CRMgeo: Linking the CIDOC CRM to GeoSPARQL through a Spatiotemporal Refinement

TECHNICAL REPORT: ICS-FORTH/TR-435, April 2013

Martin Doerr[1], Gerald Hiebel[1]

[1]Institute of Computer Science, FORTH, N. Plastira 1100, Vassilika Vouton, GR-70013 Heraklion, Greece

{ martin@ics.forth.gr, gerald@ics.forth.gr }

Contributer: Øyvind Eide[2]

[2]Unit for Digital Documentation, University of Oslo

{ oyvind.eide@iln.uio.no }

Abstract: There is a rising interest to enrich cultural heritage data with precise and well identified descriptions of location and geometry of sites of historical events or remains, objects and natural features. The "geospatial community" and the "cultural heritage community" have developed standards reflecting different foci – the OGC/ISO Standards for Geographic Information and the ontology of the CIDOC CRM which is the ISO standard for representing cultural heritage information. This report introduces the CRMgeo extension for the CIDOC CRM to provide an "articulation" (linkage) between the standards of the geospatial and the cultural heritage community in particular between GeoSPARQL and CIDOC CRM. The model was developed from the analysis of the epistemological processes of defining, using and determining places. This means that we analyzed how a question, such as "is this the place of the Varus Battle" or "is this the place where Lord Nelson died", can be verified or falsified, including geometric specifications. Consequently, we reached at a detailed model which seems to give a complete account of all practical components necessary to verify such a question, in agreement with the laws of physics, the practice of geometric measurement and archaeological reasoning. This model indeed appears to have the capability to link both ontologies and shows the way how to correctly reconcile data at any scale and time – not by inventing precision or truth that cannot be acquired, but by quantifying or delimiting the inherent indeterminacies, as it is good practice in natural sciences. This model aims at being a comprehensive theory from which mutually compatible simplification can be derived for implementations in more constraint environment, such at those lacking moving frames.

1 Introduction

There is a rising interest to enrich cultural heritage data with precise and well identified descriptions of location and geometry of sites of historical events or remains, objects and natural features. On one side there is already a tradition of more than 2 decades of using GIS systems for representing cultural-historical and archaeological data and reasoning on properties of spatial distribution, vicinity, accessibility and others. These systems tended to be closed and focused more on representing feature categories by visual symbols at different scales than integrating rich object descriptions. Cultural heritage is only a marginal application case for these systems, they have been being extremely successful in all kinds of "geosciences", resource management and public administration.

On the other side, archives, libraries and museums keep detailed historical records of things with very poor spatial determination – frequently in the language of the source or local context, in which at their time of creation there was few ambiguity about their meaning, and frequently only wider geopolitical units, such as "Parthenon in Athens". They rather focus on typologies, individual objects, people, kinds of events, precise dates and periods. This practice comes now in conflict when users want to integrate city plans, tourism guides, detailed excavation or restauration records, where the fact that "people know quite well where the Parthenon lies" or "you'll see it when you go to Athens" is not helpful for advanced IT systems. But, the two traditions, the "GIS community" and the "cultural heritage community" have developed standards which precisely reflect the two different foci – the OGC/ISO Standards for Geographic Information which are the building blocks of the recently published GeoSPARQL ontology [OGC 2012] and the ontology of the CIDOC CRM [Le Boeff et. al 2012] which is the ISO standard for representing cultural heritage information.

In an attempt to combine these two standards [xxx], we experienced a surprise: Both standards do not really match at any concepts "in between", even though the CRM was explicitly intended to interface withOGC (Open Geospatial Consotium) Standards, and **both** standards do **not** allow for expressing objectively where something **is** in a way which is robust against any change of spatial scale and time. For instance, the CRM allows for specifying a "P…has former or current location", without declaring if the location is or was the extent of the object, was within the extent of the object or included its extent. GeoSPARQL, on the other side, allows for assigning one or more precise "geometries" to a "feature", but does not say, how the real matter of the thing with its smaller irregularities relates to those. So, for any "feature" there is a spatial scale at which a "geometry" of a detail cannot be compared any more to the geometry of the whole, nor is the temporal validity range explicitly stated although OGC Standards provide mechanisms for doing that.

What is needed is an "articulation" (linkage) of the two ontologies, i.e. a more detailed model of the overlap of both models, which allows for covering the underdetermined concepts and properties of both sides by shared specializations rather than generalizations. Therefore, we took a great step back and developed a model from the analysis of the epistemological processes of defining, using and determining places. This means that we analyzed how a question, such as "is this the place of the Varus Battle" or "is this the place where Lord Nelson died", can be verified or falsified, including geometric specifications. This required to identify all kinds of sources of errors, including questioning the truth of the very historical record.

Consequently, we reached at a surprisingly detailed model which seems to give a complete account of all practical components necessary to verify such a question, in agreement with the laws of physics, the practice of geometric measurement and archaeological reasoning. This model indeed appears to have the capability to link both ontologies and show the way to how to correctly reconcile data at any scale and time – not by inventing precision or truth that cannot be acquired, but by quantifying or delimiting the immanent indeterminacies, as it is good practice in natural sciences.

2 Motivation – The Varus battle

In this chapter we want to illustrate the motivation and process why and in which way we developped this model. Through research questions in relation to the Varus battle we introduce new concepts to represent places and define the relations between them. The example of Lord Nelsons death on board of the H.M.S. Victory illustrates the motivation to have a model that is valid for moving reference spaces.

2.1 The historical context

The Varus battle at 9 AD between 3 roman legions under Varus and allied german tribes under Arminius was decisive for the halt of the Roman expansion in German territories for the following centuries. Varus recieved a complete defeat that was described in Roman sources. A few years later roman troops again visited the battlefield and buried the roman remains that were left from the battle.

The knowledge of the precise battle place was not transfered to our age and for this reason the location of the battle was unknown since roman times. In roman sources the descriptions of the battle are found with indications of the place in relation to rivers and indications of the kind of terrain in which the battle was fought. Based on these sources there has been a discussion with various hypothesis for hundreds of years about the real place of the battle. One of the hypotheses from the 19th century was supported by archaeological finds in the late 1980s. Figure 1 visualises the three main events (battle, remains burying, excavation) of the scientific discussion by symbolic Space Time Volumes in which they occurred. Trajectories of people, physical things and information objects participating in the events or resulting from them are symbolised by arrows.

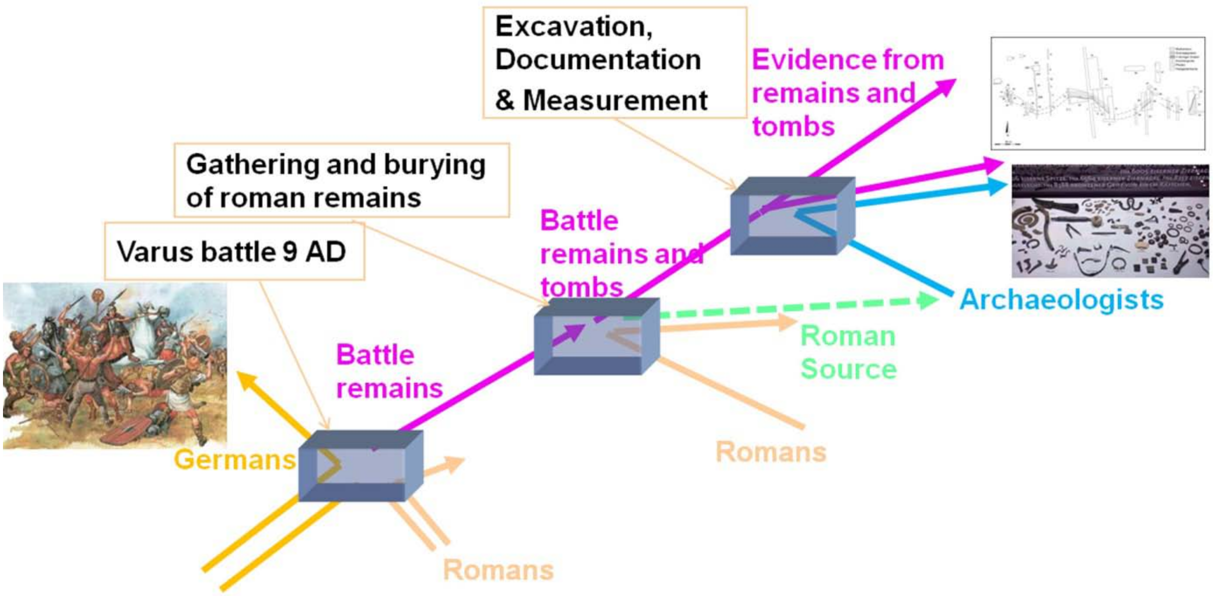

Figure 1: Main events in the discussion of the Varus battle as Space Time Volumes

2.2 What does it mean to talk about "unknown" places?

Unknown refers to our actual knowledge. From roman sources we know about the event of the Varus battle and we know it happened in today's Germany, but we do not know a further spatial approximation corresponding to a characteristic battle size of that time.

In order to have a scientific discussion about the location of the battle we need to make the following assumptions:

- the Varus battle was a true event, which means it happened in a Space Time Volume;

- this Space Time Volume has a characteristic size of a battle;
- it happened in a Reference Space that still exists (a space at rest in relation to today's geologically inert landmass under and beyond today's middle european continental plate);
- the event of the Varus Battle has a reasonable projection on this reference space which we call a “Phenomenal Place”;
- traces of the fight and roman tombs (with bones that have been buried after some exposure to the atmosphere) should be found at the phenomenal place of the battle.

The main concepts nesseccary to model these assumptions are displayed in Figure 2.

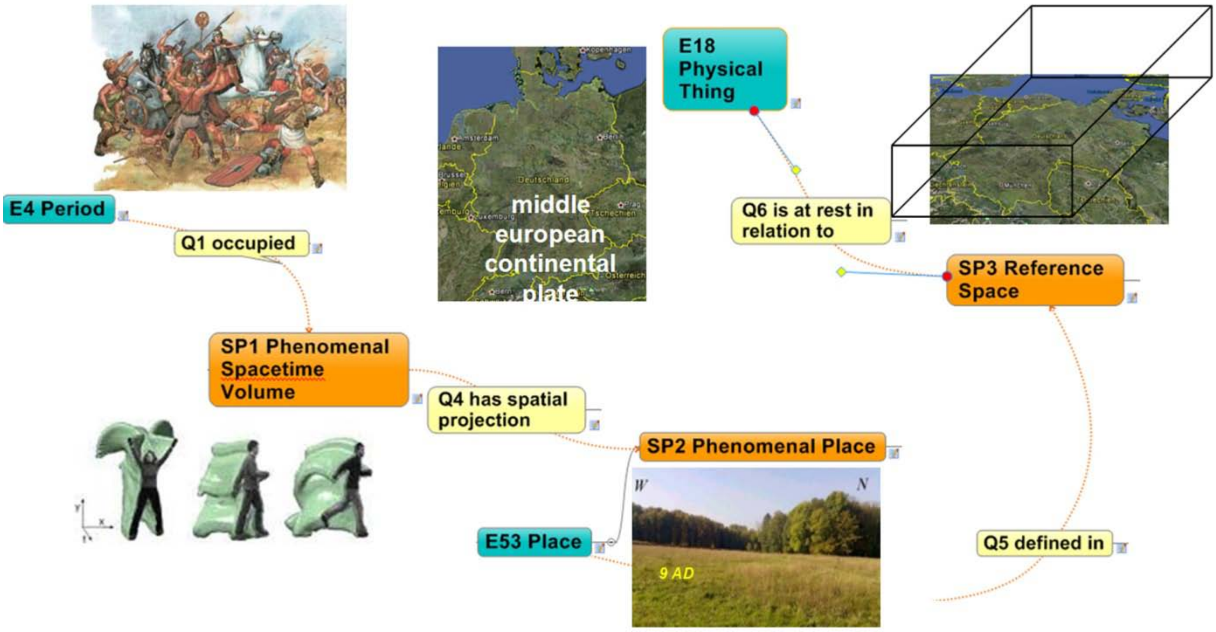

Figure 2: Main concepts and relations reflecting the assumptions

2.3 *How to state a hypothesis about the place of the Varus battle?*

After agreeing on these assumptions we want to state hypotheses about the place of the Varus battle. In order to formulate a hypothesis the reference space of the battle has to still be accessible and locations within it should be described using some kind of Reference System. For relating a reference system to the real world (here the landmass) some Reference Features are needed. If we have a reference system we can state hypotheses of the location of the battle in terms of geometric expressions containing coordinates.

