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Open Geospatial Consortium

TOPIC 25 - ABSTRACT CONCEPTUAL MODEL FOR TIME

ABSTRACT SPECIFICATION TOPIC

CANDIDATE SWG DRAFT

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Note

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I ABSTRACT

The primary goal of the Abstract Conceptual Model for Time is to establish clear concepts, their relationships, and terminology.

The fundamental concepts of events, clocks, timescales, coordinates and calendars have been long established, but there is no clear, straightforward defining document. This Abstract Specification provides clear consistent definitions of the fundamental concepts and terminology. The conceptual model enables advantages and disadvantages of adopting a particular technological approach to be identified and provides an opportunity for communities to build consistent, interoperable representations regardless of implementation.

Traditionally, geospatial communities used 2D coordinates and the vertical (third dimension) and temporal aspects were considered attributes rather than valid components of coordinate systems. In an increasingly dynamic, faster and multidimensional world, much confusion and lack of interoperability has occurred because of inconsistent approaches to defining and expressing time. Various international bodies expended considerable effort to establish the Gregorian Calendar as a consistent timeline. The Gregorian Calendar suffices for low precision applications, such as to the nearest minute, but not so when second or sub-second accuracy is required. For example, there have been differing practices and no consensus on whether leap seconds should be part of the Gregorian timeline.

This document is consistent with ISO 19111:2019 and W3C Time Ontology in OWL.

II KEYWORDS

The following are keywords to be used by search engines and document catalogues.

ogcdoc, OGC document, abstract specification, conceptual model, time, temporal referencing, referencing by coordinates, calendar, clock, timescale

III PREFACE

When OGC Standards involve time, they generally refer to the ISO documents such as Geographic Information Temporal Schema ISO 19108:2002 (now largely superseded), Geographic information Referencing by coordinates ISO 19111:2019, Date and Time Format ISO 8601, and the freely available OGC equivalents, such as OGC Abstract Specification Topic 2: Referencing by Coordinates OGC 18-005r8 (the equivalent to ISO 19111:2019).

Over decades, much effort has gone into establishing complex structures to represent calendar based time, such as the ISO 8601 notation, and many date-time schemas. A consequence of this effort is that many end-users and developers of software use calendar based “coordinates”, with the associated ambiguities about underlying algorithms, imprecision and inappropriate scope.

The aim of this OGC Temporal Abstract Specification is to establish clear concepts and terminology. This is necessary so that people are aware of the advantages and disadvantages of specifying or adopting a particular technological approach to time and then perhaps build better, more appropriate, interoperable systems for their use cases.

IV SECURITY CONSIDERATIONS

This Abstract Specification does not place any constraints on application, platform, operating system level, or network security.

V SUBMITTING ORGANIZATIONS

The following organizations submitted this Document to the Open Geospatial Consortium (OGC):

- U.K. Met Office
- HeazelTech
- Ribose Inc.

VI SUBMITTERS

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1

SCOPE

1 SCOPE

This document defines the major underlying concepts regarding time. It does not define any concrete temporal reference systems or give detailed guidance on implementations.

2 CONFORMANCE

2 CONFORMANCE

According to OGC Policy:

“The detail of the Abstract Specification shall be sufficient to provide normative references, including models, and technical guidelines as a foundation for Standards. Each Topic, to the extent possible, provides unambiguous normative and informative information that allows for implementation of Standards in software.

The level of detail of the Abstract Specification is at the discretion of the TC [Technical Committee] as reflected by the actual content that is approved for inclusion in the document itself.”

This Abstract Specification does not include any specific requirements or conformance classes. However, it does include normative references and a normative Unified Modeling Language (UML) model. Conformance is demonstrated through inclusion of the normative references in any derivative specification and by basing any derived conceptual model on the abstract model provided in this Standard.

The Clause 8 of this Abstract Specification uses UML to present conceptual schemas for describing the higher level classes of time and temporal reference systems. These schemas define conceptual classes that:

1. may be considered to comprise a cross-domain application schema, or
2. may be used in application schemas, profiles and implementation specifications.

This flexibility is controlled by a set of UML types that can be implemented in a variety of manners. Use of alternative names that are more familiar in a particular application is acceptable, provided that there is a one-to-one mapping to classes and properties in this Abstract Specification.

The UML model in this Abstract Specification defines conceptual classes. Various software systems define implementations or data structures. All of these reference the same information content. The same name may be used in implementation classes as in the model, so that types defined in the UML model may be used directly in application schemas.

3

NORMATIVE REFERENCES

3 NORMATIVE REFERENCES

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

G. Klyne, C. Newman: IETF RFC 3339, *Date and Time on the Internet: Timestamps*. RFC Publisher (2002). https://www.rfc-editor.org/info/rfc3339.

ISO: ISO 8601, *Data elements and interchange formats — Information interchange — Representation of dates and times*. International Organization for Standardization, Geneva https://www.iso.org/standard/40874.html.

ISO: ISO 19111:2019, *Geographic information — Referencing by coordinates*. International Organization for Standardization, Geneva (2019). https://www.iso.org/standard/74039.html.

ISO/IEC: ISO/IEC 22989:2022, *Information technology — Artificial intelligence — Artificial intelligence concepts and terminology*. International Organization for Standardization, International Electrotechnical Commission, Geneva (2022). https://www.iso.org/standard/74296.html.

Allen, J. F.: *Maintaining Knowledge about Temporal Intervals*. Communications of the ACM, vol. 26, pp832-843 (1983).

Roger Lott: OGC 18-005r8, *Topic 2 — Referencing by coordinates (Including corrigendum 1 and corrigendum2)*. Open Geospatial Consortium (2023). http://www.opengis.net/doc/AS/topic-2/6.0.

Cox, S., Little, C.: *W3C Time Ontology in OWL*. World Wide Web Consortium (2022) https://www.w3.org/TR/owl-time/.

4

TERMS, DEFINITIONS AND ABBREVIATED TERMS

4 TERMS, DEFINITIONS AND ABBREVIATED TERMS

This document uses the terms defined in OGC Policy Directive 49, which is based on the ISO/IEC Directives, Part 2, Rules for the structure and drafting of International Standards. In particular, the word “shall” (not “must”) is the verb form used to indicate a requirement to be strictly followed to conform to this document and OGC documents do not use the equivalent phrases in the ISO/IEC Directives, Part 2.

This document also uses terms defined in the OGC Standard for Modular specifications (OGC 08-131r3), also known as the ‘ModSpec’. The definitions of terms such as standard, specification, requirement, and conformance test are provided in the ModSpec.

For the purposes of this document, the following additional terms and definitions apply.

