Integration of CIDOC CRM with OGC Standards to Model Spatial Information

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Abstract:
The ISO certified ontology of the CIDOC CRM provides the concepts to model archaeological data in their semantic context while the Open Geospatial Consortiums (OGC) defines standards for geographic information. In this paper we present the CRMgeo extension which integrates the CIDOC CRM the with the OGC standard of 'GeoSPARQL– A Geographic Query Language for RDF Data' which is based on concepts of the existing OGC standards. To bridge the gap between the two conceptual models CRMgeo differentiates two kinds of place concepts. Phenomenal places that derive their identity through real world objects and the spacetime volumes they occupy and declarative places that have been created through human definitions and may approximate phenomenal places. These place concepts are applied to the practice of referencing places with placenames available in gazetteers and related to the corresponding OGC standard. CRMgeo provides the ontological foundation to integrate CIDOC CRM datasets with GIS data.

Keywords:
Ontology, CIDOC CRM, GIS, OGC Standards, CRMgeo

1. Introduction[1]

There is a growing 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 the one side there is already a tradition of more than two decades of using GIS systems for representing cultural-historical and archaeological data and reasoning on properties of spatial distribution, vicinity or accessibility. These systems tend to be closed and focus more on representing feature categories by visual symbols at different scales than integrating rich object descriptions. They have been very successful in all kinds of 'geosciences', resource management and public administration, whereas cultural heritage is only a marginal application area. On the other hand, archives, libraries and museums keep detailed historical records of things with very poor spatial determination. Often in the language of the source or local context, which was more or less unambiguous at the time of creation. In other cases, only wider geopolitical units, such as 'Parthenon in Athens,' are used. 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 restoration 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. Thus, the two traditions, the 'GIS community' and the 'cultural heritage community' have developed standards which precisely reflect the two different foci – the Open Geospatial Consortium (OGC) Standards for Geographic Information (OGC 2013) 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. To identify the formal language of each ontology in this paper we use subscript $_c$ for CIDOC

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CRM and subscript $_g$ for GeoSPARQL following the concepts and properties of the ontologies.

The integration of detailed geoinformation with CIDOC CRM is a research issue that has been addressed in various projects. The AnnoMAD System (Felicetti et al. 2010) already uses OGC standards to represent geoinformation within CRM structures when utilising Geography Markup Language (GML) in Information Objects that refer to Places of cultural objects. The CLAROS project (OeRC 2014) uses the 'Basic Geo Vocabulary' RDF representation (W3C 2014). English Heritage created the CRM-EH (University of South Wales 2014), an extension to the CIDOC CRM for archaeological excavations with single context recording. The extension uses the concept of Spatial Coordinates within the CRM to relate to spatial X, Y and Z coordinates through datatype properties. At the German National Museum the WissKI project (WissKI 2014) started an initiative to investigate the possibilities of integrating coordinate information within the CRM (Hiebel et al. 2012).

In this attempt to combine GeoSPARQL with CIDOC CRM, we experienced a surprise: the two standards shared no concepts. Even though the CRM was explicitly intended to interface with OGC Standards, neither of the standards allow for expressing objectively where something is in a way which is robust against changes of spatial scale and time. For instance, the CRM allows for specifying a property *has former or current location*$_c$, without declaring if the location is or was the extent of the object, was within the extent of the object or included its extent. The statement Forum Romanum *has former or current location*$_c$ Rome could mean that the built structures of the Forum Romanum are either close to, within the boundaries or overlapping with (current?) Rome. GeoSPARQL, on the other side, allows for assigning one or more precise Geometries$_g$ to a Feature$_g$, but does not say how the real matter of the Feature$_g$ with its smaller irregularities relates to those. The Forum Romanum could be represented as a point, a rectangle containing the (currently known?) extent of the built structures, polygons representing the footprints of the ruins or even 3D models representing virtual reconstructions of the buildings. So, for any Feature$_g$ there is a spatial scale at which a Geometry$_g$ of a detail cannot be compared any more to the Geometry$_g$ of the whole, nor is the temporal validity range explicitly modelled even though the OGC Standards provide mechanisms for assigning a temporal component. We need to link the two ontologies, modelling in detail the overlap. This allows for covering the underdetermined concepts and properties of each of the ontologies by shared specialisations rather than generalisations. Through this we reached 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 called CRMgeo (identified by subscript $_{cg}$), indeed appears to have the capability to link both ontologies and show the way 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 indeterminacies introduced through interpretations or measurement methods, as is good practice in natural sciences. Through the following example of representing the Varus battle in our model we will introduce concepts that are neither available in CIDOC CRM nor in GeoSPARQL. Nevertheless we believe these concepts to be necessary in order to model observations of the remains from historical events and hypotheses about the events.

