Temporal Data and Temporal Reference Systems

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Key words: GIS technology, temporal spatial data, international standard ISO 19108:2002.

SUMMARY

This paper describes the significance and role of temporal data in spatial information systems. Temporal characteristics of spatial objects unable us to describe and interpret the reality around us with additional aspects. Time is the dimension, which is according to its geometry and topology similar to other spatial extensions. Processes of updating and temporal analyses of spatial data offer an important source of spatial information. This article also presents the importance and describes the content of the international standard ISO 19108:2002 GI - Temporal schema that was developed, among others related geographic information standards, by ISO technical committee (TC) 211 Geographic Information/Geomatics. Further on, the usage of standardized temporal schema that forms a part of metadata is described and emphasized.

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1. INTRODUCTION

As the basic component of physical space, time is important for science and the majority of technical disciplines (ISO 19108). Nowadays computerized support for GIS technology enabled the inclusion of temporal properties directly into spatial data and thus among various users mediating enhanced consideration about temporal characteristics of real objects, such as their appearance, existence and persistence, temporal analyses and modeling etc. Spatial (geographic) data and information therefore are not only tied to two or state-of-the-art three-dimensional interpretation of universe of discourse. Many contemporary users of spatial data also need information derived from temporal attributes of spatial objects, such as:

- Temporal span and validity of spatial data,
- Temporal extent, updateness and temporal accuracy of spatial data,
- Time sequence and chronology of events,
- Stability, crucial events and transitions of spatial objects and systems,
- Sequence of activities, states and durability of active objects,
- Interactions and passing sequences of messages among objects,
- Lists and sequences of important outer and inner events etc.

Standardized temporal schema as an ingredient part of conceptual model for spatial data offers more versatile usage of temporal data and information for various applications as follows.

- Temporal simulations of different spatial models,
- Observation and monitoring of spatial processes as collaboration of objects,
- Studies of temporal dynamics and stability of spatial systems,
- Influence and promptness of spatial systems with respect to external and inner events,
- Modeling of development and forecasting of results for specific problem domains,
- Planning and monitoring of spatial decision making,
- Spatial and environmental simulations etc.

2. TEMPORAL CHARACTERISTICS OF SPATIAL OBJECTS

Traditionally temporal characteristics of spatial objects are handled as special or thematic attributes of the appropriate object types (classes). For instance, cadastral data about conveyance of a certain property includes date of property transaction that is crucial data. Modern interpretations of spatial data follow the principle that also the processing behavior or activities of spatial objects must be considered as a discrete functionality of time. Such approach can be conceptually only partially supported, if time is not treated as a special continuous dimension, which is independent of other spatial parameters. For example, the path of moving object can be described by a series of discrete points, where each one determines the location of this object in space at a certain instant (moment) that must be stored besides its location in a special temporal attribute.

Temporal data are most frequently used in spatial modeling procedures and various analyses, such as are different predictions of spatial development, observations of dynamics of spatial objects, stabile states and transitions of objects and wider spatial information systems etc. In the most of the mentioned approaches that treat temporal characteristics of spatial objects the prevailing is the discrete approach, which reminisces the notion of other spatial dimensions. Spatial properties of an object are normally, despite of its actual continuity, interpreted as a set of stable states that are given by a list of discrete time points. Each object should presumably have a finite number of states and is ordinarily in one of its states. Several aspects can describe a stabile state of a spatial object as follows.

- The factual data values in its attributes and established instances of associations with other objects define the present state of an object.
- The actual processing of activities determines the present state of an object.
- An object is waiting for an external or internal event in a form of an adequate message.

The change of an object state is caused by its response to some discrete and instant event. Such event appears in a form of a message and as such is important for an object or the system as a whole. The transition between two stable states is thus immediate and is interpreted as the reaction of the object concerned. The described concepts and simulation of objects' dynamics and wider as well information system processing behavior are considered as their foreseen responses to the crucial events. This prevailing somehow simplified discrete approach is distinct with the respect of our notion of time as a continuous dimension, where in fact infinite states of real and therefore complex objects can randomly change at any moment.