4.1. Terms and definitions

4.1.1. clock

regularly repeating physical phenomenon that can be counted

4.1.2. conceptual model

description of common concepts and their relationships, particularly in order to facilitate exchange of information between parties within a specific domain

Note 1 to entry: A conceptual model is explicitly chosen to be independent of design or implementation concerns.

4.1.3. coordinate

one of a sequence of numbers designating the position of a point

Note 1 to entry: In many coordinate reference systems, the coordinate numbers are qualified by units.

[**SOURCE:** ISO 19111:2019]

4.1.4. coordinate reference system; CRS

coordinate system (Clause 4.1.5) that is related to an object by a *datum* (Clause 4.1.8)

Note 1 to entry: Geodetic and vertical datums are referred to as reference frames.

Note 2 to entry: For geodetic and vertical reference frames, the object will be the Earth. In planetary applications, geodetic and vertical reference frames may be applied to other celestial bodies.

[**SOURCE:** ISO 19111:2019]

4.1.5. coordinate system

set of mathematical rules for specifying how coordinates are to be assigned to points

[**SOURCE:** ISO 19111:2019]

4.1.6. datum

reference frame ALTERNATIVE

parameter or set of parameters that realize the position of the origin, the scale, and the orientation of a *coordinate system* (Clause 4.1.5)

[**SOURCE:** ISO 19111:2019]

4.1.7. epoch

<geodesy> point in time

Note 1 to entry: In ISO 19111:2019, an epoch is expressed in the Gregorian calendar as a decimal year.

Example 2017-03-25 in the Gregorian calendar is epoch 2017.23. Other notations or reference systems are options.

[**SOURCE:** ISO 19111:2019]

4.1.8. reference frame

datum ALTERNATIVE

parameter or set of parameters that realize the position of the origin, the scale, and the orientation of a *coordinate system* (Clause 4.1.5)

[**SOURCE:** ISO 19111:2019]

4.1.9. temporal coordinate reference system; TRS

coordinate reference system (Clause 4.1.4) based on a *temporal datum* (Clause 4.1.11)

[**SOURCE:** ISO 19111:2019]

4.1.10. temporal coordinate system

<geodesy> one-dimensional *coordinate system* (Clause 4.1.5) where the axis is time
[**SOURCE:** ISO 19111:2019]

4.1.11. temporal datum

datum (Clause 4.1.8) describing the relationship of a *temporal coordinate system* (Clause 4.1.10) to an object

Note 1 to entry: The object is normally time on the Earth.

[**SOURCE:** ISO 19111:2019]

4.1.12. tick

event which is a single occurrence of the regularly repeating physical phenomenon of a clock

4.2. Abbreviated terms

2D	2-dimensional
3D	3-dimensional
BIPM	International Bureau of Weights and Measures
TAI	International Atomic Time
UML	Unified Modeling Language

5

CONVENTIONS

5 CONVENTIONS

The normative provisions in this standard are denoted by the URI:

http://www.opengis.net/doc/AS/temporal-conceptual-model/1.0

All requirements and conformance tests that appear in this document are denoted by partial URIs which are relative to this base.

6

CHARACTERISTICS OF AN ABSTRACT CONCEPTUAL MODEL

6 CHARACTERISTICS OF AN ABSTRACT CONCEPTUAL MODEL

The terms and definitions clause in this Abstract Specification provides a short definition for "conceptual model". This clause provides additional information on the OGC use of "conceptual model".

A conceptual model organizes the vocabulary needed to communicate consistently and thoroughly about the know-how of a problem domain. The aim of a conceptual model is to express the meaning of terms and concepts used by domain experts to discuss the problem, and to find the correct relationships between different concepts.

A conceptual model:

1. is a representation of a system, made of the composition of concepts which are used to help people know, understand, or simulate a subject the model represents. A documented conceptual model represents 'concepts' (entities), the relationships between them, and a vocabulary;
2. is explicitly defined to be independent of design or implementation concerns;
3. organizes the vocabulary needed to communicate consistently and thoroughly about the know-how of a problem domain;
4. contains the definitions of the concepts that it organizes. There is a high premium on high-quality, design-independent definitions, free of data or implementation biases; the model also emphasizes rich vocabulary; and
5. is always about identifying the correct choice of terms to use in communications, including statements of rules and requirements, especially where high precision and subtle distinctions need to be made. The core concepts of a temporal geospatial problem domain are typically quite stable over time.

7

TEMPORAL REGIMES

7 TEMPORAL REGIMES

7.1. General

To enable more clear reasoning about time, this Abstract Specification uses the term “Regime” to describe the fundamentally different types of time and its measurement. This is a pragmatic approach that allows the grouping of recommendations and best practices in a practical way, but without obscuring the connection to the underlying theoretical components.

The first three regimes, described below, have deep underlying physical and mathematical foundations which cannot be legislated away. The fourth regime, calendars, concerns social constructs using seemingly random mixtures of ad hoc algorithms, arithmetic, numerology and measurements. Paradoxically, the calendar regime has historically driven advances in mathematics and physics. See the article A Chronicle Of Timekeeping.

With due consideration, the regimes are applicable to other planets and outer space.

7.2. Events and Operators

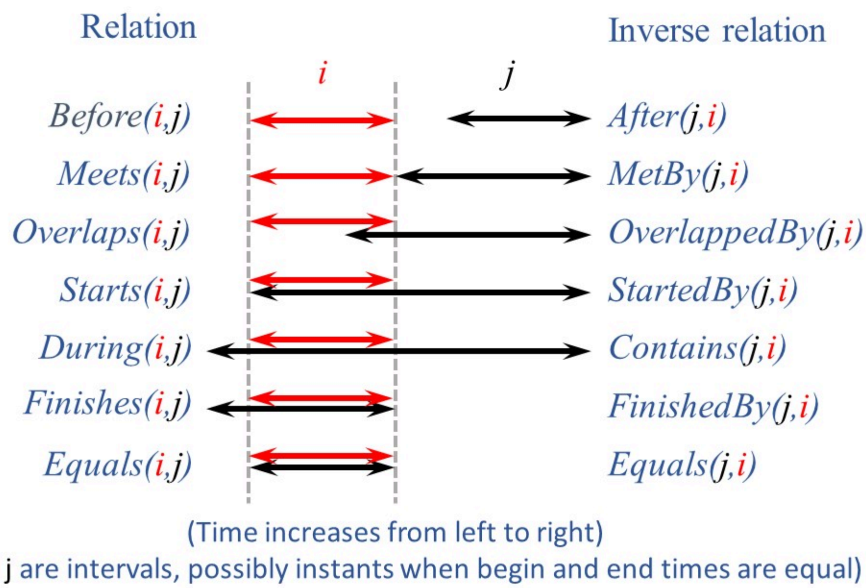
The simplest way of relating entities in time is by events that can be ordered and established in a sequence, and this sequence is used as an approximate measure of the passage of time.