These expressions we want to call “Geometric Place Expressions” relating to a known Reference System describing the Reference Space. Geometric Place Expressions define a “Declarative Place” that derives its identity through the description in the Geometric Place Expression which can be seen as prescription to find the intended place in the real world.

The relation of the Declarative Place to the true place of the Varus battle (“Phenomenal Place”) is that it is believed to approximate the real location of the battle. The concepts for stating such hypotheses are displayed in Figure 3.

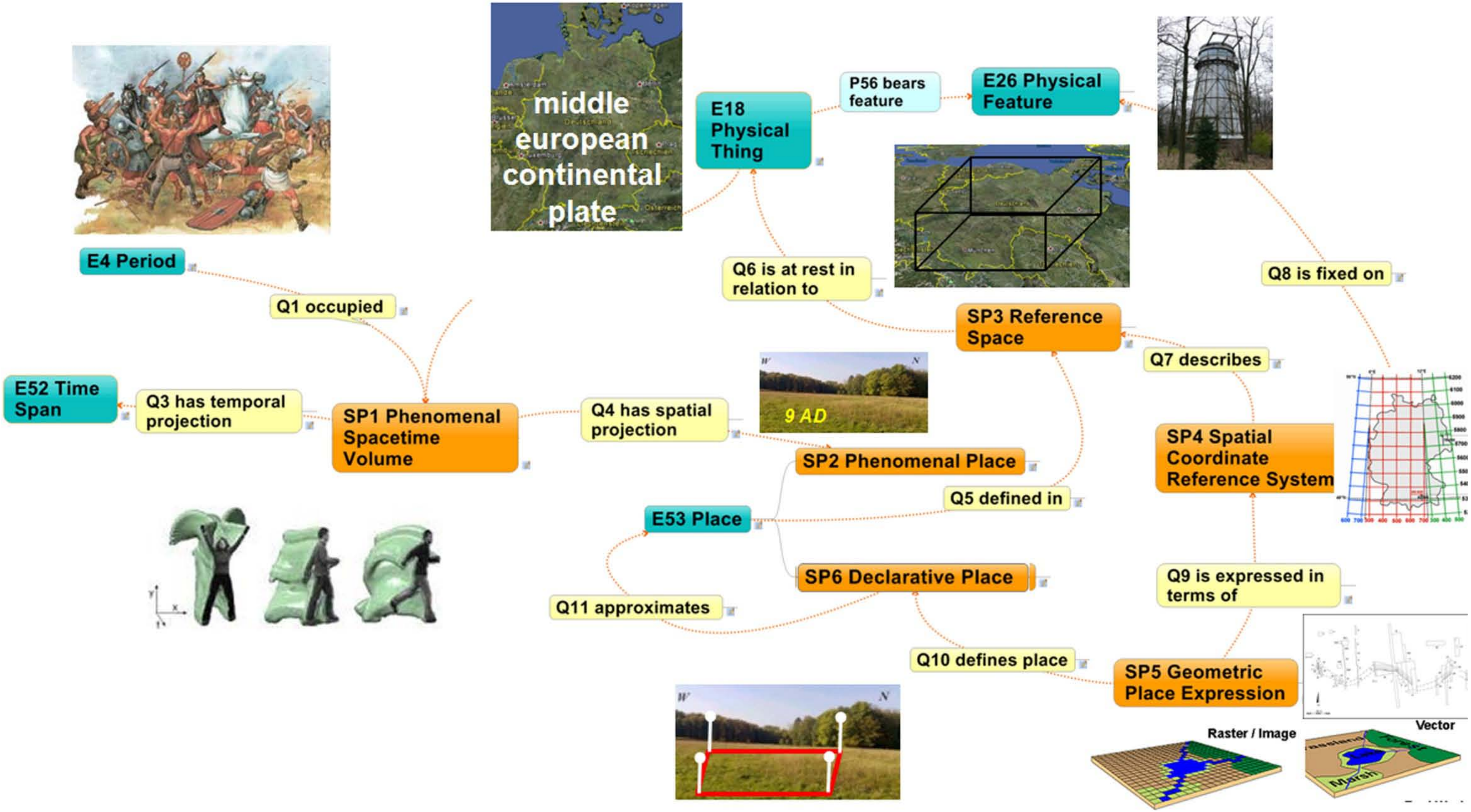

Figure 3: Concepts for stating hypothesis about places

2.4 How can we determine a Declarative Place?

In this report we want to confine the definitions of Declarative Places to Geometric Place Expressions. Other possible definitions of Declarative Places include Natural Language Place Expressions. A deeper examination and understanding of these expressions is necessary to provide a conceptual model.

Geometric Place Expressions define Declarative Places in an ideal way. Following the terms of this expression we can try to determine the corresponding physical location, i.e., a physical reality that falls within the boundaries given by the expression. The accuracy up to which we can determine these ideal boundaries in physical reality is limited by the following factors:

- the precision of determination and the geological stability of the location of the reference points within the reference system;
- the precision of distance measurement devices or GPS;
- handling errors in the measurement procedure.

Depending on these conditions we can determine an Expressional Place on the intended physical reality, for example by putting 4 poles into the ground to mark corners of a rectangle in the real landscape.

Figure 4: Determining and marking a Declarative Place in the real world

2.5 How can we verify that a Declarative Place approximates the Phenomenal Place of the Varus battle?

After I reached the Declarative Place and marked it I still have to verify if this place approximates the place of the Varus battle. This verification can only occur through an observation within the extent of the Declarative Place. In the case of the Varus battle various observations have to be mabe in order to fortify the assumption that this place approximates the real place of the battle:

- correspondance of the actual landscape to the landscape described by roman sources (taking into account potential changes in 2000 years)
- finds of battle remains that can be attributed to the described period
- find of tombs with bones that have been buried after some exposure to the atmosphere

Figure 5: Only via observations the Declarative Place can be verified as an approximation of the Phenomenal Place

In Table 1 we identified the possible Error Sources that could lead to a wrong determination of the Declarative Place approximating the Phenomenal Place of the Varus battle

Domain	Property	Range	Possible Errors
Roman Source (E73)	refers to	Varus Battle (E5)	Fictional Varus battle
Phenomenal Place (SP2)	defined in	Reference Space (SP3)	Phenomenal Place not at rest to Reference Space
Reference Space (SP3)	at rest in relation to	Physical Thing (E18)	Physical Thing (E18) lost stability of form
Spatial Coordinate Reference System (SP4)	describes	Reference Space (SP3)	Reference Points fixing the Coordinate System are imprecise, moved or lost
Geometric Place Expression (SP5)	defines place	Declarative Place (SP6)	Place Expression is not correctly measured
Declarative Place (SP6)	approximates	Phenomenal Place (SP2)	Expressional Place and Phenomenal Place do not overlap (by evidence of find)

Table 1: Possible Error Sources

2.6 Creation of Declarative Places through observations and measurements

After archaeological remains are found their positions can be measured with different methods like tachymetry or GPS. These methods can not measure positions directly but only distances and directions in relation to reference points fixed on a physical thing. In tachymetry this is more obvious as the procedure to put up a tachymetre includes the measurement of distances and directions of fixed points. Only after putting up the tachymetre correctly, positions can be calculated. Using a GPS obscures the process more as positions are the result of sophisticated measurements of distances between satellites and the GPS receiver through wavelength and time measurements.
Points are measured and interpolations between the points are made. Interpolations can be based on observations. An example would be the remains of an ancient wall where some representative points of the wall are measured and these points are connected through lines. The lines are an

interpolation based on an observation. Within the interpolation there could be an element of interpretation if parts of the wall are not existing any more but I belive that my interpolation represents the ancient wall.

The expression of measurements, interpolations or interpretations in a Geometric Place Expression creates a Declarative Place that approximates my ancient wall in an accuracy that is dependent on my measurement accuracy, the accuracy of my interpolations or interpretations and the accuracy of my Geometric Place Expression.

2.7 Motivation for Moving Reference Spaces: Lord Nelson`s death

On the example of the battle of Trafalgar between the english and allied french-spanish fleet and Lord Nelson death on the HMS Victory we want to illustrate the importance of the Reference Space concept for events taking place on moving objects. For an historian interested in Lord Nelsons death the events on board of the HMS Victory are of importance. For an archaeologist interested in the remains of the Trafalgar battle on the seafloor it is importent to formulate hypothesis in relation to the seafloor. Therefore depending on the research question the same event may be projected either on the ship as Reference Space or on the seafloor as Reference Space. Each projection creates one Phenomenal Place resulting in two Phenomenal Places of one unique Space Time Volume. The Phenomenal Place on the ship ceases to exist when the ship as base for the Reference Space ceases to exist.

The Phenomenal Place on the seafloor ceases to exist when the seafloor disapears under the continental plate (this is relevant for palaeontology). Figure 6 illustrates the projection of the one unique battle Spacetime Volume to two Reference Spaces resulting in two Phenomenal Places.

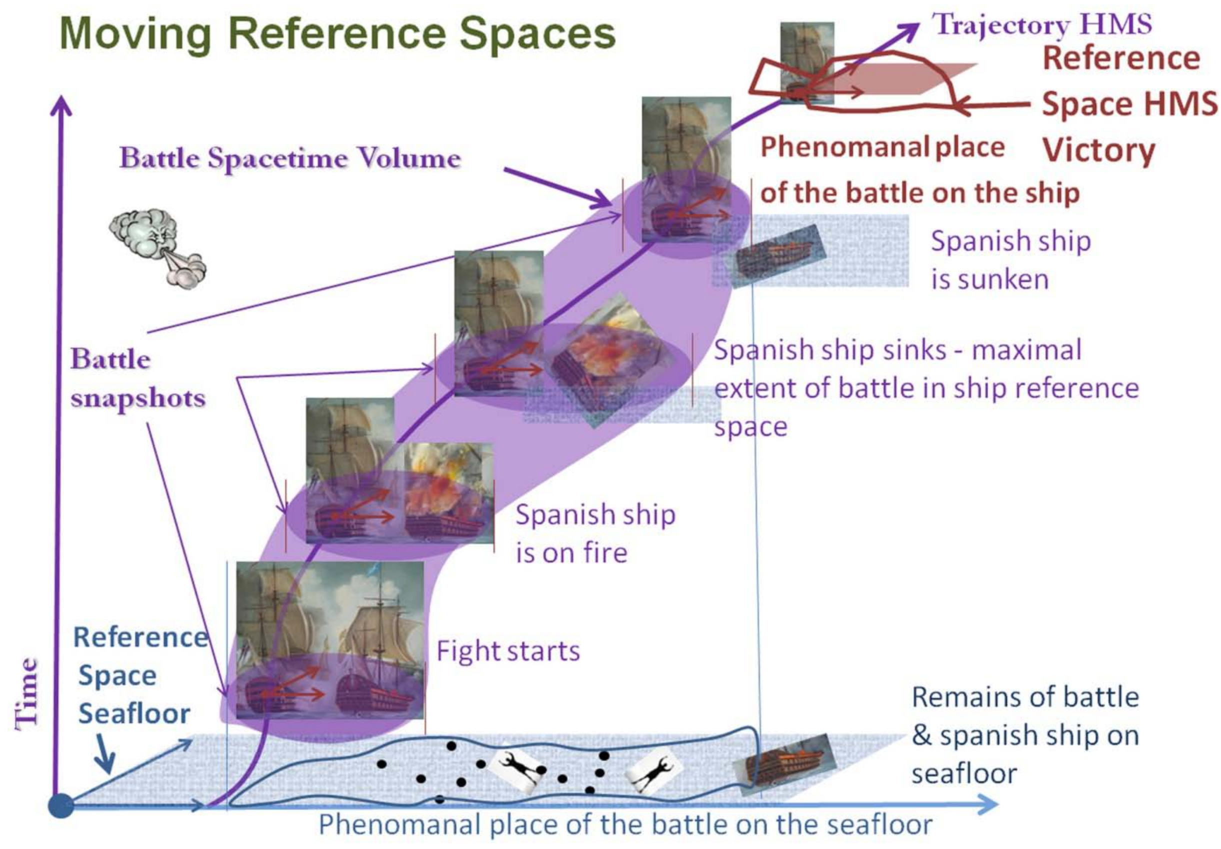

Figure 6: Events of the Trafalgar battle – Spacetime Volume projected on ship and seafloor Reference Spaces