On the level of spatial system objects exist as instances of adequate classes. At each instant spatial object keeps certain values in its attributes and collaborates in associations with other objects. Therefore, certain stable state of an object is manifested by its established associations together with values of its attributes, activities performed alone or in cooperation with other objects, and its waiting status for appropriate event or a message. When a certain event occurs or object receives appropriate message (together with or without data) that object understands, object responds with a predictable reaction. Object invokes processing behavior that can modify values of its attributes, change instances of associations, or executes foreseen activities. Such a transition often means also the change of an object state.

Therefore, when an object oriented system works it consists of a set of appropriate objects that are instances of the selected classes. In such system objects can act alone by covering their particular responsibility, but objects mostly collaborate by performing more complex tasks. Objects interact and communicate by sending appropriate messages, which can include needed data for exchange. When they work together objects can produce required high-level functionality that is needed for execution of composed operations. All the stable states of an object-oriented system can be manifested by the predefined collaborations of its objects.

3. INTERNATIONAL STANDARD ISO 19108 - TEMPORAL SCHEMA

The international standard ISO 19108:2002 - Geographic Information (GI) - Temporal schema that is among others developed by ISO Technical Committee (TC) 211 specifies concepts, norms as a unified temporal schema, which is needed for specification of temporal characteristics of spatial (geographical) objects. Temporal properties of spatial data pertain to classes (object types), their attributes, relationships, operations and metadata, or in general to all the elements that may have values in the domain of time. ISO standard 19108 provides the basic elements in the form of the unified temporal schema, which serves for specification of temporal properties of spatial objects. This standard is also related and harmonized with the rest of information technology standards that deal with definition and exchange of temporal data. Because ISO standard 19108 is primary related to the temporal characteristics of spatial data and information, the main focus is on the temporal validity of spatial datasets and not on the management of data transactions (ISO 19108). Figure 1 shows the main packages that form the basic structure of the standardized temporal schema on a UML class diagram.

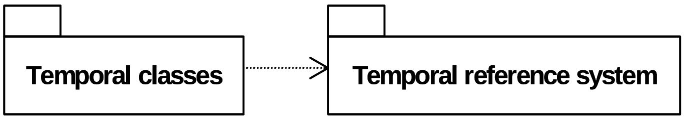


Figure 1: Basic structure of the temporal schema (source ISO 19108)

Many temporal notions that ISO standard 19108 deals with, can be used also outside the spatial data and information problem domain. ISO TC 211 had no intention to develop special standards that will deal with time issues instead of using existing ones, but gradually prevailed the opinion that also the temporal notions of spatial objects in any spatial data set should be unified. Therefore, the host of GIS technology applications can now use the harmonized temporal schema that is specified in the ISO standard 19108 and which provides consistent temporal structure for variety of spatial datasets.

Temporal characteristics and processing behavior of spatial objects can be better described, if temporal dimension can be combined with other spatial dimensions in a way that the observed objects can be considered as spatial-temporal ones. For example, the motion of spatial feature can be given as a discrete path sequence that is at the observed instant t_i given by a set of coordinates (x_i, y_i, z_i). ISO standard 19108 is developed especially in order to unify and harmonize the usage of time and its specification in attributes of spatial objects. Although the geometry and topology of an object are not explicitly combined with its temporal attributes, ISO standard 19108 has forwarded the unified norms that can be applied in order to specify temporal properties in conjunction with any other data values.