In this regime, no clocks or time measurements are defined, only events, that are ordered in relation to each other. Examples are geological layers, sediment or ice core layers, archaeological sequences, sequential entries in computer logs without coordinated time.

One set of events may be completely ordered with respect to each other, but another set of similar internally consistent ordered events cannot be cross-referenced to the first set unless extra information is available. Even then, only partial orderings may be possible.

In this regime, the Allen Operators (see Figure 1) can be used. If A occurs before B and B occurs before C, then it can be correctly deduced that A occurs before C. The full set of operators also covers pairs of intervals. So in our example, B occurs in the interval (A,C). However, arithmetic operations like (B-A) or (C-A) cannot be performed as any timescale or measurements are not defined. For example, in geology, ‘subtracting’ Ordovician from Jurassic is meaningless. In archeology, ‘subtracting’ a layer with a certain type of pottery remains from the layer containing burnt wood and bones is again not meaningful. Only the ordering can be deduced.

This regime constitutes an ordinal temporal reference system, with discrete enumerated ordered events.



The Allen operators: thirteen elementary possible relations between two time intervals.
From Allen, J.F: *Maintaining Knowledge about Temporal Intervals*. Commun. ACM, vol. 26, no. 11, pp 832-843 (1983)

Figure 1

7.3. Simple Clocks and Discrete Timescales

In this regime, a clock is defined as any regularly repeating physical phenomenon, such as a pendulum swing, earth's rotation about the sun, earth's rotation about its axis, heart beat, vibrations of electrically stimulated quartz crystals or the resonance of the unperturbed ground-state hyperfine transition frequency of the cesium-133 atom. Each occurrence of the repeating phenomenon is, of course, an event, but as there are usually very many that can only be distinguished by counting, they are considered a separate class of ticks.

In terms of the number of repetitions possible, some phenomena make better clocks than others, because of the consistency of each repetition and the precision of each tick. A mechanism for counting, or possibly measuring, the ticks is desirable.

An assumption is that the ticks are regular and homogeneous.

There is no sub-division between two successive clock ticks. Measuring time consists of counting the complete number of repetitions of ticks since the clock started, or since some other event at a given clock tick count.

There is no time measurement before the clock starts, or after it stops.

It may seem that time can be measured between ticks by interpolation, but this needs another clock, with faster ticks. This process of devising more precise clocks continues down to the atomic scale. At that scale the deterministic process of physically trying to interpolate between ticks is not possible.

The internationally agreed atomic time, TAI International Atomic Time is an example of a timescale with an integer count as the measure of time. However in practice, TAI is an arithmetic compromise across about two hundred separate atomic clocks, corrected for differing altitudes and temperatures.

In this regime, Allen Operators (see Figure 1) also can be used. If L occurs before M and M occurs before N, it can be correctly deduced that L occurs before N. The full set of operators also covers pairs of intervals. So if M occurs in the interval (L,N), integer arithmetic operations such as (M-L) or (N-L) can be performed. This is because an integer timescale or measurement is defined by the count of ticks.

This regime constitutes a temporal coordinate reference system, with discrete integer units of measure which can be subject to integer arithmetic.

7.4. CRS and Continuous Timescales

This regime takes a clock from the previous regime and assumes that between any two adjacent ticks, it is possible to interpolate indefinitely to finer and finer precision, using ordinary arithmetic, rather than any physical device. Units of measure may be defined that are different from the ticks. For example, a second may be defined as 9,192,631,770 vibrations of the ground-state hyperfine transition of the cesium-133 atom. Alternatively and differently, a second may be defined as 1/86400th of the rotation of the earth on its axis with respect to the sun. The count of rotations is the ticks of an earth-day clock. This latter definition is not precise enough for many uses, as the rotation of the earth on its axis varies from day to day.

Alternatively, it may be that the ticks are not counted but measured, and the precision of the clock is determined by the precision of the measurements, such as depth in an ice core subject to seasonal depositions of snow, or angular position of an astronomical body, such as the sun, moon or a star.

It is also assumed that time can be extrapolated before the time when the clock started and into the future, possibly past when the clock stops.

This gives us a continuous number line to perform theoretical measurements. With a datum/origin/epoch, a unit of measure (a name for the ticks on the axis), positive and negative directions and the full range of normal arithmetic, this is a coordinate reference system (CRS).

In this regime, the Allen Operators (see Figure 1) also can be used. If A occurs before B and B occurs before C, it can be correctly deduced that A occurs before C. The full set of operators also covers pairs of intervals. So if B occurs in the interval (A,C), real number arithmetic operations like (B-A) or (C-A) can be performed. This is because a timescale or measurement has been defined, and between any two instants, an infinite number of other instants can be found.

Example: Some examples are:

- Unix milliseconds since 1970-01-01T00:00:00.0Z

- Julian Days, and fractions of a day, since noon on 1st January, 4713 BCE.

This regime constitutes a temporal coordinate reference system, with a continuous number line and units of measure, which can be subject to the full range of real, or floating-point, arithmetic.

7.5. Calendars

In this regime, counts and measures of time are related to the various combinations of the rotations of the earth, moon and sun or other astronomical bodies. Typically there is no simple arithmetic connecting calendar systems and timescales. For example, the current civil year count of years in the Current Era (CE) and Before Current Era (BCE) is a very simple calendar, as there is no year zero. That is, Year 14CE – Year 12CE is a duration of 2 years, and Year 12BCE — Year 14BCE is also two years. However Year 1CE — Year 1BCE is one year, not two as there is no year 0CE or 0BCE.

In this regime, the use of the Allen Operators (see Figure 1) is not straightforward. If A occurs before B and B occurs before C, then correctly deducing that A occurs before C is not always easy. This is because the calendar's timeline may contain gaps, changes of units of measure, or even duplicated times.

The full set of Allen Operators also covers pairs of intervals. So in the example, B occurs in the interval (A,C). However, simple arithmetic operations like (B-A) or (C-A) cannot usually be done simply because of the vagaries of the calendar algorithms, multiple timescales, and multiple units of measure.

Example: For example, in the Gregorian calendar, calculating the number of days between the 1st February and the 30th March depends on whether the year is a leap year or not, which also depends on the century and millenium. Calculating the precise number of seconds between two dates in the Gregorian calendar also depends on whether leap seconds have been declared between the dates. There have been 27 leap seconds added between 1972 and 2022.

Calendars are social constructs made by combining several clocks and their associated timescales. Calendars may also have local or regional variations at different times of the year or season, such as for 'day-light saving' in mid-latitudes. Again, this makes calculations more complicated and prone to change.