3 A spatio-temporal refinement of the CIDOC CRM Model

3.1 Model Overview

The model developed from the analysis of epistemological processes of defining, using and determining places lead us to the conclusion that we have to define what we mean by “where” if we commit to one reality. Archaeology commits to one common reality regardless of the different opinions that exist of this reality.

A central concept representing this one reality is the Phenomenal (or true) Space Time Volume defined as a 4 dimensional fuzzy point set (volume) which material phenomena like Events or Physical Things occupy in Space-Time. It is regarded to be unique but unknown and unobservable in its exact extent. Nevertheless we can tell if we are in or out of a specific Phenomenal Space Time Volume. It is necessary to compare and relate Events or Physical Things with each other which are not defined by their Phenomenal Space Time Volumes but define it. The spatial projection of one such Volume is a Phenomenal Place which derives its identity from the Volume and thus from the Event or Physical Thing. As a Phenomenal Place depends on the Reference Space it is projected upon one unique Phenomenal Space Time Volume may have various projected Phenomenal Places that are independent from time but bound in existence through their Reference Space. The example of the death of Lord Nelson on board of the HMS Victory illustrates the existence of different Reference Spaces. The event can either be projected on the seafloor as Reference Space or on the Reference Space of the ship, thus creating two Phenomenal Places of one unique Space Time Volume. The Phenomenal Place on the ship ceases to exist when the ship as base for the Reference Space ceases to exist. The identity of a Phenomenal Place comes from the following identity chain:

Event or Pysical Thing -> Phenomenal Space Time Volume -> Phenomenal Place

As Phenomenal Places can not be exactly observed or determinated we try to approximate them. This is done through Declarative Places that are defined by humans through Place Expressions. In this paper we want to restrict us to Geometric Place Expressions that use Spatial Coordinate Reference Systems to define Declarative Places with Coordinate Expressions.

A Declarative Place could be derived from a measurement, of some points related to a physical feature or a result of interpreting a place on a map (which in turn is a result of some measurements and interpolations).

Further research will be necessary to examine the nature of natural language place expressions to define Declarative Places. A Geometric Place Expression can be created from an observation with a measurement device or the the simple drawing of a line on a map. Both actions create a Declarative Place that can be visited in the corresponding Reference Space of the real world. A Declarative Place derives its identity through a Place Expression and not through a Phenomenal Places that it may want to approximate. Thus the identity chain of a Declaritive Place looks like this:

Place Expression -> Declarative Place.

This report focuses on the explicit modeling of different identities of phenomenal and declarative places. It provides the classes and properties that relate these two kinds of places with each other. This distinction allows linking CIDOC CRM conceptualisations with OGC (Open Geospatial Consortium) concepts bridging the gap to the geoinformation world. Through this model a representation of spatial content represented in GeoSPARQL (OGC 2012) within the CRM is possible. Three classes provide the hooks for GeoSPARQL. E4 Period and E18 Physical Thing are defined subclasses of the GeoSPARQL class "Feature" and SP 5 Geometric Place Expression is defined as subclass of the GeoSPARQL class "Geometry". Figure 7 provides a graphical view of CRMgeo classes(orange) and properties, the relation to existing CIDOC CRM classes (green) and the hooks for GeoSPARQL.

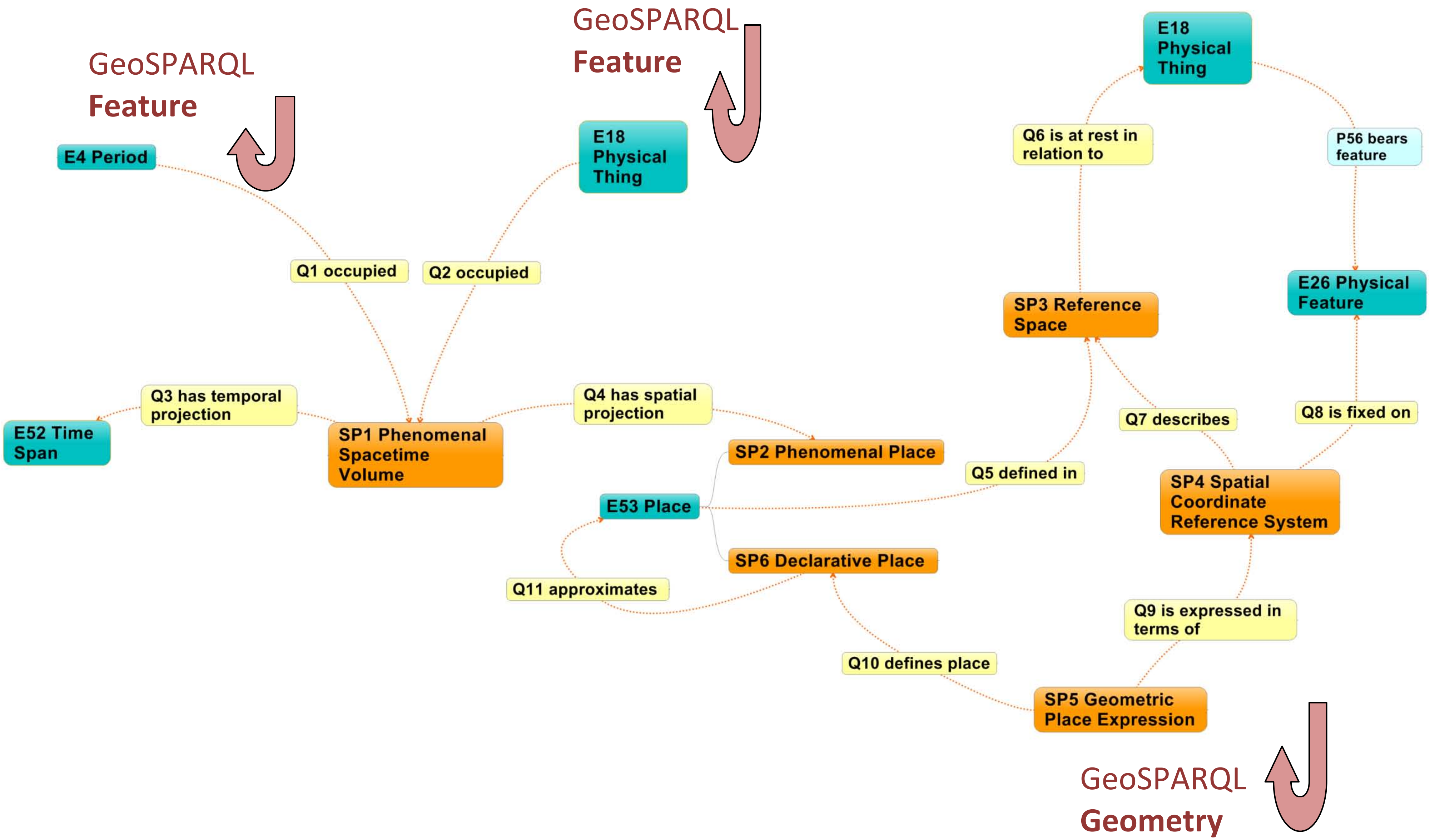

Figure 7: Graphical view of Classes and Properties to refine Place representation in the CIDOC CRM

3.2 Analog conceptualisation of Time and Spacetime Volume

Applying the above conceptualizations to time and spacetime volumes leads to the enhancement of the proposed model with seven new concepts. The already existing CIDOC CRM class “E52 Time Span” is the superclass of a “SP13 Phenomenal Time-Span” and a "SP10 Declarative Time-Span". “SP14 Time Expression” is analog to “SP5 Place Expression” and is related to a "SP11 Temporal Reference System". A general "SP8 Spacetime Volume" and a "SP7 Declarative Space Time Volume" are included in the model in order to be able to argue on space time volumes. The “SP7 Declarative Space Time Volume” is defined through a “SP12 Space Time Volume Expression” that is expressed in terms of a temporal and a spatial reference system. The expression can be a combination of a "SP 5 Geometric Place Expression" and a "SP14 Time Expression" or a different form of expressing spacetime in an integrated way like a formula containing all 4 dimensions. As we restrict the model to Galilean physics and explicitly exclude systems with very high velocities or high precsion observation of long time intervals we do not model a “Reference Time” as it would be necessary for relativistic physics. Nevertheless there are use cases containing relativistic effects like questions related to systems where satilites are involved (e.g. GPS positioning). In this case the modeling of a Reference Time would be necessary.

Figure 8 illustrates the full spatiotemporal model with its 13 new classes and the properties relating them.
The classes of the model reflect the explicit modeling of the different identities of phenomenal and declarative entities. The phenomenal world classes consist of real world phenomena and the classes representing the space and time occupied by real world phenomena. The declarative world classes consist of the defined extents in space and time through human expressions. Figure 9 illustrates the main division between phenomenal and declarative world classes and the subdivision within the phenomenal and declarative world classes.