4. TEMPORAL GEOMETRY

4.1 Time as dimension

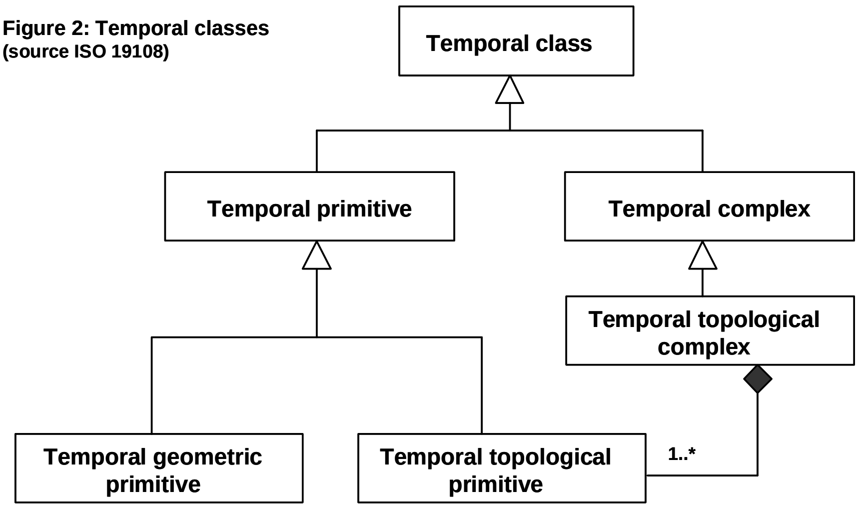
Time is a special dimension that is similar and related to the other dimensions of space. As well as space, time has its own geometry and topology (ISO 19108). Temporal point or an instant occupies a location, which can be located in a temporal reference system. Temporal distances or periods (intervals) can be measured between instants. But with respect to other conceptual models of reality time has only one extension. Temporal reference and coordinate system are mostly similar to a linear reference system that is sometimes used in certain applications for specification of single dimensional spatial properties, such as distance, length etc. Although time has always the assumed absolute or positive direction, because time motions are, accordingly to the basic notion of time, possible only forward, time span can be in general determined in both directions. Time as a quantity can be measured in standardized units in two ways that are as follows.

- The ordinal temporal scale determines data and information only about the relative temporal locations or sorted instants, which can be implicitly ordered in accordance with time or a certain imposed chronological principle.
- The interval temporal scale enables all kinds of temporal measurements and can as well give data about the duration of periods.

4.2 Temporal geometric and topological classes

Temporal geometry and topology can be used for specification of any temporal properties and values of spatial objects that are defined and exist in a certain spatial data set. As on the conceptual level also when modeling temporal characteristics of certain problem domain one ought to discern the type and the instance level. Object type level consists of the declarations of selected classes that appear in certain application schema, which gives the formal definition of conceptual model of the selected universe of discourse. On the instance level temporal objects are congruent with the properties (attributes and associations) of the pertinent classes and are characterized by their present data values. Figure 2 shows on a UML class diagram the hierarchy of the main temporal classes.

Figure 2: Temporal classes (source ISO 19108)



4.2.1 Basic geometric temporal classes

Two basic geometric primitives in the dimension of time are the instant and the period that in conceptual sense represent temporal classes (ISO 19108). These two geometric primitives are given analytically, if time is measured on an interval scale, or analogically, if it is given on an ordinal scale. Namely, it is impossible to measure duration on the ordinal temporal scale, because feasible is only ordering, therefore an instant on the ordinal scale cannot be discerned from a period. Figure 3 shows the basic temporal geometric classes on a UML class diagram.

An instant is zero dimensional (0D) temporal point, which is as a geometric primitive that is conceptually similar to a geometric point. Any instant gives a temporal location of an observed moment. In theory, an instant is also an interval, which duration is shorter than temporal resolution of applied temporal scale. A period is single dimensional (1D) temporal geometric primitive that represents and interval of time. A period is analogue to a geometric segment and is conceptually a temporal connection between the beginning and ending instant. The temporal position of a period is given by its beginning and ending instants and positive direction is adopted according to the normal course of time. Any period has also a measurable quantity that is its duration, which is equal to the temporal difference of its bordering instants.

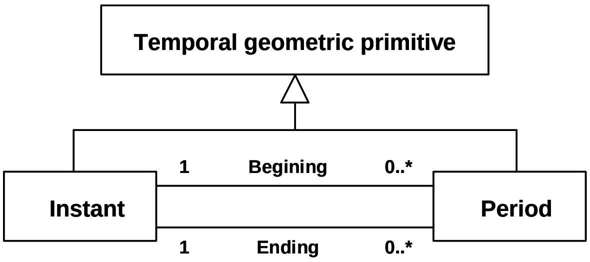


Figure 3: Temporal geometric primitives (source ISO 19108)

4.2.2 Basic topological temporal classes

In general topology determines connectivity, consecutiveness and adjacency among spatial objects. Temporal topology as well gives logical relations among objects in time and may provide information about the ordering of objects in time (ISO 19108), but temporal topology does not provide data about position of objects. Topological relations can be derived from geometric properties, but data about temporal position is sometimes not suitable, therefore explicit specification of temporal topology might often be needed. Regardless of the kind of application, thus as a rule, topology for temporal data is generally stored explicitly, although it might be also indirectly derived from the temporal attributes of spatial objects.