This Abstract Specification only addresses the internationally agreed Gregorian calendar. The book Calendrical Calculations by Nachum Dershowitz and Edward M. Reingold provides overwhelming detail for conversion to numerous other calendars that have developed around the world and over the millennia and to meet the various social needs of communities, whether agricultural, religious or other. The reference is comprehensive but not exhaustive, as there are calendars that have been omitted.

A calendar is a temporal reference system, but it is not a temporal coordinate reference system nor an ordinal temporal reference system.

7.6. Other Regimes

There are other regimes, whose detailed description are out of scope of this Abstract Specification. This could include local solar time, which is useful, for example, for the calculation of illumination levels and the length of shadows on aerial photography, or relativistic time for very fast moving features.

7.6.1. Accountancy

The financial and administrative domains often use weeks, quarters, and other calendrical measures. These may be convenient for the requisite tasks, but are usually inappropriate for scientific or technical purposes. This Abstract Conceptual Model for Time can support this regime.

7.6.2. Agents and Agency

Agents require a different concept of time from regimes where time is a coordinate axis or measured by clocks. An agent is an entity that senses, responds, and maintains a model of its environment, while performing actions to achieve its goals. See ISO/IEC 22989:2022, Artificial intelligence concepts and terminology. For an agent, the conceptual model of time is about flow and continuity including a sense of now, a memory of past events, and a speculation about future events. This regime addresses how the agent has awareness of the flow of events:

- Temporal awareness integrates impression, retention, and protention, representing the continuous movement of time;
- Agents continuously revise their models of the environment by integrating new observations with existing models;
- Observations are used to update an agent's model, leading to a more accurate understanding of the environment and enabling effective goal-directed behavior.

This regime of time is relevant to any feature which has agency. This Abstract Conceptual Model for Time can support this regime.

7.6.3. Astronomical Time

Astronomers have traditionally measured the apparent locations of stars, planets and other heavenly bodies by measuring angular separations from reference points or lines and the timing of transits across a meridian. Generally astronomers use time determined by earth's motion relative to the distant stars rather than the sun. This is called sidereal time. Times are usually measured from an epoch in daylight, such as local midday, rather than midnight. Accurate measurements of positions of stars, planets and moons were and are essential for navigation on

Earth. See the book Astronomical Algorithms by Jean Meeus for examples of the calculations involved. This Abstract Conceptual Model for Time can support this regime.

7.6.4. Local Solar Time

Local solar time may or may not correspond to the local statutory or legal time in a country. Local solar time can be construed as a clock and timescale, with an angular measure of the apparent position of the sun along the ecliptic (path through the sky) as the basic physical principle. But the sun does not appear to progress evenly along the ecliptic throughout the days and year. There may be variations of up to 15 minutes compared to an even angular speed. This Abstract Conceptual Model for Time can support this regime.

7.6.5. Space-time

When dealing with moving objects, the location of the object in space depends on its location in time. That is to say, location is an event in space and time.

Originally developed by Hermann Minkowski to support work in Special Relativity, the concept of space-time is useful whenever the location of an object in space is dependent on its location in time.

Since the speed of light, c , in a vacuum is a observable constant, space-time uses that constant to create a coordinate axis with spatial units of measure (meters per second * seconds = meters). The result is coordinate reference system with four orthogonal axes all with the same units of measure, that is, distance. However, the measure of distance in this 4D space is not the usual Pythagorean $d^2 = x^2 + y^2 + z^2 + (ct)^2$ but $d^2 = x^2 + y^2 + z^2 - (ct)^2$, so reality is constrained to lying within a double cone subset around the ct axis of the full space.

7.6.6. Relativistic

A regime may be needed for ‘space-time’, off the planet Earth, such as for recording and predicting space weather approaching from the sun, where the speed of light and relativistic effects such as gravity may be relevant.

Once off planet Earth, distances and velocities can become very large. The speed of light becomes a limiting factor in measuring both where and when an event takes place. Special Relativity deals with the accurate measurement of space-time events as measured between two moving objects. The core concepts are the Lorentz Transforms. These transforms allow one to calculate the degree of “contraction” a measurement undergoes due to the relative velocity between the observing and observed object.

The key to this approach is to ensure each moving feature of interest has its own local clock and time, known as its ‘proper time’. This example can be construed as a fitting into the clock and timescale regime of this Abstract Specification. The relativistic effects are addressed through the relationships between the separate clocks, positions and velocities of the features.

Relativistic effects may need to be considered for satellites and other spacecraft because of their relative speed and position in Earth's gravity well.

The presence of gravitational effects requires special relativity to be replaced by general relativity, and it can no longer be assumed that space (or space-time) is Euclidean. That is, Pythagoras' Theorem does not hold except locally over small areas, or that the circumference of a circle is not precisely $2\pi r$. This is somewhat familiar territory for geospatial experts. This Abstract Conceptual Model for Time can support this regime, providing each feature has its own clock.

8

ABSTRACT CONCEPTUAL MODEL FOR TIME

8 ABSTRACT CONCEPTUAL MODEL FOR TIME

This Temporal Abstract Conceptual Model follows ISO 19111:2019, which is the ISO adoption of OGC 18-005r8.

The model is also informed by the W3C Time Ontology in OWL.

