fall into multiple categories; SensorML is an encoding standard, but since it is narrowly focused on sensors, it has been placed in the "Sensor Web" category, whereas GML in a broadly focused encoding standard and is classified in the "Encoding" category.

13.7.5 Relation of the OGC to ISO/TC 211

The OGC and ISO/TC 211 *Geographic information/Geomatics* were established almost simultaneously in the early 1990s. Both were aimed at international standardization of geographic information, and both accomplished it with different backgrounds in tradition and thinking. The OGC started primarily as a mainly US-based industry-oriented consortium. ISO/TC 211 was proposed by Canada in order to link the European traditions with work in other parts of the world. The OGC has grown to become a global consortium (Fig. 13.152), focused on the efficient development of joint solutions among the members of the consortium, while the goal of ISO standards is long-term, generic solutions developed through democratic participation of all interested parties.

The concurrent development of two independent suites of standards in the same domain is not feasible for practical solutions. In addition, it means a heavy

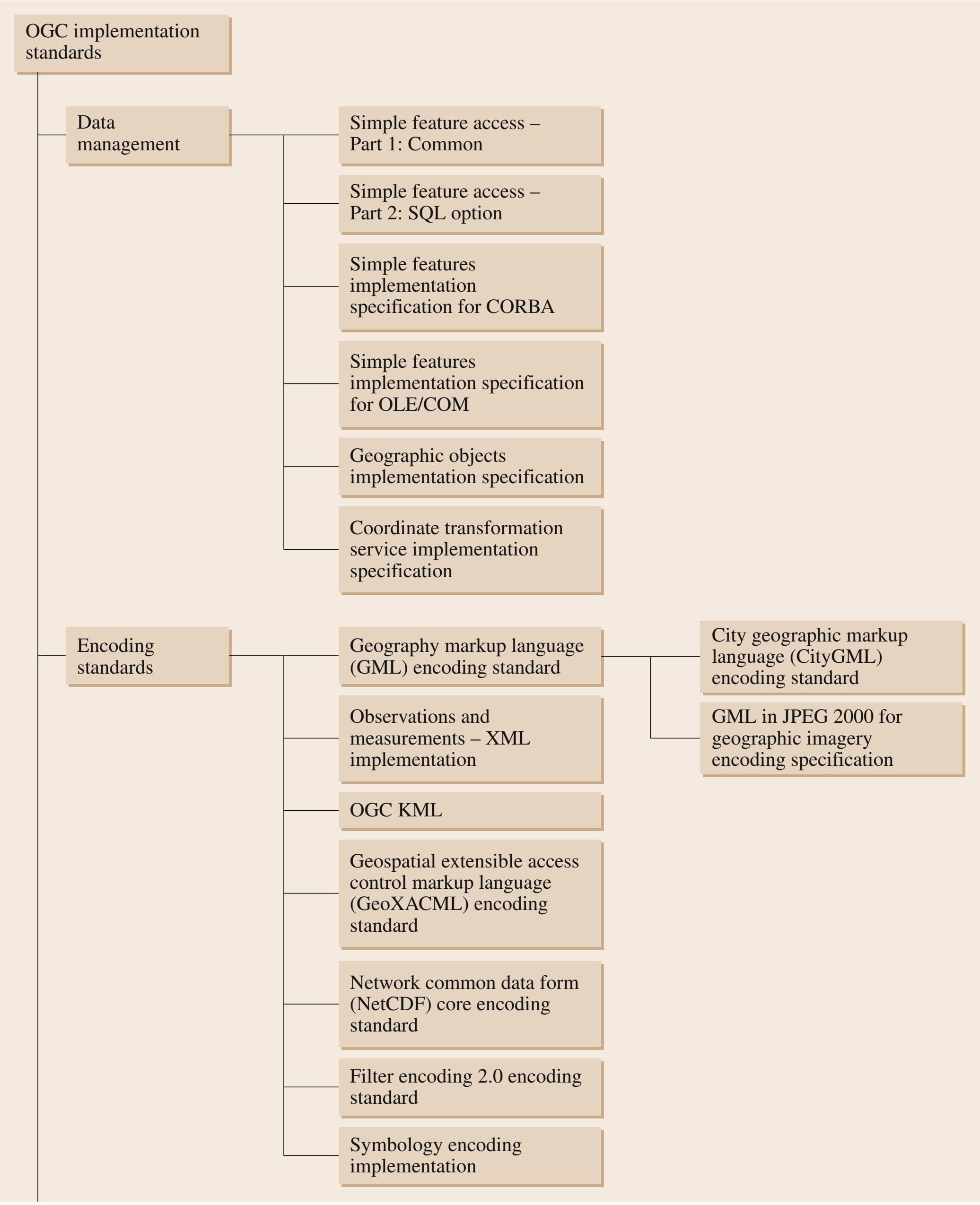


Fig. 13.151 Classification of OGC implementation standards

waste of resources, because one of the two standards will sooner or later fall out of favor. Overall, the field of geographic information is small compared with other businesses such as the automotive industry or the money market.

Originally, the OGC was only an external liaison member to ISO/TC 211, as were many others. The OGC and ISO/TC 211 formally signed a cooperative agreement in 1998 wherein ISO/TC 211 adopted OGC specifications and published them as ISO standards.