Temporal topology determines the basic rules of single dimensional topology. Temporal node is a zero-dimensional (0D) topological primitive that geometrically represents a temporal point or an instant. Temporal edge or vector is a single dimensional (1D) topological primitive (segment) that geometrically determines an interval in time or a period (from - to) between the starting and ending temporal nodes. The positive orientation of temporal edge is always assumed to be according to the course of time. Figure 4 shows the main temporal topological classes on a UML class diagram.

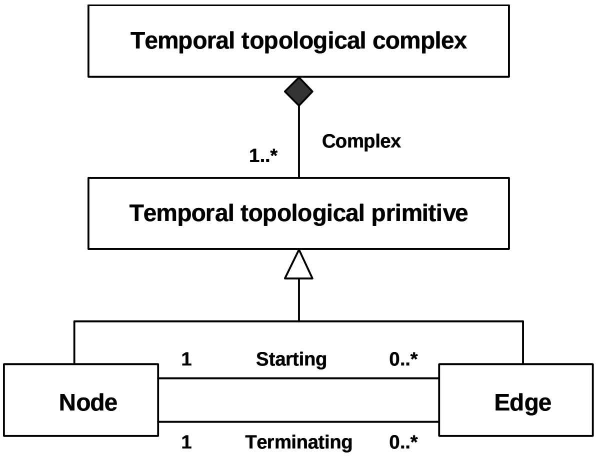


Figure 4: Temporal topological classes (source ISO 19108)

5. TEMPORAL REFERENCE SYSTEMS

Any temporal reference system is a temporal location system that enables measurements and specifications of time. The basic entity in the temporal domain is a temporal location (point), which is determined relatively with respect to the used temporal reference system. The international standard ISO 8601 suggests and describes the application of the Gregorian calendar and UTC (Coordinated Universal Time) as the basic measures for specification and exchange of temporal data and information. Figure 5 shows the main temporal reference systems on a UML class diagram.

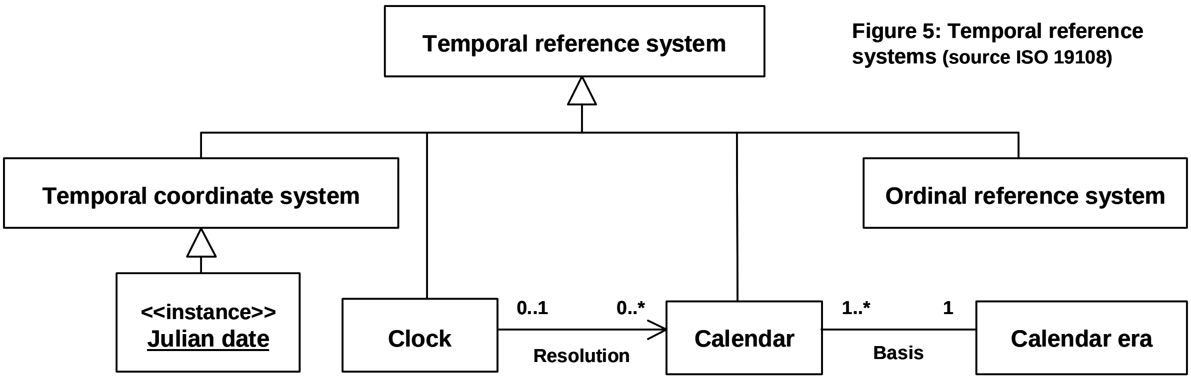


Figure 5: Temporal reference systems (source ISO 19108)

As world time UTC is the standard time scale that is maintained by the International Bureau of Weights and Measures (Bureau International des Poids et Mesures), which resides in Paris, and agency IERS (International Earth Rotation Service) that together maintain clocks, frequencies and distribute time signals. The international standard ISO 19108 also suggests for specification and exchange of temporal data and information usage of the Gregorian calendar (YYYY-MM-DD) and 24-hour local time given as UTC (HH:MM:SS). UTC is thus selected as the primary temporal reference system (clock) for spatial (geographic) data and information. Such a provision is also conformant with the ISO standard 8601.