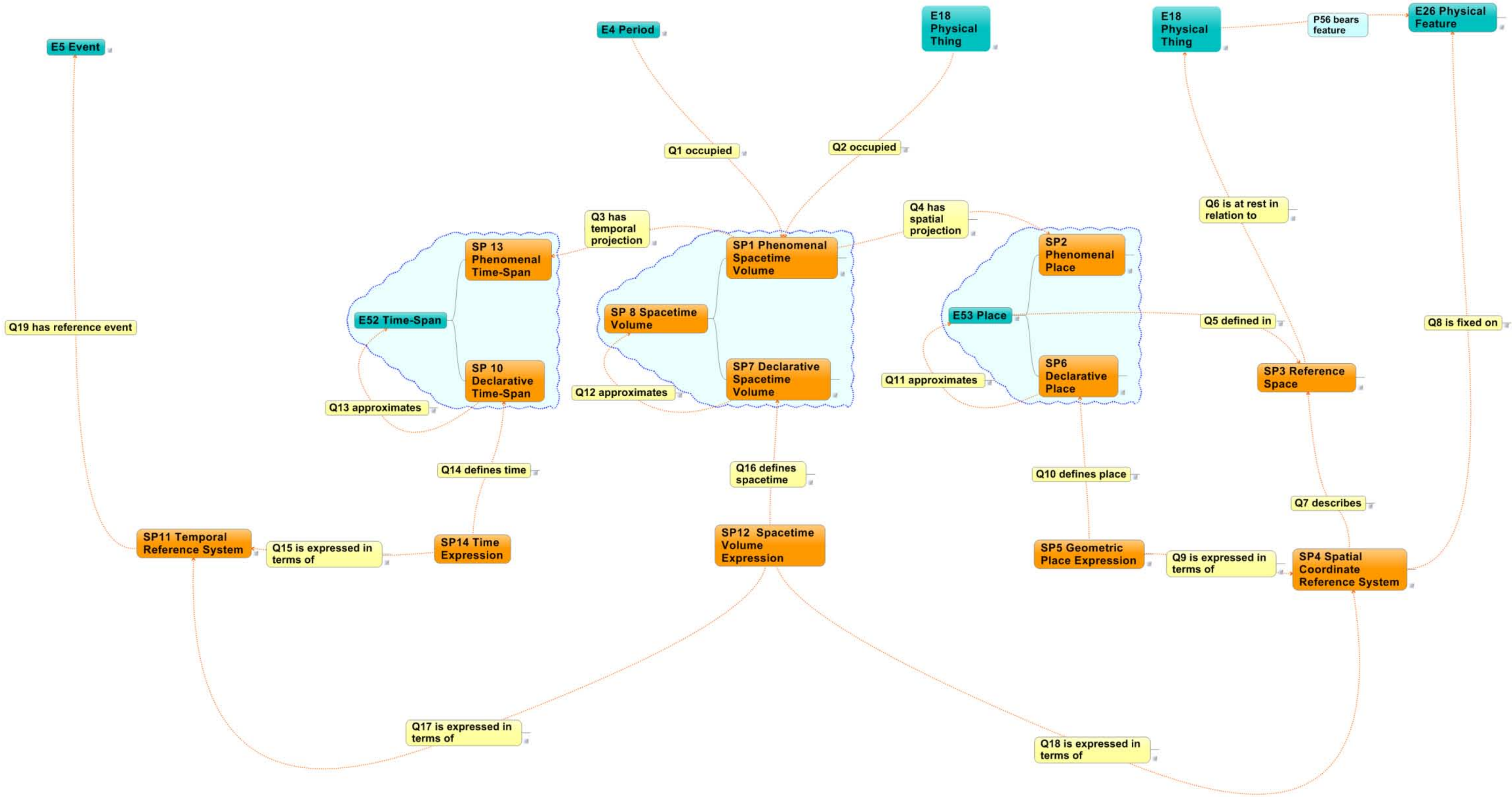

Figure 8: Graphical view of an enhanced model for analog conceptualization of time and spacetime volume

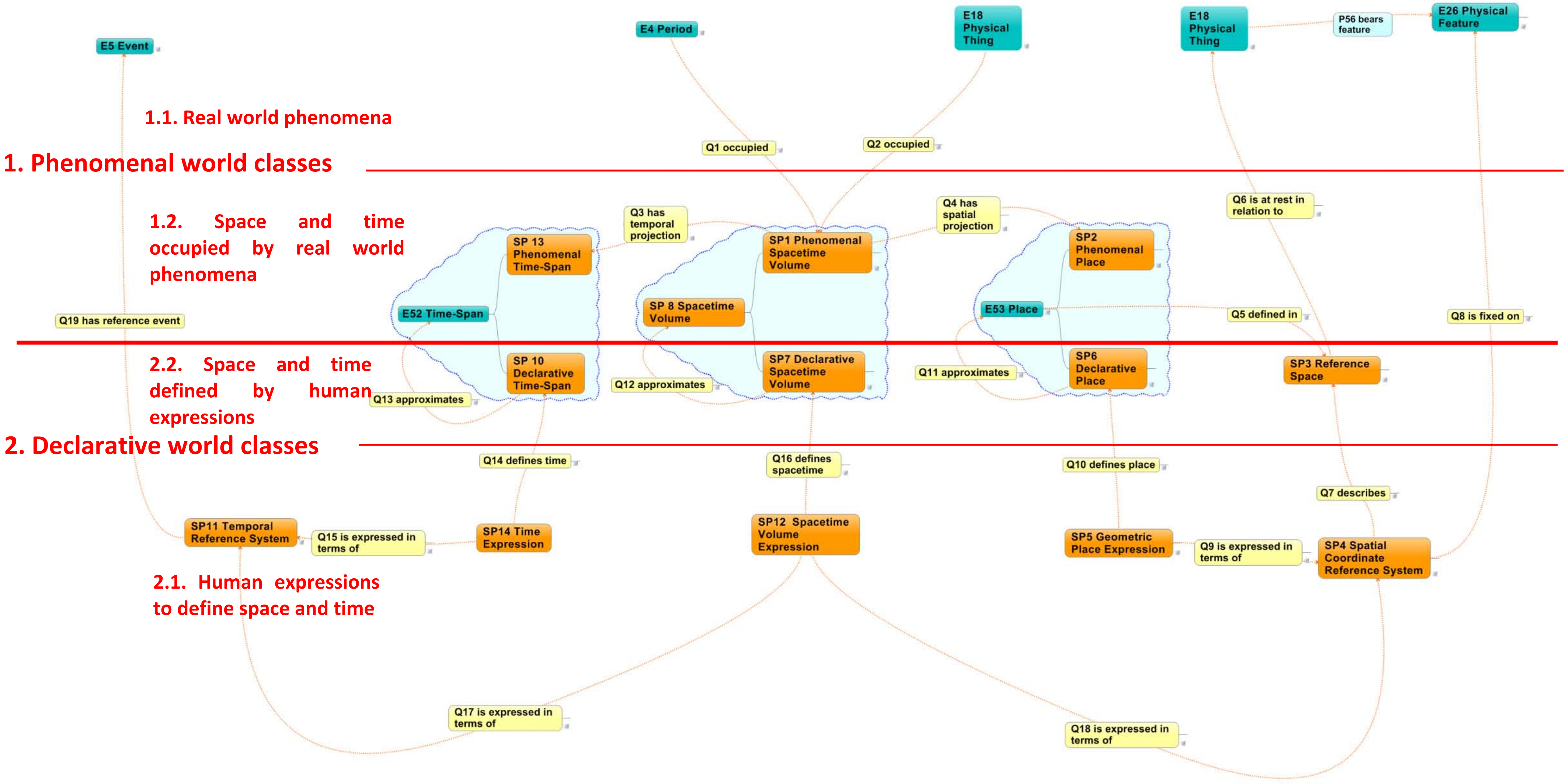

Figure 9: Graphical view of the devision between phenomenal world and declarative world within the model

3.3 Applied Form

This refinement of the CRM uses the applied form that is described within the CRM definition (Le Boeuf et al. 2012). In particular this means it is an ontology in the sense used in computer science and has been expressed as an object-oriented semantic model. It can be converted to machine-readable formats such as RDF Schema, KIF, DAML+OIL, OWL, STEP, etc.
The terminology of the CRM is used in this refinement and the intended meaning for the following terms is defined there like class, subclass, superclass, intension, extension, scope note, instance, property, subproperty, superproperty, domain, range, inheritance, ...
Quantifiers for properties are provided for the purpose of semantic clarification only, and should not be treated as implementation recommendations. The CRM has been designed to accommodate alternative opinions and incomplete information, and therefore all properties should be implemented as optional and repeatable for their domain and range ("many to many (0,n:0,n)"). Therefore the term "cardinality constraints" is avoided here, as it typically pertains to implementations. A list of all possible property quantifiers occurring in this document including their notation together with an explanation in plain words can be found in the CRM definition (Le Boeuf et al. 2012).
The following naming conventions have been changed for this refinement of the CRM, all other naming conventions are in line with the CRM definition:
Classes are identified by numbers preceded by the letter "SP" and are named using noun phrases (nominal groups) using title case (initial capitals). For example, SP1 Space Time Volume.
Properties are identified by numbers preceded by the letter "Q" and are named in both directions using verbal phrases in lower case. Properties with the character of states are named in the present tense, such as "has type", whereas properties related to events are named in past tense, such as "carried out." For example, Q1 occupied spatiotemporal volume.

For the proposed classes the criteria for substance, identity, existence and unity are explicitly stated because we came to the conclusion that the key to defining good ontological classes is to constrain a class to:

a) Substance criteria: What is the essential substance a thing is made of? [Wiggins 2001]
b) Identity criteria: how to distinghuish instances of a class. [Guarino 2001]
c) Existence criteria: how to decide when an instance of a class comes into being and when it ceases to exist.
d) Unity criteria: How to decide what is in the extent of the substance of an item?

The following questions may help for the practical application of the criteria:
Substance(S): What is the essential substance a thing is made of? This should not be mistaken with physical matter, for instance the substance of a text is characters and spaces. What are the substantial traits necessary for something to be an instance of a particular class?
Identity (I): How to recognize manifestations of individual instances in the world (at different times or places) as being the same? Does this amount of substance of a class represent one or more instances of this class? How to recognize if two references to instances of a class existing at the same time refer to the same or different instances?
Existence (E): Through which kind of process does an instance of a class begin to exist (e.g. through birth, creation, production) and by what does its existence end (e.g. through death, destruction, dissolution or transformation)?
Unity (U): How do I recognize all parts of an instance? What are the temporal or spatial boundaries of an instance? What is in or out of an instance? Note that it is not necessary that for all potential parts of a thing we can decide if they are a part or not of it [Wiggins 2001]. E.g. , a mountain may be well defined even though we don't know precisely where its boundaries are.
Within the scope notes of the classes the abriviations (E,U,I,S) of the criteria are used within a sentence to mark up the use of these criteria.

4 CRMgeo

4.1 Class & Property Hierarchies

Although they do not provide comprehensive definitions, compact monohierarchical presentations of the class and property IsA hierarchies have been found to significantly aid in the comprehension and navigation of the model, and are therefore provided below.

The class hierarchy presented below has the following format:

- Each line begins with a unique class identifier, consisting of a number preceded by the letter “SP”, or “E”.
- A series of hyphens (“-”) follows the unique class identifier, indicating the hierarchical position of the class in the IsA hierarchy.
- The English name of the class appears to the right of the hyphens.
- The index is ordered by hierarchical level, in a “depth first” manner, from the smaller to the larger sub hierarchies.
- Classes that appear in more than one position in the class hierarchy as a result of multiple inheritance are shown in an italic typeface.

The property table presented below has the following format:

- Each line begins with a unique property identifier, consisting of a number preceded by the letter “Q”.
- The English name of the property appears to the right of the hyphens.
- The domain class for which the property is declared.
- The range class for which the property is declared.