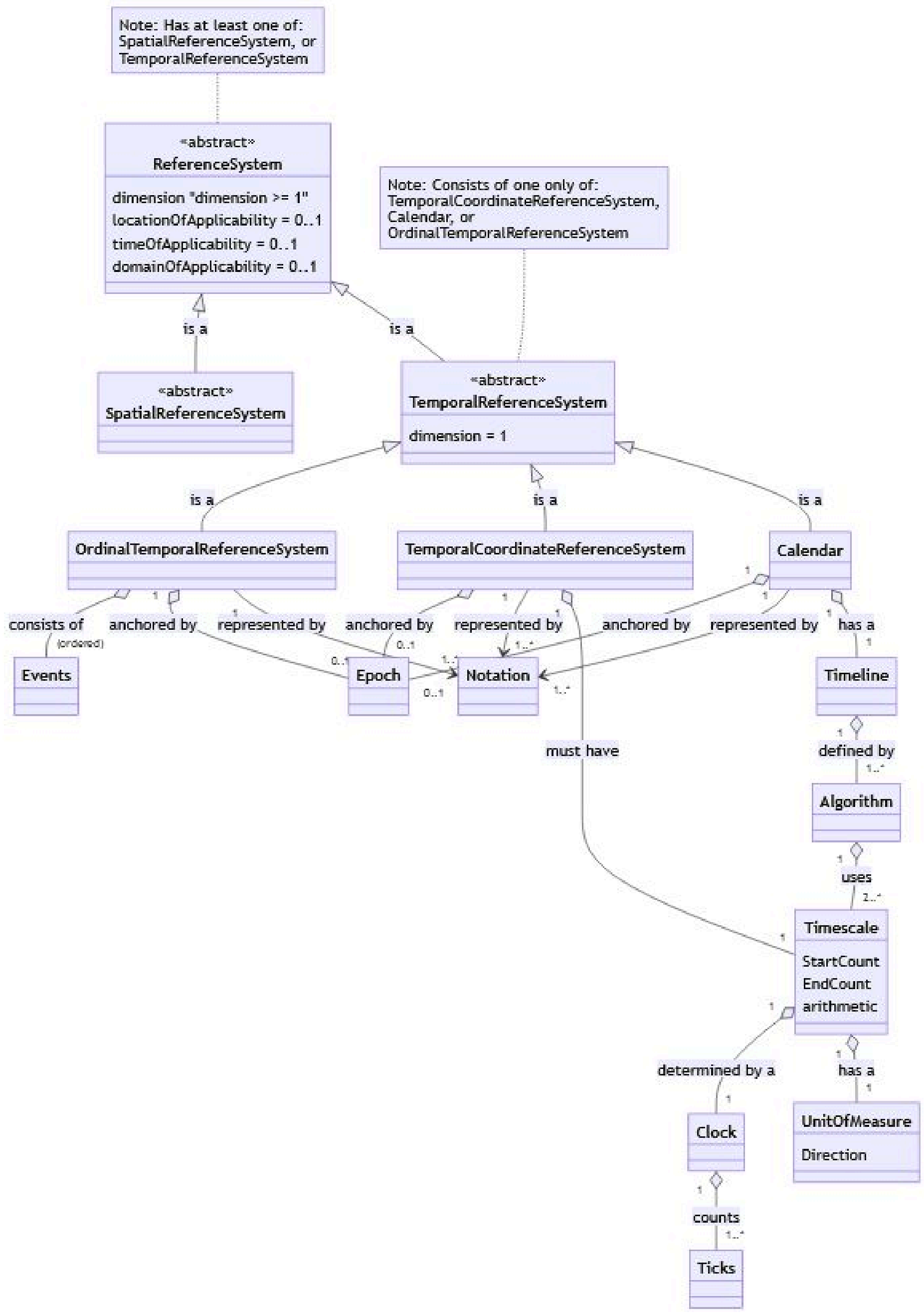


Figure 2

9

CLASSES AND THEIR ATTRIBUTES AND PROPERTIES

9 CLASSES AND THEIR ATTRIBUTES AND PROPERTIES

9.1. Reference Systems

The top level `Reference System` class is an abstract super-class and does not have many attributes or properties. Only the total dimension of the reference system and the location, time or domain of applicability have been identified as essential.

The reference system class has two abstract sub-classes: `Spatial Reference System`, which is defined in ISO 19111:2019, and `Temporal Reference System`, each with the inherited attributes of dimension and domains of applicability.

The value for dimension is one for time, or a vertical reference system, but may be as high as six for spatial location with orientation as in the GeoPose Implementation Standard.

For example, a reference system may be applicable to Mars, rather than Earth, or perhaps to a specific building site with local coordinates, or a specific time range while coordinate errors are within acceptable bounds.

Besides the conventional space and time, there may be other reference systems, such as wavelength or frequency, that could be addressed by future additions to this Abstract Conceptual Model.

9.2. Ordinal Temporal Reference Systems

An ordinal temporal reference system has a well-ordered finite sequence of events against which other events can be compared.

An ordinal temporal reference system is a type of temporal reference system. Therefore, it inherits the following attributes from the temporal reference system class:

1. applicable location time or domain: the location, time or domain of applicability;
2. dimension: the number of dimensions in this reference system. For ordinal temporal reference systems this value is fixed at 1.

An ordinal temporal reference system does not have any attributes of its own. However, it does use associations with other classes to fully describe itself.

1. Epoch: An ordinal temporal reference system may be ‘anchored by’ one optional Epoch

2. Notation: An ordinal temporal reference system ‘is represented by’ one or more Notations to represent itself.

3. Event: An ordinal temporal reference system ‘consists of’ an ordered set of Events. These events are identifiable temporal instances.

Example: Ancient annals of a country may give a sequence of emperors which could be used to ‘date’ another event such as “Emperor Gaozu (Chinese: 漢高祖) built a canal”, or may be used to date a particular reign. For example: “In the reign of Emperor Qin Shi Huang (Chinese: 秦始皇), a comet was sighted” and later research identifies this as an appearance of Halley’s Comet.

9.2.1. Events

An event is an identifiable happening or occurence of something. The events can be instants, such as the ascension of a king to a throne, or intervals, such as the complete reign of each king.

Other documents may enable two such ‘king lists’ to be related, though usually not completely.

Example: Several archeological layers may be identified as containing broken pottery, overlaid with a layer of burnt wood and brick, then followed by another layer with a different style of pottery and including a coin embossed with a king’s name. Thus the pottery styles can be classified as ‘early’ and ‘late’ and the late pottery associated with the named king, who may be identified from a separate inscribed ‘king list’.

9.3. Temporal Coordinate Reference Systems

A temporal coordinate reference system is a type of temporal reference system. Therefore, it inherits the following attributes from the temporal reference system class:

1. applicable location time or domain: the location, time or domain of applicability;

2. dimension: the number of dimensions in this reference system. For temporal coordinate reference systems this value is fixed at 1.

A temporal coordinate reference system does not have any attributes of its own. However, it does use associations with other classes to fully describe itself.

1. Epoch: A temporal coordinate reference system ‘anchored by’ one optional Epochs

2. Notation: A temporal coordinate reference system ‘represented by’ one or more Notations to represent itself.

3. Timescale: A temporal coordinate reference system ‘must have’ one Timescale which is used to represent the values along its single axis. This timescale can be either discrete or continuous.

9.4. Calendar Reference Systems

Calendars combine different timescales and their clocks and units of measure, and other events, to make a complex timeline against which events can be compared. Calculated algorithms are used to determine which instants or intervals on the compound timeline are identified and labeled.

A calendar is a type of temporal reference system. Therefore, it inherits the following attributes from the temporal reference system class:

1. applicable location time or domain: the location, time or domain of applicability
2. dimension: the number of dimensions in this reference system. For calendars this value is fixed at 1.

A calendar does not have any attributes of its own. However, it does use associations with other classes to fully describe itself.

1. Timeline: A calendar ‘has a’ one Timeline which serves to aggregate a number of Timescales into a single coherent measure of date and time.
2. Algorithm: A timeline ‘is defined by’ one or more Algorithms. These algorithms specify how the multiple timescales are aggregated into a single Timeline.
3. Timescale: An algorithm ‘uses’ two or more Timescales which are used to construct a Timeline.
4. Epoch: A calendar is ‘anchored by’ one optional Epoch
5. Notation: A calendar is ‘represented by’ one or more Notations to represent itself.