Special or separately adopted temporal reference systems can be more suitable for certain specific users of spatial data. In such cases applied temporal reference system must be interpreted in metadata and also in the classification scheme for a certain data set. The detailed specification of such temporal reference systems must be explicitly given or a reference to the source or documentation that formally outlines such a system should be provided.

5.1 Temporal coordinate system

Any temporal coordinate system is a temporal reference system that is based on a defined continuous interval scale (ISO 19108). Specification of temporal location with calendar date and local time can cause difficulties when computing periods or comparing distances between various time points. The operations applied and their functional descriptions can become complicated. For such cases and applications the use of special or dedicated temporal coordinate system, such as for example the Julian date, is more suitable. Such system should be based on a consistent interval scale that must be specified on one single time interval. A temporal period can be measured as distance from coordinate system origin and given as multiple of the basic temporal unit. A temporal coordinate is a location (point) in time that is measured relatively to the origin of the temporal coordinate system applied.

Each temporal coordinate system must be based on two principal parameters that are as well basic attributes of such temporal reference system.

- The origin defines the start of time scale in the sense of the basic date that determines the calendar era. As well the starting instant for measuring the hours of a day must be clearly defined.
- The period specifies the primary temporal unit that is used as the basic interval on the time scale.

The temporal period can be selected or adjusted with respect to the requirement of particular application. Temporal coordinate is thus date data, which as a span from the origin of time scale, defines the temporal location of a time point in a certain temporal coordinate system

Nowadays the Julian day counting principle is a dedicated temporal coordinate system that has its origin on the Greenwich meridian on the 01. of January 4713 BC. The Julian date consists of the whole Julian day number, which is appended by a fractal day part since the last midday. The Julian day number is therefore a decimal number of days since the system origin, which is as defined at noon of –4713-01-01 on the zero meridian. The Julian date as a real number thus enables a very detailed and uniform resolution of time that is also suitable as an intermediate date for transformations among different temporal reference systems.

5.2 Ordinal temporal reference system

For certain branches or applications that also use spatial data and temporal referencing, such as anthropology, archeology, geology etc., it is easier and more reliable to determine relative temporal relationships and spatial layout than precise locations in time. Relative temporal order of events can be for example well specified, but on the other side the extent or the span of intervals between events cannot be reliably determined. In such cases the usage of adequate ordinal temporal reference system could be more appropriate. An ordinal temporal reference system must be based a consecutive arrangement or imposed by the selected ordinal measure. Figure 6 shows the main properties of an ordinal temporal reference system on a UML class diagram.

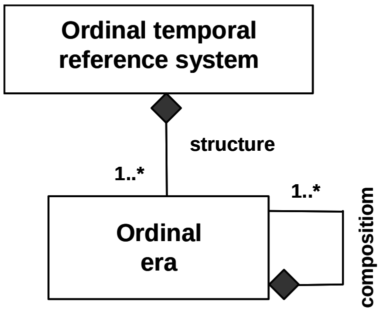


Figure 6: Ordinal reference system (source ISO 19108)

An ordinal temporal reference system consists of a set of named eras ordered in time (ISO 19108). Such an era can also impose hierarchical structure in a way that certain period can consist of a set of sorted shorter periods, which are introduced on a lover conceptual level. In its most simple form such a temporal system enables only sorting of events. In general, any given temporal point may be connected to a series of additional events. Temporal relations among various points can be determined only in the cases, when temporal event on a certain location is correlated with a similar event on another location on the basis of temporal characteristics of such events, which can be supplemented by other additional attribute values. The defined dependency among temporal points can be used also wider for development of dedicated temporal reference system that is specified in the sense of periods in which such events occurred. Such periods are then named and considered as appropriate sorted eras.