CRMgeo Classes Hierarchy aligned with (part of) CIDOC CRM Classes Hierarchy

E1		CRM Entity
E53	-	Place
SP2	- -	Phenomenal Place
SP6	- -	Declarative Place
SP8	-	Spacetime Volume
SP1	- -	Phenomenal Spacetime Volume
SP7	- -	Declarative Spacetime Volume
E52	-	Time-Span
SP13	- -	Phenomenal Time-Span
SP10	- -	Declarative Time-Span
E73	-	Information Object
SP5	- -	Geometric Place Expression
SP14	- -	Time Expression
SP12	- -	Space Time Volume Expression
E29	-	Design_or_Procedure
SP4	- - -	Spatial Coordinate Reference System
SP11	- - -	Temporal Reference System
S3	-	Reference_Space

CRMgeo Properties

P. id	Property Name	Entity – Domain	Entity - Range
Q1	occupied	E4 Period	*SP1* Phenomenal Spacetime Volume
Q2	occupied	E18 Physical Thing	*SP1* Phenomenal Spacetime Volume
Q3	has temporal projection	*SP1* Phenomenal Spacetime Volume	*S13* Phenomenal Time-Span
Q4	has spatial projection	*SP1* Phenomenal Spacetime Volume	SP2 Phenomenal Place
Q5	defined in	E53 Place	SP3 Reference Space
Q6	is at rest in relation to	SP3 Reference Space	E18 Physical Thing
Q7	describes	SP4 Spatial Coordinate Reference System	SP3 Reference Space
Q8	is fixed on	SP4 Spatial Coordinate Reference System	E26 Physical Feature
Q9	is expressed in terms of	SP5 Geometric Place Expression	SP4 Spatial Coordinate Reference System
Q10	defines place	SP5 Geometric Place Expression	SP6 Declarative Place
Q11	approximates	SP6 Declarative Place	E53 Place
Q12	approximates	SP7 Declarative Spacetime Volume	SP8 Spacetime Volume
Q13	approximates	SP10 Declarative Time-Span	E52 Time-Span
Q14	defines time	SP14 Time Expression	SP10 Declarative Time-Span
Q15	is expressed in terms of	SP14 Time Expression	SP11 Temporal Reference System
Q16	defines spacetime volume	SP12 Spacetime Expression	SP7 Declarative Spacetime Volume
Q17	is expressed in terms of	SP12 Spacetime Expression	SP11 Temporal Reference System
Q18	is expressed in terms of	SP12 Spacetime Expression	SP4 Spatial Coordinate Reference System
Q19	has reference event	SP11 Temporal Reference System	E5 Event

4.2 CRMgeo Class Declaration

The classes of CRMgeo are comprehensively declared in this section using the following format:

- Class names are presented as headings in bold face, preceded by the class' unique identifier;
- The line "Properties:" declares the list of the class' properties;
- The line "Subclass of:" declares the superclass of the class from which it inherits properties;
- The line "Scope note:" contains the textual definition of the concept the class represents;
- The line "Examples:" contains a bulleted list of examples of instances of this class. If the example is also instance of a subclass of this class, the unique identifier of the subclass is added in parenthesis. If the example instantiates two classes, the unique identifiers of both classes is added in parenthesis. Non-fictitious examples may be followed by an explanation in brackets.

SP1 Phenomenal Spacetime Volume

Subclass of: E1 CRM Entity

Scope note: This class comprises the 4 dimensional point sets (volumes) (S) which material phenomena (I) occupy in Space-Time (S). An instance of S1 Space Time Volume represents the true (I) extent of an instance of E4 Period in spacetime or the true (I) extent of the trajectory of an instance of E18 Physical Thing during the course of its existence, from production to destruction. A fuzziness of the extent lies in the very nature of the phenomenon, and not in the shortcomings of observation (U). The degree of fuzziness with respect to the scale of the phenomenon may vary widely, but the extent is never exact in a mathematical sense. According to modern physics, points in space-time are absolute with respect to the physical phenomena happening at them, regardless the so-called Galilean relativity of spatial or temporal reference systems in terms of which an observer may describe them. Following the theory, points relative to different spatial or temporal reference systems can be related if common points of phenomena in space-time are known in different systems. Instances of SP1 Phenomenal Space-Time Volume are sets of such absolute space-time points of phenomena (I).The (Einstein) relativity of spatial and temporal distances is of no concern for the scales of things in the cultural-historical discourse, but does not alter the above principles. The temporal projection of an instance of SP1 Phenomenal Space-Time Volume defines an E52 Time-Span while its spatial projection defines an SP2 Phenomenal Place. The true location of an instance of E18 Physical Thing during some time-span can be regarded as the spatial projection of the restriction of its trajectory to the respective time-span.

Examples:

- The Space Time Volume of the Event of Ceasars murdering
- The Space Time Volume where and when the carbon 14 dating of the "Schoeninger Speer II" in 1996 took place
- The spatio-temporal trajectory of the H.M.S. Victory from its building to its actual location
- The Space Time Volume of the temple in Abu Simbel before its removal

Properties:

Q3 has temporal projection: SP13 Phenomenal Time-Span

Q4 has spatial projection: SP2 Phenomenal Place

SP2 Phenomenal Place

Subclass of: E53 Place

Scope note: This class comprises instances of E53 Place (S) whose extent (U) and position is defined by the spatial projection of the spatiotemporal extent of a real world phenomenon that can be observed or measured. The spatial projection depends on the instance of S3 Reference Space onto which the extent of the phenomenon is projected. In general, there are no limitations to the number of Reference Spaces one could regard, but only few choices are relevant for the cultural-historical discourse. Typical for the archaeological discourse is to choose a reference space with respect to which the remains of some events would stay at the same place, for instance, relative to the bedrock of a continental plate. On the other side, for the citizenship of babies born in aeroplanes, the space in which the boundaries of the overflown state are defined may be relevant (I). Instances of SP2 Phenomenal Place exist as long as the respective reference space is defined. Note that we can talk in particular about what was at a place in a country before a city was built there, i.e., before the time the event occurred by which the place is defined, but we cannot talk about the place of earth before it came into existence due to lack of a reasonable reference space (E).

Examples:

- The place where the murder of Ceasar happened
- Place on H.M.S. Victory at which Nelson died
- The Place of the Varus Battle
- The volume in space of my vine glass
- The place the H.M.S Victory occupied over the seafloor when Nelson died
- The space enclosed by this room
- The space in borehole Nr. 405

SP3 Reference Space

Subclass of: E1 CRM Entity

Scope note: This class comprises the (typically Euclidian) Space (S) that is at rest (I) in relation to an instance of E18 Physical Thing and extends (U) infinitely beyond it. It is the space in which we typically expect things to stay in place if no particular natural or human distortion processes occur. This definition requires that at least essential parts of the respective physical thing have a stability of form. The degree of this stability (e.g., elastic deformation of a ship on sea, landslides, geological deformations) limits the precision to which an instance of SP3 Reference Space is defined. It is possible to construct types of (non Euclidian) reference spaces which adapt to elastic deformations or have other geometric and dynamic properties to adapt to changes of form of the reference object, but they are of rare utility in the cultural-historical discourse.

An instance of SP3 Reference Space begins to exist with the largest thing that is at rest in it and ceases to exist with its E6 Destruction. If other things are at rest in the same space and their time-span of existence falls within the one of the reference object, they share the same reference space (I). It has therefore the same temporal extent (time-span of existence) as the whole of the E18 Physical Things it is at rest with (E).

Examples:

- The Space inside and around H.M.S. Victory while it is moving through the Atlantic Ocean
- The Space inside and around the Eurasian Continental Plate
- The Space inside and around the Earth
- The Space inside and around the Solar system

Properties:

Q6 is at rest in relation to: **E18** Physical Thing

SP4 Spatial Coordinate Reference System

Subclass of: E29 Design or Procedure

Scope note: This class compromises systems that are used to describe locations in a SP3 Reference Space (S). An instance of SP4 Spatial Coordinate Reference System is composed of two parts: The first is a Coordinate System which is a set of coordinate axes with specified units of measurement and axis directions. The second part is a set of reference features at rest in the Reference Space it describes in the real world that relate the Coordinate System to real world locations (U) and fix it with respect to the reference object of its Reference Space . In surveying and geodesy, instance of SP4 Spatial Coordinate Reference System are called a datum. In the case of spatial coordinate reference systems for the earth the datum consists of the reference points and an ellipsoid that approximates the shape of the earth. National systems often use ellipsoids that approximate their territory best and shift them in an appropriate position relative to the earth while WGS84 is an ellipsoid for the whole earth and used in GPS receivers. In engineering a datum is a reference feature of an object used to create a reference system for measurement.The set of reference features in the real world are subset of E26 Physical Feature that are within the described reference space at rest and pertain to the E18 Physical Thing the reference space is at rest with.

SP4 Spatial Coordinate Reference Systems have a validity for a certain spatial extent of the SP3 Reference Space and in addition a temporal validity. The combination of coordinate reference system and datum provides a unique identity (I). SP4 Spatial Coordinate Reference Systems may be defined for the earth, moving objects like planes or ships, linear features like boreholes or local systems. If there is a standardised identifier system available, such as EPSG codes, it should be used.

Examples:

- Longitude-Latitude(ellipsoidal Coordinate System) in WGS84 (Datum)
- EPSG 3241
- the coordinate system to describe locations on H.M.S. Victory taking the deck foundation of the middle mast as origin, the mast as z axis, the line at right angle to the bow line as x axis and a right angle to both as y axis.
- The printed lines of the millimeter paper on which an archaeological feature is drawn

Properties:

Q7 describes: SP3 Reference Space

Q8 is fixed on **E26** Physical Feature

SP5 Geometric Place Expression

Subclass of: E73 Information Object , E47 Spatial Coordinates, Geometry

Scope note: This class comprises definitions of places by quantitative expressions. An instance of SP5 Geometric Place Expression can be seen as a prescription of how to find the location meant by this expression in the real world (S), which is based on measuring where the quantities referred to in the expression lead to, beginning from the reference points of the respective reference system.

A form of expression may be geometries or map elements defined in a SP4 Spatial Coordinate Reference System that unambiguously identify locations in a SP3 Reference Space. Other forms may refer to areas confined by imaginary lines connecting Phenomenal Places such as trees, islands, cities, mountain tops.

The identity of a SP5 Place Expression is based on its script or symbolic form (I). Several SP5 Place Expressions can denote the same SP6 Declarative Place .

Instances of SP5 Geometric Place Expressions that exist in one SP4 Spatial Coordinate Reference System can be transformed to geometries in other SP4 Spatial Coordinate Reference System if there is a known and valid transformation. The product of the transformation in general defines a new instance of SP6 Declarative Place , albeit close to the source of the transformation. This can be due to distortions resulting from the transformation and the limited precision by which the relative position of the reference points differing between the respective reference systems are determined.

Examples:

- Coordinate Information in GML like <gml:Point gml:id="p21" srsName="http://www.opengis.net/def/crs/EPSG/0/4326"> <gml:coordinates>45.67, 88.56</gml:coordinates> </gml:Point>
- The expression of a polygon defining the extent of France

Properties:

Q9 is expressed in terms of: **SP4** Spatial Coordinate Reference System
Q10 defines place: **SP6** Declarative Place

SP6 Declarative Place

Subclass of: E53 Place

Scope note: This class comprises instances of E53 Place (S) whose extent (U) and position is defined by a SP5 Geometric Place Expression (S). There is one implicit or explicit SP3 Reference Space in which the SP5 Place Expression describes the intended place. Even though SP5 Geometric Place Expressions have an unlimited precision, measurement devices and the precision of the position of reference features relating the SP4 Spatial Coordinate Reference System to a SP3 Reference Space impose limitations to the determination of a SP6 Declarative Place in the real world (U).
Several SP5 Geometric Place Expressions may denote the same SP6 Declarative Place if their precision falls within the same range (I).
Instances of SP6 Declarative Places may be used to approximate instances of E53 Places or parts of them. They may as well be used to define the location and spatial extent of property rights or national borders.