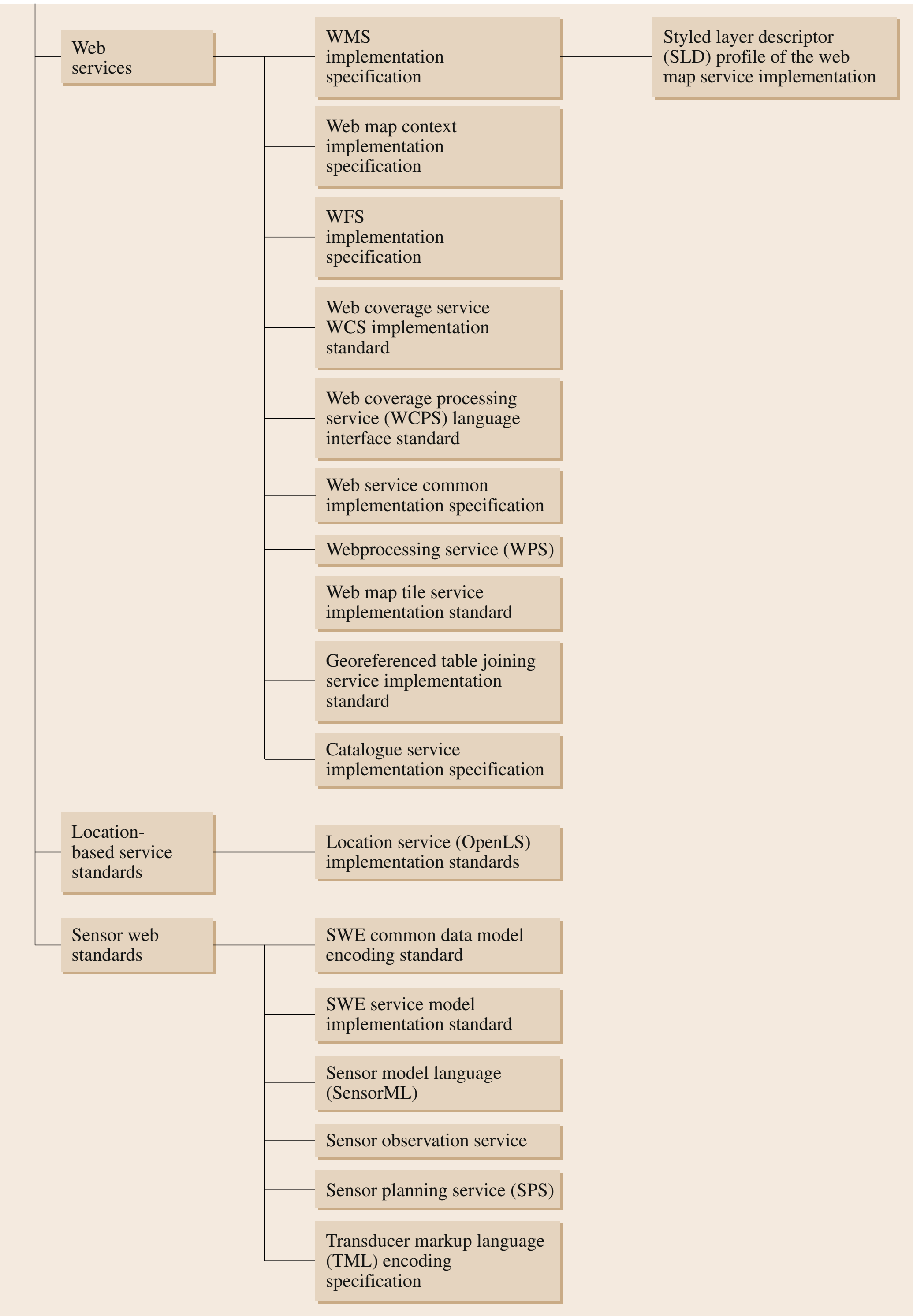


Fig. 13.151 (continued)

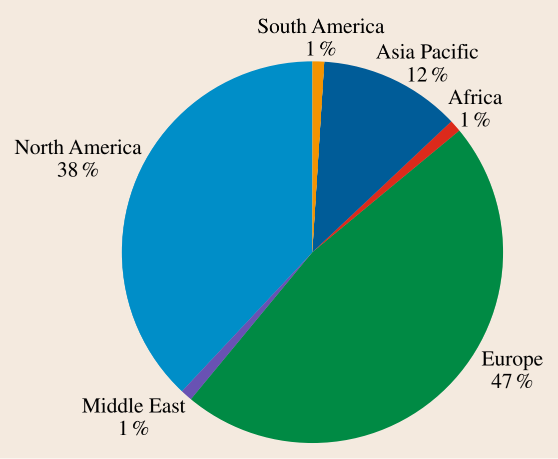


Fig. 13.152 OGC global membership distribution

Conversely, the OGC has the right to publish ISO standards under the OGC cover. To monitor matters rising from this agreement, the ISO/TC 211–Open Geospatial Consortium Inc. joint advisory group (JAG) was established. This group facilitates the smooth running of the agreement, monitors the liaison at the work item level, and functions as a clearinghouse.

In practice, the alignment of the work of both organizations is not a simple task. The intentions of both organizations and the formal process of standards development are not fully compatible. A simple, but not always applied, border separates the abstract standards (being the domain of ISO) from the implementation specifications (being the domain of the OGC). However, the cooperative agreement aligns the milestones of the standard developments of ISO and of the OGC.

It is sometimes questioned whether ISO should use its name for nonabstract standards. Most of the implementation specifications are living documents that evolve according to users' needs. It might happen that the international standard being published by ISO becomes outdated by the time the formal processes are complete. During that time, the OGC and their member companies may already have considerably advanced the implementation and the documentation in a later version. Previous experiences have shown that the most efficient way of transferring an industry standard to an ISO standard is by waiting until the industry has finalized their consensus-building process. A similar procedure is deemed advisable for OGC specifications intended to become ISO standards.

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