6. CALENDARS AND HOURS

Both fundamental temporal classes calendar and clock are based on the interval scale. A calendar is a discrete temporal reference system that enables determination of position in time with a daily resolution, which is ordinarily the basic unit of calendars. A clock provides a basis for defining temporal position within a day. A clock must be used with a calendar in order to provide a complete description of a temporal position within a particular day (ISO 19108). Each calendar provides a set of rules for specification of a date, which on the basic calendar includes components that are year, month and day. In any calendar years are given relatively with respect to the origin of that calendar, which normally is an important event given by its date that determines the calendar era. A day is usually the basic unit of calendar and is counted as an integer number forward or backward from the calendar era or its starting date. Figure 7 shows the main calendar relations on a UML class diagram.

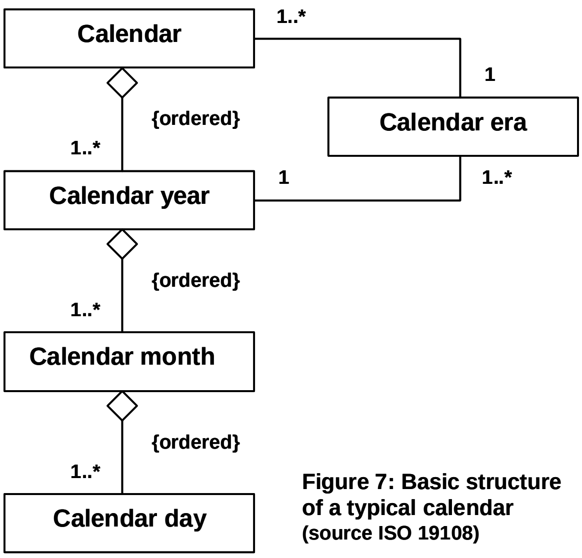


Figure 7: Basic structure of a typical calendar (source ISO 19108)

6.1 Types of calendars

Nowadays the Gregorian calendar is a formal international standard (ISO 8601) that is used also as a temporal reference system for spatial data and information. The Gregorian calendar is in use since 1582 as a correction and supplement to in those days prevailing Julian calendar, which was mostly in use since the Roman empire. The Gregorian calendar finally and ultimately introduced 365 days long general year and a 366 days long leap year that repeats in a four-year cycle. A calendar year is further divided to 12 consecutive months. Besides the Gregorian calendar also many others traditional calendars are used in different parts of the World, such as Chinese, Hebrew, Islamic, Japanese, Orthodox etc. In certain branches also dedicated technical calendars are in use, such as for example GPS calendar. As well for the specific scientific purposes i.e. archeology or history some ancient or abolished calendars are often used, such as Aztec, Babylonian, Egyptian, Greek etc.

The Julian calendar is an example of a systematic antic temporal reference system that was introduced in 45 BC by the emperor Julius Cesar in the sense of reform of the ancient Roman calendar. The main objective was to unify and harmonize common calendar all over the Roman empire that was as well consistent with the Sun yearly cycle. The general year in the Julian calendar lasted 365 days and every forth year a one day longer leap year was introduced. After the death of Cesar various emperors and priests partly misused this basic calendar rules, which resulted in a three-year cycle of leap years. In the year 9 BC emperor Augustus imposed an adjustment process of leap years in order to synchronize discordant calendar with the sun year and up to the year 8 AD no leap years were taken into account.

In the Roman empire the Julian calendar was used with various origins, but mostly the calendar era was based on the assumed foundation date of city Rome that was in the year 753 BC. Emperor Augustus also introduced 01.01. as the starting date for a calendar year and divided a year into 12 consecutive (named) months. In the year 525 AD Dionysius Exiguus proposed the year numbering system that is based on the presumed birth year of Jesus Christ. The Christian calendar era prevailed in Western Europe around the 11. century and in the eastern parts even after the 15 century (ISO 19108).

7. STANDARDIZED TEMPORAL POSITION SPECIFICATION

The method used for determination of temporal position is specific for each type of temporal reference system. Date is a data type that with its unit (day) servers for determination of temporal position in the calendar used. Clock time (hours:minutes:seconds) is given as addition to the date for specification of temporal position within a particular day. For exchange of spatial data ISO standard 19108 proposes usage of the Gregorian calendar, and the 24-hour local time should be given as UTC. Such an approach, which bases on the acknowledged temporal reference system, is prescribed also for any specification of temporal data or attributes that are used together with other categories of spatial data or information. ISO standard 19108 is also conformant with already mentioned ISO 8601 standardized approach and therefore includes all the basic forms and extendable possibilities that can be applied for specification of temporal data.