Examples:

- the place defined by <gml:Point gml:id="p21" srsName="http://www.opengis.net/def/crs/EPSG/0/4326"> <gml:coordinates>45.67, 88.56</gml:coordinates> </gml:Point>
- the place defined by a line approximating the Danube river
- The place of the Orinoco river defined in the map of Diego Ribeiro
- the place defined through a polygon that represents the boundaries of the
- UK in the year 2003

Properties:

Q11 approximates: **E53** Place

SP7 Declarative Spacetime Volume

Subclass of: SP8 Spacetime Volume

Scope note: This class comprises instances of SP8 Spacetime Volumes (S) whose temporal and spatial extent (U) and position is defined by a SP12 Spacetime Volume Expression. There is one implicit or explicit SP3 Reference Space in which the SP12 Spacetime Volume Expression describes the intended Spacetime Volume. As we restrict the model to Galilean physics and explicitly exclude systems with velocities close to the speed of light we do not model a “Reference Time” as it would be necessary for relativistic physics. This implies that there is only one Reference Time.
Even though SP12 Spacetime Volume Expressions have an unlimited precision, measurement devices and the precision of the position of reference features relating the SP4 Spatial Coordinate Reference System to a SP3 Reference Space impose limitations to the determination of the spatial part of a SP7 Declarative Spacetime Volume in the real world (U).
The same limitation to precision is true for the temporal part of a SP7 Declarative Spacetime Volume due to precision of time measurement devices and of the determination of the reference event of a SP11 Temporal Reference System.
Several SP12 Spacetime Volume Expressions may denote the same SP7 Declarative Spacetime Volume if their precision falls within the same range (I).

Instances of SP7 Declarative Spacetime Volumes may be used to approximate instances of SP8 Spacetime Volumes or parts of them. They may as well be used to define the spatial and temporal extent of property rights or national borders.

Examples:

- the spacetime volume defined by a polygon approximating the Danube river flood in Austria between 6th and 9th of August 2002
- the spacetime volume of the Orinoco river in 1529 defined in the map of Diego Ribeiro in 1529
- the spacetime volume representing the boundaries of the UK from 1900-1950

Properties:

Q12 approximates: SP8 Spacetime Volume

SP8 Spacetime Volume

Subclass of: E1 CRM Entity

Scope note: This class comprises 4 dimensional possibly fuzzy point sets (volumes) in physical spacetime regardless its true geometric form (S). They may derive their identity from being the extent of a material phenomenon or from being the interpretation of an expression (I) defining an extent in Space Time. The duration of existence of an instance of a spacetime volume is trivially its projection on time (E).

Examples:

- the spacetime Volume of the Event of Ceasars murdering
- the spacetime Volume where and when the carbon 14 dating of the "Schoeninger Speer II" in 1996 took place
- the spatio-temporal trajectory of the H.M.S. Victory from its building to its actual location
- the spacetime volume defined by a polygon approximating the Danube river flood in Austria between 6th and 9th of August 2002

SP10 DeclarativeTime-Span

Subclass of: E52 Time-Span

Scope note: This class comprises instances of E52 Time-Spans that represent the Time Span defined by a SP 14 Time Expression. Thus they derive their identity through an expression defining an extent in time. Even though SP10 Declarative Time Spans have an unlimited precision, measurement devices and the possible precision within the SP11 Temporal Reference System impose limitations to the determination of a SP10 Declarative Time Span. The accuracy of a SP10 Declarative Time Spans depends upon the documentation and measurement method.

SP10 Declarative Time Spans may be used to approximate actual (phenomenal) Time-Spans of temporal entities.

Examples:

- Extent in time defined by the expression “1961”
- Extent in time defined by the expression “From 12-17-1993 to 12-8-1996”
- Extent in time defined by the expression “14h30 – 16h22 4th July 1945”

Properties:

Q13 approximates: E52 Time-Span

SP11 Temporal Reference System

Subclass of: E29 Design or Procedure

Scope note: This class compromises systems(S) that are used to describe positions and extents in a Reference Time. If relativistic effects are negligible in the wider spacetime area of interest and the speeds of associated things, then there is only one unique global reference time. The typical way to measure time is to count the cycles of a periodic process for which we have a hypothesis of constant frequency, such as oscillations of a crystal, molecular arrangement, rotation of earth around itself or around the sun. The origin for a Temporal Reference System is fixed on a reference event. As long as the number of cycles passed from that reference event until now are known, the temporal reference system exists (E) and expressions in this Reference System can be interpreted with respect to the Reference Time.

A temporal reference system represents time as a continuous linear interpolation over the infinit series of cycles extended from the reference event to he past and the future, regardless of the temporal position of the mathematical point zero of an instance of E61 Time Primitive, such for instance the gregorian calender begins with the event an arbitrary positiong the point zero as beeing the date of the „Birth of Christ“. The actual date of birth of christ is regarded to be unknown and therefor is not the reference event.

The identity of a Temporal Reference System is defined through the type of periodic process it is based on, the reference event and through the distance of the reference event to the position of the mathematical point zero (I).

A value in the Reference Time is a temporal position measured relative to a temporal reference system. ISO 8601 specifies the use of the Gregorian Calendar and 24 hour local or Coordinated Universal Time (UTC) for information interchange.

In ISO 19108 three common types of temporal reference systems are explicitly stated: calendars (used with clocks for greater resolution), temporal coordinate systems, and ordinal temporal reference systems.

Calendars and clocks are both based on interval scales. A calendar is a discrete temporal reference system that provides a basis for defining temporal position to a resolution of one day. 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 specific day. Every calendar provides a set of rules for composing a calendar date from a set of elements such as year, month, and day. In every calendar, years are numbered relative to the date of a reference event that defines a calendar era [ISO 19108].

Specifying temporal position in terms of calendar date and time of day complicates the computation of distances between points and the functional description of temporal operations. A temporal coordinate system may be used to support applications of this kind. [ISO 19108].

Ordinal temporal reference systems as specified in ISO 19108 are no instances of SP11 Temporal Reference Systems as they do not define cycles of a periodic process but define a system of time intervals based on reverence periods related to certain natural or cultural phenomena.

Examples:

- Gregorian Calendar
- Coordinated Universal Time (UTC)
- Julian date
- Greenwich time
- ISO 8601

Properties:

Q19 has reference event: E5 Event

SP12 Spacetime Volume Expression

Subclass of: E73 Information Object, Geometry

Scope note: This class comprises definitions of Spacetime Volumes by quantitative expressions(S). An instance of SP12 Spacetime Volume Expression can be seen as a prescription of how to find the projected declarative place of a Spacetime Volume meant by this expression in the actual real world. In addition the SP12 Spacetime Volume Expression states a temporal interval at what projected time interval this declarative Spacetime Volume existed.
The expression can be a combination of a "SP 5 Geometric Place Expression" and an "SP 14 Declarative Time-Span" or a different form of expressing spacetime in an integrated way like a formula containing all 4 dimensions.

Examples:

- Spatial and temporal information in GML like the movement of a cyclone

```
<app:Cyclone gml:id="c1">
<gml:history>
<gml:MovingObjectStatus>
<gml:validTime><gml:TimeInstant>
<gml:timePosition>2005-11-28T13:00:00Z</gml:timePosition>
</gml:TimeInstant></gml:validTime>
<gml:location><gml:Point gml:id="p1" srsName="urn:x-ogc:def:crs:EPSG:6.6:4326">
<gml:pos>-35 140</gml:pos>
</gml:Point></gml:location> <gml:speed uom="#kph">12</gml:speed>
<gml:bearing> <gml:CompassPoint>SE</gml:CompassPoint> </gml:bearing>
</gml:MovingObjectStatus>
<gml:MovingObjectStatus>
<gml:validTime><gml:TimeInstant>
<gml:timePosition>2005-11-28T14:00:00Z</gml:timePosition>
</gml:TimeInstant></gml:validTIme>
<gml:location><gml:Point>
<gml:pos>-34.9 140.1</gml:pos gml:id="p1" srsName="urn:x-
ogc:def:crs:EPSG:6.6:4326">
</gml:Point></gml:location> <gml:speed uom="#kph">23</gml:speed>
<gml:bearing> <gml:CompassPoint>ESE</gml:CompassPoint> </gml:bearing>
</gml:MovingObjectStatus>
</gml:history> </app:Cyclone>
```

- a spacetime volume expressed in KML defining the extent of France from 1792-1816

Properties:

Q17 is expressed in terms of: SP11 Temporal Reference System

Q18 is expressed in terms of: **SP4** Spatial Coordinate Reference System

SP13 Phenomenal Time-Span

Subclass of: E52 Time-Span

Scope note: This class comprises instances of E52 Time-Spans whose extent (U) and position is defined by the temporal projection of the spatiotemporal extent that can be observed or measured. Thus they derive their identity through the extent in time of a real world phenomenon (I).

Examples:

- Duration of the phenomenal temporal extent of the Trafalgar battle
- The real duration of the Ming Dynasty
- The real extent of the lifetime of Ceasar starting with his birth and ending with his death

SP14 Time Expression

Subclass of: E73 Information Object, E49 Time Appellation, Geometry

Superclass of: E61 Time Primitive

Scope note: This class comprises definitions of temporal extents by quantitative expressions(S). An instance of SP14 Time Expression defines a declarative temporal interval using a temporal reference system. The identity of a SP14 Time Expression is based on its script or symbolic form (I). Several SP14 Time Expressions can denote the same SP10 Declarative Time-Span.
Instances of SP14 Time Expression that exist in one SP11 Temporal Reference System can be transformed to time expressions in other SP11 Temporal Reference Systems if there is a known and valid transformation.

Examples:

- Temporal information in GML
  <gml:validTime><gml:TimeInstant>
  <gml:timePosition>2005-11-28T13:00:00Z</gml:timePosition>
  </gml:TimeInstant></gml:validTime>
- 1961
- From 12-17-1993 to 12-8-1996
- 14h30 – 16h22 4th July 1945
- 9.30 am 1.1.1999 to 2.00 pm 1.1.1999

Properties:

Q14 defines time: SP10 Declarative Time-Span

Q15 is expressed in terms of: SP11 Temporal Reference System

4.3 CRMgeo Property Declaration

The properties of the CRM spatial refinement are comprehensively declared in this section using the following format:

- Property names are presented as headings in bold face, preceded by unique property identifiers;
- The line "Domain:" declares the class for which the property is defined;
- The line "Range:" declares the class to which the property points, or that provides the values for the property;
- The line "Quantification:" declares the possible number of occurrences for domain and range class instances for the property. Possible values are: 1:many, many:many, many:1;
- The line "Scope note:" contains the textual definition of the concept the property represents;

Q1 occupied

Domain: E4 Period

Range: SP1 Phenomenal Spacetime Volume

Quantification: many to one, necessary (1,1:0,n)
Scope note: This property associates an instance of E4 Period with the 4 dimensional point sets (volumes) in spacetime that it occupied. This instance of SP1 Phenomenal Spacetime Volume includes the trajectories of the participating physical things during their participation in the instance of E4 Period, the open spaces via which they have interacted and the spaces by which they had the potential to interact during that period or event in the way defined by the type of the respective period or event, such as the air in a meeting room transferring the voices. It also comprises the areas controlled by some military power. Therefore instances of E4 Period have fuzzy boundaries in spacetime.

Q2 occupied

Domain: E18 Physical Thing

Range: SP1 Phenomenal Spacetime Volume

Quantification: many to one, necessary (1,1:0,n)
Scope note: This property describes the 4 dimensional point sets (volumes) in spacetime that the trajectory of an instance of E18 Physical Thing occupies in spacetime in the course of its existence. We include in the occupied space the space filled by the matter of the physical thing and all inner spaces not accessible in regular function.

Q3 has temporal projection

Domain: SP1 Phenomenal Spacetime Volume

Range: S13 Phenomenal Time-Span

Quantification: one to one (1,1:1,1)
Scope note: This property describes the temporal projection of an instance of a SP1 Phenomenal Spacetime Volume. The property P4 has time-span is a shortcut of the more fully developed path from E4 Period through Q1 occupied, SP1 Phenomenal Spacetime Volume Q3 has temporal projection to E52 Time Span.This property can be extended in a future model to a ternary (3-ary) relationship describing the temporal projection under a spatial constraint.