9.4.1. Timeline

The timeline is usually a set of instants from the past to the future and is compounded from multiple timescales, with multiple units of measures, and complicated arithmetic determined by the calendar algorithm(s). The timeline is usually not even continuous, having gaps or even duplicated times or multiple simultaneous representations.

A timeline does not have any attributes of its own. Nor does it inherit any attributes from a parent class. However, it does use associations with other classes to fully describe itself.

1. Algorithm: A timeline is 'defined by' one or more Algorithms. These algorithms specify how the multiple timescales are aggregated into a single timeline.
2. Timescale: An algorithm 'uses' two or more Timescales which are used to construct a timeline.

9.4.2. Algorithm

An algorithm specifies the logic used to construct a timeline from its constituent Timescales. An algorithm does not have any attributes of its own. It does make use of timescales to construct the timeline of a calendar.

1. Timescale: An algorithm 'uses' two or more Timescales which are used to construct a timeline.

9.4.3. Calendar Examples

Example 1: The modern Gregorian calendar is a calculated solar calendar, with various epochs from 1588 CE through to 1922 CE depending on location or country.

The constituent timescales are days (earth's rotations), months (moon's orbit around the earth), years (earth's orbit around the sun) and seconds determined by atomic clocks. To accommodate discrepancies, leap days and leap seconds are intercalated in some years. The commonest notations for the Gregorian calendar are ISO 8601 and its various restrictive profiles.

Example 2: The timeline in a country may have gaps when clocks 'spring forward' for enacting daylight-saving time. There may not be any time corresponding to the times between 01:00 and 02:00. When the daylight-saving time is revoked, and clocks 'fall back', the times between 01:00 and 02:00 occur twice.

Example 3: The modern Islamic calendar is an observed lunar calendar, and the major religious dates progress throughout the year, year on year. The important months are determined by the observation of new moons from Mecca.

Example 4: The modern Jewish calendar is a calculated lunisolar calendar, and discrepancies from the solar year are addressed by adding 'leap months' every few years.

Example 5: The Ba'hai calendar is a calculated solar calendar, but without any other astronomical aspects. The year consists of 19 months of 19 days each, with 4 or 5 intercalated days for a new year holiday.

Example 6: The West African Yoruba traditional calendar is a solar calendar with months, but rather than subdividing a nominal month of 28 days into 4 weeks, 7 weeks of 4 days are used. This perhaps gave rise to the fortnightly (every 8 days) markets in many villages in the grasslands of north-west Cameroon.

Example 7: Teams controlling remote vehicles on Mars use a solar calendar, with Martian years and Martian days (called sols). Months are not used because there are two moons, with different, rather short, orbital periods.

Example 8: The International Fixed Calendar was a solar calendar with 13 months of 28 days, with an extra day at the year's end after the thirteenth month and leap days inserted at the end of the sixth month. Months all started on the same day of the week, Sunday, and ended on a Saturday. The year-end day and leap days are not part of any week. The IFC was considered for global introduction by the League of Nations but finally rejected in 1937, though it formed the basis for some financial accounting systems for many years.

9.5. Discrete and Continuous Time Scales

A clock may be a regular, repeating, physical event, or tick, that can be counted. The sequence of tick counts form a discrete (counted) timescale.

Some clocks allow the measurement of intervals between ticks, such as the movement of the sun across the sky. Alternatively, the ticks may not be completely distinguishable, but are still stable enough over the time of applicability to allow measurements rather than counting to determine the passage of time. These clocks generate a continuous (measured) timescale.

The duration of a tick is assumed constant. The duration of a tick is specified using a Unit Of Measure.

9.5.1. Timescale

A timescale is a linear measurement (one dimension) used to measure or count monotonic events. Timescale has three attributes:

1. Arithmetic: an indicator of whether this timescale contains counted integers or measured real/floating point numbers.
2. StartCount: the lowest value in a timescale. The data type of this attribute is specified by the 'arithmetic' attribute.
3. EndCount: the greatest value in a timescale. The data type of this attribute is specified by the 'arithmetic' attribute.

In addition to the attributes, the timescale class maintains associations with two other classes to complete its definition.

1. Clock: A timescale is 'determined by' one clock. This is the process which generates the ticks which are counted or measured for the timescale.

2. UnitOfMeasure: A timescale ‘has a’ one UnitOfMeasure. This class specifies the units of the clock measurement or count as well as the direction of increase of that measurement or count.

9.5.2. Clock

A clock represents the process which generates the ticks which are counted or measured for a timescale. Clock does not have any attributes of its own. Nor does it inherit any attributes from a parent class. However, it does use an association with another class to fully describe itself.

1. Ticks: a description of the process which is being used to generate monotonic events.

Example 1: An atomic clock may be calibrated to be valid only for a given temperature range and altitude.

Example 2: A pendulum clock may have each tick or swing of the pendulum adjusted to be an exact fraction or multiple of a second. The famous London “Big Ben” clock’s pendulum is 4.4 m long and ticks every two seconds.

9.5.3. Unit of Measure

The direction attribute indicates whether counts or measures increase in the positive (future) or negative (past) direction. The attribute could be part of timescale or temporal coordinate reference system rather than a separate class of measure, but on balance, it seems better here, as the names often imply directionality, such as fathoms increasing downwards, MYA (Millions of Years Ago) increasing earlier, atmospheric pressure in hPa (hectopascals) decreasing upwards, and FL (flight level) increasing upwards.

1. Direction: indicates the direction in which a timescale progresses as new ticks are counted or measured.

Example: The number of the years before the Current Era (BCE, previously known as BC) increase further back in time, whereas the number of the years in the Current Era (CE, previously known as AD) increase further into the future. This is an example of two timescales, adjacent but with no overlap. If there was a year zero defined, they could be replaced with one continuous timescale.

9.5.4. Time Scale Examples

Example 1: A long, deep ice core is retrieved from an ice sheet. From chemical identification of layers representing known large scale volcanic eruptions, the connection between depth and time is known, so length can be converted to time. This enables the dates of some previously unknown large scale volcanic eruptions to be identified and timed.

Example 2: A long, deep, sediment core is extracted from the bottom of a lake with a long geological history. Two layers in the core are dated using radiocarbon dating. Assuming steady rates of sediment deposition, a continuous timescale can be interpolated between the dated layers, and extrapolated before and after the dated layers.

Example 3: A well preserved fossilized log is recovered and the tree rings establish an annual 'tick'. The start and end times may be known accurately by comparison and matching with other known tree ring sequences, or perhaps only dated imprecisely via Carbon Dating, or its archaeological or geological context.