8. GPS CALENDAR

The Global positioning system (GPS) uses specially arranged temporal reference system (calendar and clock) that serves for specification of temporal position for GPS data. Date is given as a week number (WN) in the calendar era that has its origin at the midnight (00:00:00 UTC) on 1980-01-06. Days are given ordinarily as the day in the week (DN-Day Number). In both cases numbering starts from zero (ISO 19108). The GPS continuous time system measures clock as the time of a week (TOW) that is given in seconds, and not as usual time of the day. GPS week has 604.800 seconds. GPS time is based on a continuous scale and drifts within a one microsecond relative to UTC, which is periodically adjusted with leap seconds because of its synchronization with Earth rotation.

9. TEMPORAL METADATA ELEMENTS

In the conceptual model attributes of classes describe selected properties of real objects on the abstracted level as user-defined classes. The international standard ISO 19115 Geographic information (GI) - Metadata that is among others developed by ISO Technical Committee (TC) 211 specifies a set of standardized metadata elements (meta-schema) for interpretation of spatial (geographic) data and information. Metadata or data about data describe technical and administrative characteristics of a certain data set. Metadata elements are usually given on the level of a data set, but can also be more detailed and interpreting particular objects or data records. Standardized metadata elements provide minimal harmonized interpretation of spatial data itself. This ISO metastandard also supports users' extensions to basic metadata schema. Such profiles are based on the standardized methodology and enable development of additional metadata according to the specific users' application schema.

Temporal metadata elements are similar to general temporal attributes, because both types deal with temporal characteristics of spatial objects, such as instance of event, period of duration, state of object etc. that are all associated with a certain position in time. Standard metadata elements in ISO 19115, which describe the general temporal properties of a data set, primary specify the chosen temporal reference system and temporal properties of classes and their attributes. The Gregorian calendar and UTC are, according to the international standard ISO 19108 GI - Temporal schema, prescribed as the basic reference system for temporal attributes of spatial objects. Special normative annex C of ISO 19108 gives the general instructions about the interpretation of any specific temporal reference system that is applied in a certain data set by using the presented table with unified metadata elements. As needed additional temporal metadata elements can be added to the existing mandatory or optional ones in accordance with the methodology that is defined in ISO 19115 standard. Both mentioned ISO standards 19108 and 19115 are consistent with respect to the methodology applied and the means needed to interpret and describe temporal metadata.

10. CONCLUSIONS

Spatial (geographic) data and information are not anymore limited to two or modern three-dimensional interpretation of the selected problem domain. Contemporary spatial information systems can use the power of GIS technology in order to handle temporal properties of spatial data as well. The development and future applications of standardized temporal schema offer possibilities to consider time as an additional dimension of physical space. The international standard ISO 19108:2002 - Temporal schema, which is consistent with other ISO time and GIS technology related standards, defines standardized concepts and norms that are needed for determination of any temporal schema for spatial data. The described development provides basic concepts that users can further develop and apply in order to analyze also temporal aspects of spatial data sets.

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BIOGRAPHICAL NOTES

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In 1980 I completed the engineering degree at the University of Ljubljana, Faculty of Civil and Geodetic Engineering, Geodetic Department. In 1987 I concluded regular postgraduate studies at the same institution. PhD (doctoral) thesis I defended in 1993 also at the Geodetic Department. Additional postgraduate studies I carried out in 1986/87 at the ITC, Enschede, NL, as a one-year postgraduate study course on Land Information Management with the cadastral orientation. In 1991 I also spent six months as research fellow at the Technical University Deft, Faculty of Geodesy, NL.
As associated professor I teach several subjects at the Faculty of Civil and Geodetic Engineering, related to computer and GIS technology application in geodesy and surveying, on both graduate and post graduate studies. My research work concentrates on several GIS technology fields, such as standardization, legal issues related to spatial data, GIS databases, conceptual modeling with UML, application of OOAD tools for cadastral database modeling etc.

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