Q4 has spatial projection

Domain: SP1 Phenomenal Spacetime Volume

Range: SP2 Phenomenal Place

Quantification: one to many, necessary, dependent (1,n:1,1)

Scope note: This property describes the spatial projection of an instance of a SP1 Phenomenal Spacetime Volume on an instance of SP2 Phenomenal Place. Even though the projection of a spacetime volume to one instance of SP3 Reference Space is unique, each reference space gives rise to another projection. The projections overlap at the time of the spacetime volume, the respective instances of SP2 Phenomenal Place may later drift apart, or earlier be yet apart.

The property P7 took place at is a shortcut of the more fully developed path from E4 Period through Q1 occupied, SP1 Phenomenal Spacetime Volume Q4 has spatial projection to SP2 Phenomenal Place. This property can be extended in a future model to a ternary (3-ary) relationship describing the spatial projection under a temporal constraint.

Q5 defined in

Domain: E53 Place

Range: SP3 Reference Space

Quantification: many to one, necessary (1,1:0,n)

Scope note: This property associates an instance of E53 Place with the instance of SP3 Reference Space it is defined in.

Q6 is at rest in relation to

Domain: SP3 Reference Space

Range: E18 Physical Thing

Quantification: many to many, necessary, dependent (1,n:1,n)

Scope note: This property associates an instance of SP3 Reference Space with the instance of E18 Physical Thing that is at rest in it. For all instances of E18 Physical Thing exist at least one reference space it is at rest with because of their relative stability of form. Larger constellations of matter may comprise many physical features that are at rest with them.

Q7 describes

Domain: SP4 Spatial Coordinate Reference System

Range: SP3 Reference Space

Quantification: many to one, necessary (1,1:0,n)

Scope note: This property associates an instance of SP4 Spatial Coordinate Reference System with the instance of SP3 Reference Space for which it can be used to describe locations.

Q8 is fixed on

Domain: SP4 Spatial Coordinate ReferenceSystem

Range: E26 Physical Feature

Quantification: one to many, necessary, dependent (1,n:1,1)

Scope note: This property defines the physical reference features that ground a spatial coordinate reference system in the real world.
In surveying and geodesy this is part of the datum definition and is often a point identified by a physical feature on earth (sometimes monuments) where the earth approximation ellipsoid touches the earth and one axis of the ellipsoid runs through.

Q9 is expressed in terms of

Domain: SP5 Geometric Place Expression

Range: SP4 Spatial ReferenceSystem

Quantification: many to many (0,n:0,n)

Scope note: This property defines the coordinate reference system in terms of which a geometric place expression is formulated.

Q10 defines place

Domain: SP5 Geometric Place Expression

Range: SP6 Declarative Place

Quantification: many to one, necessary, dependent (1,1:1,n)

Scope note: This property associates an instance of SP5 Geometric Place Expression with the instance of SP6 Declarative Place it defines. Syntactic variants or use of different scripts may result in multiple instances of SP5 Geometric Place Expression defining exactly the same place. Transformations between different reference systems in general result in new definitions of places approximating each other.

Q11 approximates

Domain: SP6 Declarative Place

Range: E53 Place

Quantification: many to one (0,1:0,n)

Scope note: This property approximates an E53 Place which is defined in the same reference space.
The property does not state the quality or accuracy of the approximation, but states the intention to approximate the place.

Q12 approximates

Domain: SP7 Declarative Spacetime Volume

Range: SP8 Spacetime Volume

Quantification: many to one (0,1:0,n)

Scope note: This property approximates a SP8 Spacetime Volume. The property does not state the quality or accuracy of the approximation, but states the intention to approximate the spacetime volume.

Q13 approximates

Domain: SP10 Declarative Time-Span

Range: E52 Time-Span

Quantification: many to one (0,1:0,n)

Scope note: This property approximates a E52 Time-Span. The property does not state the quality or accuracy of the approximation, but states the intention to approximate the time span .

Q14 defines time

Domain: SP14 Time Expression

Range: SP10 Declarative Time-Span

Quantification: many to one, necessary, dependent (1,1:1,n)

Scope note: This property associates an instance of SP14 Time Expression with the instance of SP10 Declarative Time Span it defines. Syntactic variants or use of different scripts may result in multiple instances of SP14 Time Expression defining exactly the same time span. Transformations between different temporal reference systems in general result in new definitions of time spans approximating each other.

Q15 is expressed in terms of

Domain: SP14 Time Expression

Range: SP11 Temporal Reference System

Quantification: many to many (0,n:0,n)

Scope note: This property defines the temporal reference system in terms of which an SP14 Time Expression is formulated.

Q16 defines spacetime volume

Domain: SP12 Spacetime Volume Expression

Range: SP7 Declarative Spacetime Volume

Quantification: many to one, necessary, dependent (1,1:1,n)

Scope note: This property associates an instance of SP12 Spacetime Volume Expression with the instance of SP7 Declarative Spacetime Volume it defines. Syntactic variants or use of different scripts may result in multiple instances of SP12 Spacetime Volume Expressions defining exactly the same SP7 Declarative Spacetime Volume. Transformations between different temporal or spatial reference systems in general result in new definitions of Spacetime Volumes approximating each other.

Q17 is expressed in terms of

Domain: SP12 Spacetime Volume Expression

Range: SP11 Temporal Reference System

Quantification: many to many (0,n:0,n)

Scope note: This property defines the temporal reference system in terms of which a SP12 Spacetime Volume Expression is formulated.

Q18 is expressed in terms of

Domain: SP12 Spacetime Volume Expression

Range: SP4 Spatial Coordinate ReferenceSystem

Quantification: many to many (0,n:0,n)

Scope note: This property defines the spatial coordinate reference system in terms of which a SP12 Spacetime Volume Expression is formulated.

Q19 has reference event

Domain: SP11 Temporal Reference System

Range: E5 Event

Quantification: one to many (1,1:1,n)

Scope note: This property defines the reference event for a SP11 Temporal Reference System

5 Referred CIDOC CRM Classes

E1 CRM Entity

Superclass of: E2 Temporal Entity
E52 Time-Span
E53 Place
E54 Dimension
E77 Persistent Item

Scope note: This class comprises all things in the universe of discourse of the CIDOC Conceptual Reference Model.

It is an abstract concept providing for three general properties:

1. Identification by name or appellation, and in particular by a preferred identifier
2. Classification by type, allowing further refinement of the specific subclass an instance belongs to
3. Attachment of free text for the expression of anything not captured by formal properties

With the exception of E59 Primitive Value, all other classes within the CRM are directly or indirectly specialisations of E1 CRM Entity.

Examples:

- the earthquake in Lisbon 1755 (E5)

Properties:

P1 is identified by (identifies): E41 Appellation
P2 has type (is type of): E55 Type
P3 has note: E62 String
(P3.1 has type: E55 Type)
P48 has preferred identifier (is preferred identifier of): E42 Identifier
P137 exemplifies (is exemplified by): E55 Type

E4 Period

Subclass of: E2 Temporal Entity

Superclass of: E5 Event

Scope note: This class comprises sets of coherent phenomena or cultural manifestations bounded in time and space.

It is the social or physical coherence of these phenomena that identify an E4 Period and not the associated spatio-temporal bounds. These bounds are a mere approximation of the actual process of growth, spread and retreat. Consequently, different periods can overlap and coexist in time and space, such as when a nomadic culture exists in the same area as a sedentary culture.

Typically this class is used to describe prehistoric or historic periods such as the “Neolithic Period”, the “Ming Dynasty” or the “McCarthy Era”. There are however no assumptions about the scale of the associated phenomena. In particular all events are seen as synthetic processes consisting of coherent phenomena. Therefore E4 Period is a superclass of E5 Event. For example, a modern clinical E67 Birth can be seen as both an atomic E5 Event and as an E4 Period that consists of multiple activities performed by multiple instances of E39 Actor.

There are two different conceptualisations of ‘artistic style’, defined either by physical features or by historical context. For example, “Impressionism” can be viewed as a period lasting from approximately 1870 to 1905 during which paintings with particular characteristics were produced by a group of artists that included (among others) Monet, Renoir, Pissarro, Sisley and Degas. Alternatively, it can be regarded as a style applicable to all paintings sharing the characteristics of the works produced by the Impressionist painters, regardless of historical context. The first interpretation is an E4 Period, and the second defines morphological object types that fall under E55 Type.

Another specific case of an E4 Period is the set of activities and phenomena associated with a settlement, such as the populated period of Nineveh.

Examples:

- Jurassic
- European Bronze Age
- Italian Renaissance
- Thirty Years War
- Sturm und Drang
- Cubism

Properties:

P7 took place at (witnessed): E53 Place

P8 took place on or within (witnessed): E19 Physical Object

P9 consists of (forms part of): E4 Period

P10 falls within (contains): E4 Period

P132 overlaps with: E4 Period

P133 is separated from: E4 Period

E5 Event

Subclass of: E4 Period

Superclass of: E7 Activity

E63 Beginning of Existence

E64 End of Existence

Scope note: This class comprises changes of states in cultural, social or physical systems, regardless of scale, brought about by a series or group of coherent physical, cultural, technological or legal phenomena. Such changes of state will affect instances of E77 Persistent Item or its subclasses.

The distinction between an E5 Event and an E4 Period is partly a question of the scale of observation. Viewed at a coarse level of detail, an E5 Event is an 'instantaneous' change of state. At a fine level, the E5 Event can be analysed into its component phenomena within a space and time frame, and as such can be seen as an E4 Period. The reverse is not necessarily the case: not all instances of E4 Period give rise to a noteworthy change of state.

Examples:

- the birth of Cleopatra (E67)
- the destruction of Herculaneum by volcanic eruption in 79 AD (E6)
- World War II (E7)
- the Battle of Stalingrad (E7)
- the Yalta Conference (E7)
- my birthday celebration 28-6-1995 (E7)
- the falling of a tile from my roof last Sunday
- the CIDOC Conference 2003 (E7)

Properties:

P11 had participant (participated in): E39 Actor

P12 occurred in the presence of (was present at): E77 Persistent Item

E18 Physical Thing

Subclass of: E72 Legal Object
Superclass of: E19 Physical Object
E24 Physical Man-Made Thing
E26 Physical Feature

Scope Note: This class comprises all persistent physical items with a relatively stable form, man-made or natural.

Depending on the existence of natural boundaries of such things, the CRM distinguishes the instances of E19 Physical Object from instances of E26 Physical Feature, such as holes, rivers, pieces of land etc. Most instances of E19 Physical Object can be moved (if not too heavy), whereas features are integral to the surrounding matter.

The CRM is generally not concerned with amounts of matter in fluid or gaseous states.

Examples:

- the Cullinan Diamond (E19)
- the cave "Ideon Andron" in Crete (E26)
- the Mona Lisa (E22)

Properties:

P44 has condition (is condition of): E3 Condition State
P45 consists of (is incorporated in): E57 Material
P46 is composed of (forms part of): E18 Physical Thing
P49 has former or current keeper (is former or current keeper of): E39 Actor
P50 has current keeper (is current keeper of): E39 Actor
P51 has former or current owner (is former or current owner of): E39 Actor
P52 has current owner (is current owner of): E39 Actor
P53 has former or current location (is former or current location of): E53 Place
P58 has section definition (defines section): E46 Section Definition
P59 has section (is located on or within): E53 Place

E26 Physical Feature

Subclass of: E18 Physical Thing
Superclass of: E25 Man-Made Feature
E27 Site

Scope Note: This class comprises identifiable features that are physically attached in an integral way to particular physical objects.

Instances of E26 Physical Feature share many of the attributes of instances of E19 Physical Object. They may have a one-, two- or three-dimensional geometric extent, but there are no natural borders that separate them completely in an objective way from the carrier objects. For example, a doorway is a feature but the door itself, being attached by hinges, is not.