Example 4: A clock is started, but undergoes a calibration process against some standard clock, so the initial, reliable start time does not start at a count of zero. The clock is accidentally knocked so that it is no longer correctly calibrated, but is still working. The end time is not the last time that the clock ticks.

Example 5: TAI International Atomic Time (or Temps Atomique International) is coordinated by the BIPM (International Bureau of Weights and Measures, Bureau International de Poids et Measures) in Paris, France. TAI is based on the average of hundreds of separate atomic clocks around the world, all corrected to be at mean sea level and standard pressure and temperature. The epoch is defined by Julian Date 2443144.5003725 (1 January 1977 00:00:32.184).

Example 6: The Julian Day is the continuous count of days (rotations of the Earth with respect to the Sun) since the beginning of the year 4173 BCE and will terminate at the end of the year 3267 CE. The count then starts again as "Period 2". Many computer based timescales, such as Unix Time, are based on the Julian Day timescale, but with different epochs, to fit the large numbers into computer words of limited size.

9.6. Supporting Classes

9.6.1. Epoch

The epoch class provides an origin or datum for a temporal reference system.

9.6.2. Notation

The notation class identifies a widely agreed, commonly accepted, notation for representing values in accordance with a temporal reference system.

10

NOTATION

10 NOTATION

There are often widely agreed, commonly accepted, notations used for temporal reference systems, but few have been standardized. Any particular notation may be capable of expressing a wider range of times than are valid for the reference system.

Example: The IETF RFC 3339 timestamp notation, a restrictive profile of ISO 8601, can express times before 1582CE, when the Gregorian calendar was first introduced in some parts of the world.

11

SYNCHRONIZATION OF CLOCKS

11 SYNCHRONIZATION OF CLOCKS

If there are two or more clocks, stationary with respect to each other, and a practical method of communicating their times to each other, the clocks can be perfectly synchronized.

However, if the clocks are moving with respect to each other, perfect synchronization would require communication to be instantaneous. As communication speed is limited by the finite constant speed of light, perfect synchronization is not possible, though repetitive protocols can be used to reduce the synchronization error to any practical desired level.

See the book A Brief History of Timekeeping, pages 187-191.

12

TEMPORAL GEOMETRY

12 TEMPORAL GEOMETRY

The geospatial community has often used analogies between space and time to construct 'temporal-geometry'. This analogy is useful but can be misleading and must not be taken too far. For example, taken from A Treatise on Time and Space by J R Lucas, and assuming a `thing` has classical rather than quantum properties:

1.1 A thing cannot be in two places at one time;

1.2 A thing can be in one place at two times;

2.1 Two things cannot be in the same place at the same time;

2.2 Two things can be in the same place at different times.

These statements are not symmetrical between space and time.

Temporal constructs such as instants, durations or intervals, multi-instants (a set of instants), and multi-intervals (a set of intervals) are not included in this conceptual model. These do have strongly analogous equivalents in space, such as points and multi-points, especially in a single dimension, such as vertical. The temporal constructs are well described in Maintaining Knowledge about Temporal Intervals by J. F. Allen (see Figure 1) and apply across all of the regimes, so do not need to be in this Abstract Conceptual Model.

A

ANNEX A (INFORMATIVE) EXAMPLES

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ANNEX A (INFORMATIVE) EXAMPLES

These show how the concepts of the Abstract Cocenptual Model for Time can be applied to realistic use cases. Of course, the logical and implementation details are outside the scope of this standard.

A.1. Ordinal Temporal Reference System

Geological eras and periods are forms of compound ordinal reference systems. A consistent sequence of rock strata in a region form an ordinal temporal reference system with the events being ordered by changes from one type of rock stratum to another immediately above it, or by the appearance of distinctly different embedded fossils in the rock layers.

Another consistent sequence of strata from another region can also form another ordinal temporal reference system. It may be possible to relate the two systems to each other because of layers that may share specific varieties of fossils, or a specific distinctive stratum type.

Figure A.1 shows how the four different geological ordinal temporal reference systems of sequences of rocks and fossils, called Periods, from west Wales (Ordovician), south Wales (Silurian), Devon (Devonian), and coal-bearing rocks (Carboniferous) have been combined to define a longer geological ordinal temporal reference system called the Paleozoic Era.