Instances of E26 Physical Feature can be features in a narrower sense, such as scratches, holes, reliefs, surface colours, reflection zones in an opal crystal or a density change in a piece of wood. In the wider sense, they are portions of particular objects with partially imaginary borders, such as the core of the Earth, an area of property on the surface of the Earth, a landscape or the head of a contiguous marble statue. They can be measured and dated, and it is sometimes possible to state who or what is or was responsible for them. They cannot be separated from the carrier object, but a segment of the carrier object may be identified (or sometimes removed) carrying the complete feature.

This definition coincides with the definition of "fiat objects" (Smith & Varzi, 2000, pp.401-420), with the exception of aggregates of "bona fide objects".

Examples:

- the temple in Abu Simbel before its removal, which was carved out of solid rock
- Albrecht Duerer's signature on his painting of Charles the Great
- the damage to the nose of the Great Sphinx in Giza
- Michael Jackson's nose prior to plastic surgery

E29 Design or Procedure

Subclass of: E73 Information Object

Scope note: This class comprises documented plans for the execution of actions in order to achieve a result of a specific quality, form or contents. In particular it comprises plans for deliberate human activities that may result in the modification or production of instances of E24 Physical Thing.

Instances of E29 Design or Procedure can be structured in parts and sequences or depend on others. This is modelled using *P69 is associated with*.

Designs or procedures can be seen as one of the following:

1. A schema for the activities it describes
2. A schema of the products that result from their application.
3. An independent intellectual product that may have never been applied, such as Leonardo da Vinci's famous plans for flying machines.

Because designs or procedures may never be applied or only partially executed, the CRM models a loose relationship between the plan and the respective product.

Examples:

- the ISO standardisation procedure
- the musical notation for Beethoven's "Ode to Joy"
- the architectural drawings for the Kölner Dom in Cologne, Germany
- The drawing on the folio 860 of the Codex Atlanticus from Leonardo da Vinci, 1486-1490, kept in the Biblioteca Ambrosiana in Milan

Properties:

P68 foresees use of (use foreseen by): E57 Material

P69 is associated with: E29 Design or Procedure

(P69.1 has type: E55 Type)

E47 Spatial Coordinates

Subclass of: E44 Place Appellation

Scope Note: This class comprises the textual or numeric information required to locate specific instances of E53 Place within schemes of spatial identification.

Coordinates are a specific form of E44 Place Appellation, that is, a means of referring to a particular E53 Place. Coordinates are not restricted to longitude, latitude and altitude. Any regular system of reference that maps onto an E19 Physical Object can be used to generate coordinates.

Examples:

- "6°5'29"N 45°12'13"W"
- "Black queen's bishop 4" [chess coordinate]

E49 Time Appellation

Subclass of: E41 Appellation
Superclass of E50 Date

Scope Note: This class comprises all forms of names or codes, such as historical periods, and dates, which are characteristically used to refer to a specific E52 Time-Span.

- The instances of E49 Time Appellation may vary in their degree of precision, and they may be relative to other time frames, "Before Christ" for example. Instances of E52 Time-Span are often defined by reference to a cultural period or an event e.g. 'the duration of the Ming Dynasty'.

Examples:

- "Meiji" [Japanese term for a specific time-span]
- "1st half of the XX century"
- "Quaternary"
- "1215 Hegira" [a date in the Islamic calendar]
- "Last century"

E52 Time-Span

Subclass of: E1 CRM Entity

Scope note: This class comprises abstract temporal extents, in the sense of Galilean physics, having a beginning, an end and a duration.

Time Span has no other semantic connotations. Time-Spans are used to define the temporal extent of instances of E4 Period, E5 Event and any other phenomena valid for a certain time. An E52 Time-Span may be identified by one or more instances of E49 Time Appellation.

Since our knowledge of history is imperfect, instances of E52 Time-Span can best be considered as approximations of the actual Time-Spans of temporal entities. The properties of E52 Time-Span are intended to allow these approximations to be expressed precisely. An extreme case of approximation, might, for example, define an E52 Time-Span having unknown beginning, end and duration. Used as a common E52 Time-Span for two events, it would nevertheless define them as being simultaneous, even if nothing else was known.

Automatic processing and querying of instances of E52 Time-Span is facilitated if data can be parsed into an E61 Time Primitive.

Examples:

- 1961
- From 12-17-1993 to 12-8-1996
- 14h30 – 16h22 4th July 1945
- 9.30 am 1.1.1999 to 2.00 pm 1.1.1999
- duration of the Ming Dynasty

Properties:

P78 is identified by (identifies): E49 Time Appellation
P79 beginning is qualified by: E62 String
P80 end is qualified by: E62 String
P81 ongoing throughout: E61 Time Primitive
P82 at some time within: E61 Time Primitive
P83 had at least duration (was minimum duration of): E54 Dimension
P84 had at most duration (was maximum duration of): E54 Dimension
P86 falls within (contains): E52 Time-Span

E53 Place

Subclass of: E1 CRM Entity

Scope note: This class comprises extents in space, in particular on the surface of the earth, in the pure sense of physics: independent from temporal phenomena and matter.

The instances of E53 Place are usually determined by reference to the position of "immobile" objects such as buildings, cities, mountains, rivers, or dedicated geodetic marks. A Place can be determined by combining a frame of reference and a location with respect to this frame. It may be identified by one or more instances of E44 Place Appellation.

It is sometimes argued that instances of E53 Place are best identified by global coordinates or absolute reference systems. However, relative references are often more relevant in the context of cultural documentation and tend to be more precise. In particular, we are often interested in position in relation to large, mobile objects, such as ships. For example, the Place at which Nelson died is known with reference to a large mobile object – H.M.S Victory. A resolution of this Place in terms of absolute coordinates would require knowledge of the movements of the vessel and the precise time of death, either of which may be revised, and the result would lack historical and cultural relevance.

Any object can serve as a frame of reference for E53 Place determination. The model foresees the notion of a "section" of an E19 Physical Object as a valid E53 Place determination.

Examples:

- the extent of the UK in the year 2003
- the position of the hallmark on the inside of my wedding ring
- the place referred to in the phrase: “Fish collected at three miles north of the confluence of the Arve and the Rhone”
- here -> <-

Properties:

P87 is identified by (identifies): E44 Place Appellation
P89 falls within (contains): E53 Place
P121 overlaps with: E53 Place
P122 borders with: E53 Place

E61 Time Primitive

Subclass of: E59 Primitive Value

Scope Note: This class comprises instances of E59 Primitive Value for time that should be implemented with appropriate validation, precision and interval logic to express date ranges relevant to cultural documentation.

E61 Time Primitive is not further elaborated upon within the model.

Examples:

- 1994 – 1997
- 13 May 1768
- 2000/01/01 00:00:59.7
- 85^{th} century BC

E73 Information Object

Subclass of: E89 Propositional Object
E90 Symbolic Object

Superclass of: E29 Design or Procedure
E31 Document
E33 Linguistic Object
E36 Visual Item

Scope note: This class comprises identifiable immaterial items, such as a poems, jokes, data sets, images, texts, multimedia objects, procedural prescriptions, computer program code, algorithm or mathematical formulae, that have an objectively recognizable structure and are documented as single units.

An E73 Information Object does not depend on a specific physical carrier, which can include human memory, and it can exist on one or more carriers simultaneously.
Instances of E73 Information Object of a linguistic nature should be declared as instances of the E33 Linguistic Object subclass. Instances of E73 Information Object of a documentary nature should be declared as instances of the E31 Document subclass. Conceptual items such as types and classes are not instances of E73 Information Object, nor are ideas without a reproducible expression.

Examples:

- image BM000038850.JPG from the Clayton Herbarium in London
- E. A. Poe's "The Raven"
- the movie "The Seven Samurai" by Akira Kurosawa
- the Maxwell Equations

6 Referred GeoSPARQL Classes

GeoSPARQL (OGC 2012) does not provide scope notes as the CIDOC CRM but extensive descriptions to the semantics of the classes are found in the OGC standards, or respective ISO standards on geographic information. Some descriptions are cited here and the references to the sources are given.

Feature

`GeoSPARQL: Feature` is defined as superclass of everything feature

Definitions within the ISO 19100 series:

"A feature is an abstraction of a real world phenomenon" [ISO 19101];
A feature is a geographic feature if it is associated with a location relative to the Earth. Vector data consists of geometric and topological primitives used, separately or in combination, to construct objects that express the spatial characteristics of geographic features.
Attributes of (either contained in or associated to) a feature describe measurable or describable properties about this entity. Unlike a data structure description, feature instances derive their semantics and valid use or analysis from the corresponding real world entities' meaning.
Documenting feature instances, types, semantics and their properties is often detailed in an information model. An information model details how to take real world ideas or objects and make them useful to a computer system. In the geospatial world the focus is on depicting things in the real world as points, lines, or polygons (the geometry "primitives" we use to assemble location data about those real world objects) and their attributes (information about those objects). When linked together, a pair (geometry and attributes) representing one or more real world objects, is called a feature.
There are three popular approaches for the modeling of geospatial features.
The first models the spatial extent of a feature with point, lines, polygons, and other geometric primitives that come from a list of well-known types. Features modeled in this fashion are called "Features with Geometry."
The second approach is called a "Feature as Coverage". This technology includes images as a special case.
The third approach is "Feature as Observation". An Observation is an action with a result which has a value describing some phenomenon. The observation is modelled as a Feature within the context of the General Feature Model [ISO 19101, ISO 19109]. An observation feature binds a result to a feature of interest, upon which the observation was made. The observed property is a property of the feature of interest.
All these primary Features types are intimately related, yet have distinct concepts (OGC 2009)

Geometry

GeoSPARQL: The class Geometry, superclass of everything geometry.

The Geometry class is based on the specifications in ISO 19107 (ISO 2003) and in particular of the GM_Object.
GM_Object is the root class of the geometric object taxonomy and supports interfaces common to all geographically referenced geometric objects. GM_Object instances are sets of direct positions in a particular coordinate reference system. A GM_Object can be regarded as an infinite set of points that satisfies the set operation interfaces for a set of direct positions, TransfiniteSet<DirectPosition>. Since an infinite collection class cannot be implemented directly, a Boolean test for inclusion shall be provided by the GM_Object interface. This International Standard concentrates on vector geometry classes, but future work may use GM_Object as a root class without modification (ISO 2003).

7 Literature

Patrick Le Boeuf, Martin Doerr, Christian Emil Ore, Stephen Stead (2012), Definition of the CIDOC Conceptual Reference Model, http://www.cidoc-crm.org/official_release_cidoc.html (4.12.2012)

N. Guarino and C. Welty (2002), "Evaluating ontological decisions with OntoClean," Communiations of the ACM, 45 (2), pp. 61-65, 2002

Gerald Hiebel , Øyvind Eide , Mark Fichtner, Klaus Hanke , Georg Hohmann, Dominik Lukas, Siegfried Krause (2012) OGC GeoSparql and CIDOC CRM, Presentation at CRM-SIG 2012 in Heraklion, Crete

ISO (2003) ISO 19107 Geographic information -- Spatial schema, http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=26012 (4.4.2013)

OGC (2012), OGC GeoSPARQL - A Geographic Query Language for RDF Data, http://www.opengeospatial.org/standards/geosparql (4.12.2012)

OGC (2009), The OpenGIS® Abstract Specification: Topic 5: Features , http://www.opengeospatial.org/standards/as, http://portal.opengeospatial.org/files/?artifact_id=29536 (4.4.2013)

Wiggins David (2001), Sameness and Substance Renewed, Cambridge University Press

Acknowledgement

This research project has been funded within the Marie Curie Actions—Intra-European Fellowships (IEF) Funding scheme under project number 299998