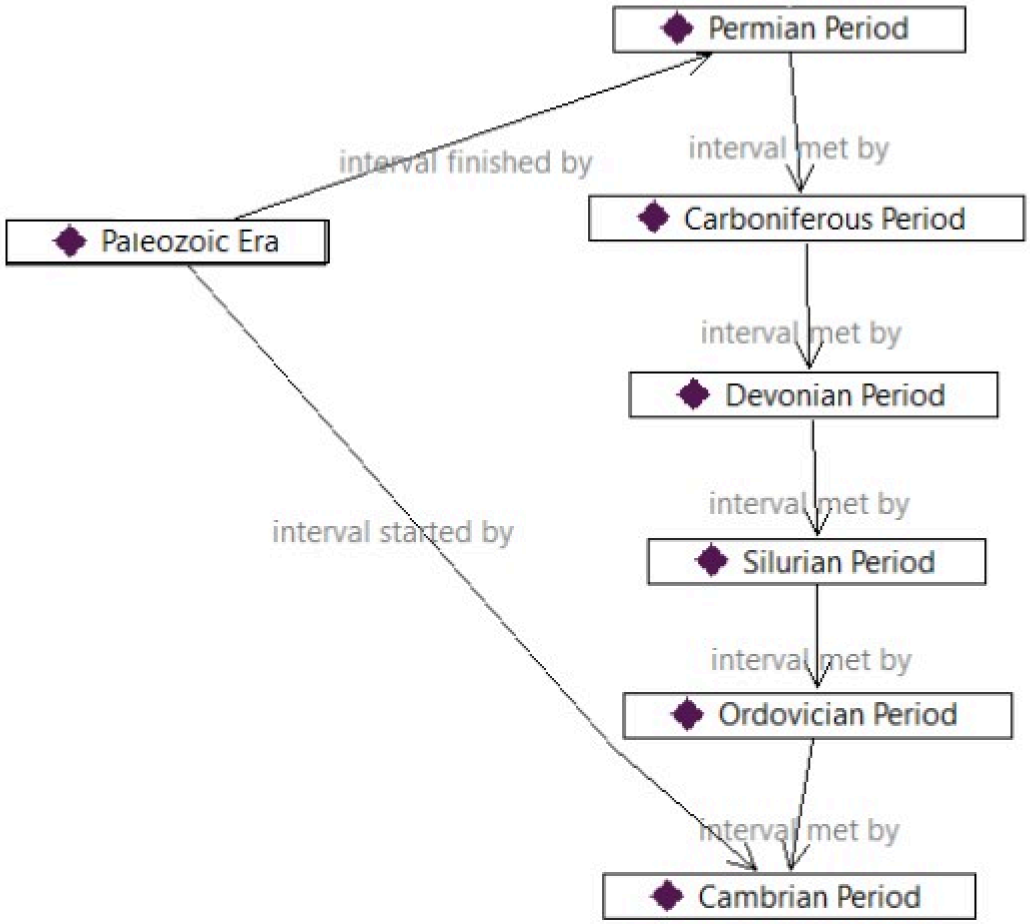

Figure A.1

A.2. Temporal Coordinate Reference System

1. A remote autonomous underwater drone, known as a 'glider' is making regular measurements of temperature and salinity deep in the Atlantic Ocean. The measurements are time-stamped by an on-board computer clock. The clock was synchronized to a satellite's atomic clock when the drone was launched. When the drone surfaces to report its findings, or to be picked up by a research vessel, it is found that the computer clock has 'drifted' compared to time from the satellite. The drone's clock is assumed to have 'drifted' in a consistent, linear, fashion, and the error correction is distributed proportionately along the time series of measurements.

2. Several timescales have been defined using the same atomic clocks. For various reasons, such as the year of starting, or the need to store numbers in limited length computer words, different epochs have been chosen. This is illustrated in Figure A.2. The figure also illustrates how UTC is not a timescale, but a timeline, as it has been adjusted with leap seconds to correspond to the Gregorian

calendar and not deviate more than 0.6 seconds from Earth's actual day length. This is because UTC is based on the atomic definition of a second, the SI second, whereas the Gregorian calendar assumes that a day, based on Earth's rotation with respect to the sun, is 86,400 seconds, but this daily rotation varies in duration every day throughout the year for a variety of reasons.

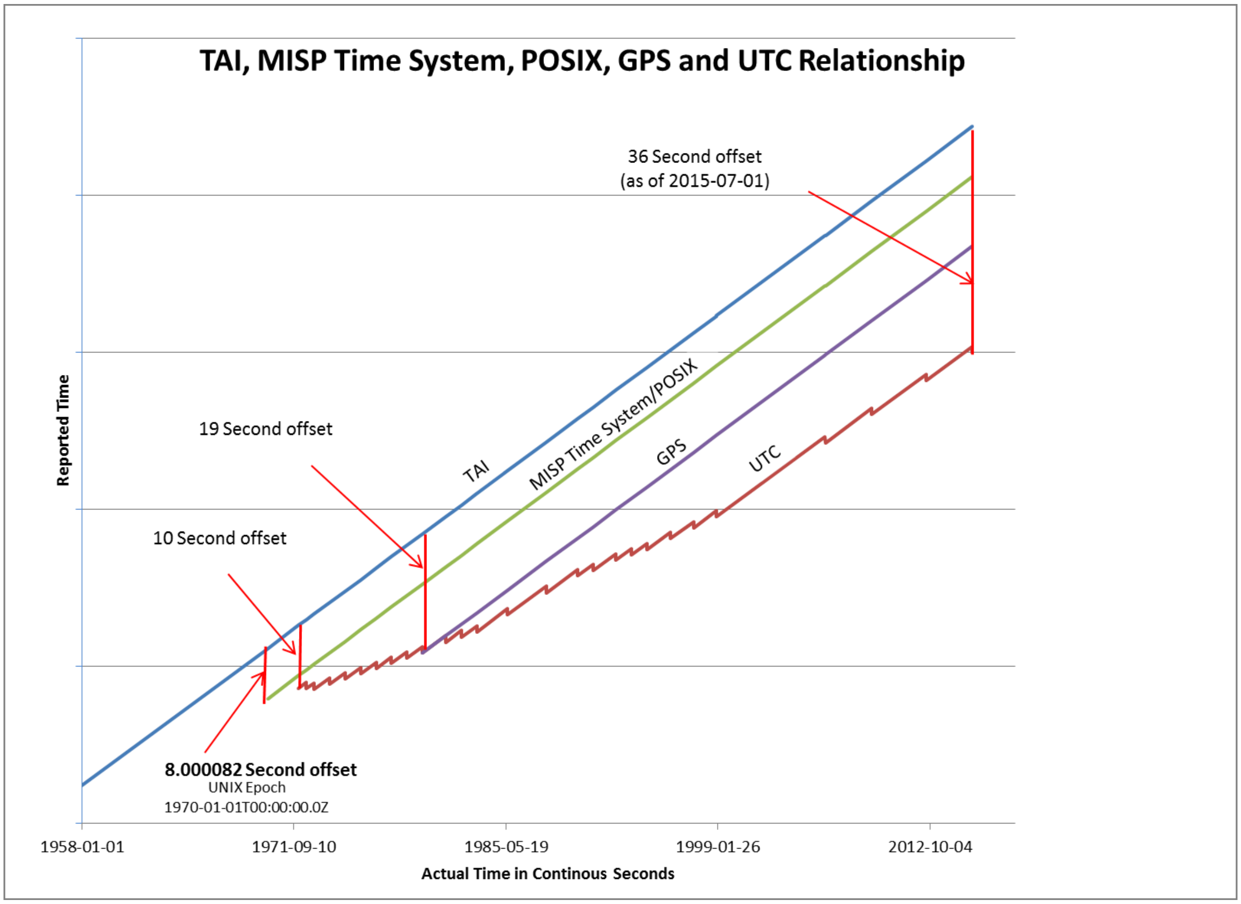

Figure A.2

A.3. Calendar

A remote and partially autonomous 'rover' is on Mars. To manage activities, a Mars calendar is needed. The year is determined by Mars's orbit around the Sun with respect to a distant fixed point (usually in the constellation of Aries, as used for Earth's year). This is one timescale, with a unit of measure "Mars Year" to avoid confusion with Earth years.

Months are not useful as there are two small fast moving moons. One orbits three times per Mars day, the other about every 1 1/2 Mars days, so they do not supply a useful intermediate duration between years and days.

The 'day', the rotation of Mars on its axis with respect to the Sun, is the other timescale that comprises the Mars calendar. To avoid confusion with Earth's days, they are called 'Sols'. This solar day, with a similar definition to an Earth day, would be useful for planning day time and night time activities, pehaps requiring solar power generation.

Other definitions of a day could have been adopted:

1. A sidereal Mars day, the rotation of Mars with respect to the distant stars, like the sidereal day on Earth. This could be useful if the rover was performing astronomical measurements, such as for navigating using the equivalent of a sextant;

2. An Earth orientated day, the rotation of Mars with respect to Earth in its orbit. This could be useful for planning activities needing extended communication periods with direct line-of-sight with Earth.

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