2. Refining the Place$_c$ Concept of the CIDOC CRM Ontology

We want to illustrate our refinement of the Place$_c$ concept with the historical event of the Varus battle to describe the epistemological process of defining Places$_c$ based on historical sources and archaeological evidence. In 9 CE, three Roman legions under Varus were ambushed by allied German tribes under Arminius. A few years later Roman troops visited the battlefield and buried the Roman remains. This story was described in Roman sources like the Annals of Tacitus (The Latin Library 2014). The precise location of the battle place was not included in ancient texts and is unknown. The descriptions of the battle from Roman sources include 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, various hypothesis have been formulated about the real place of the battle. One of the hypotheses from the 18th century (Stüve 1789) was supported by archaeological finds in the late 1980s (Harnecker

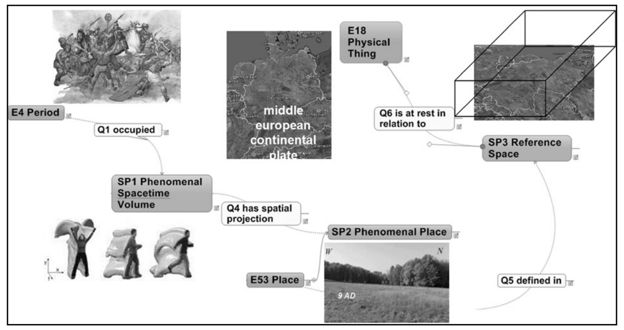

***Figure 1**. Introducing Phenomenal Space Time Volume$_{cg}$, Phenomenal Place$_{cg}$ and Reference Space$_{cg}$.*

1999). A key indication of the correct identification of the battle place is the recovery *in situ* of human bones that show clear traces of having been exposed to the elements for some time before being buried: this sequence matches the story proposed by the Roman sources.

2.1 Phenomenal Places$_{cg}$ based on Phenomenal Spacetime Volumes$_{cg}$ and Reference Spaces$_{cg}$

We want to introduce the concept of a Phenomenal Place$_{cg}$ to represent the real place where an event happened in history. A prerequisite for the use of the concept in our example is the belief that the Varus battle was a true event. As the battle is bound in time we need another concept that includes the real temporal extent of the battle in addition to the place.

We want to call this concept the Phenomenal (or true) Spacetime Volume$_{cg}$ which is a 4 dimensional point set (volume) that material phenomena like Events$_c$ (more generally Periods$_c$) or Physical Things$_c$ occupy in spacetime. It is regarded to be unique but unknown and unobservable in its exact extent. However, in general, there exist kinds of evidence of points in spacetime for which we can tell if they are in or out of a specific Phenomenal Spacetime Volume$_{cg}$. It is necessary to compare and relate Events$_c$ or Physical Things$_c$ with each other. As Archaeology commits to one common reality regardless of the different opinions that exist of this reality the Phenomenal Spacetime Volume$_{cg}$ is a central concept representing this one reality. The Phenomenal Place$_{cg}$ is a spatial projection of the Phenomenal Spacetime Volume$_{cg}$ within a Reference Space$_{cg}$ which is the (typically Euclidian) Space that is at rest in relation to an instance of a

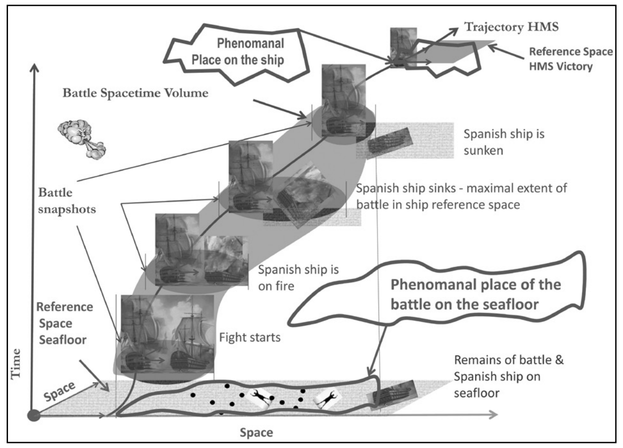

***Figure 2**. Creation of two Phenomenal Places$_{cg}$ from one Spacetime Volume$_{cg}$.*

Physical Thing$_c$ and extends infinitely beyond it. In the case of the Varus battle we assume the space is at rest in relation to today's middle European continental plate. Phenomenal Places$_{cg}$ derive their identity through Events$_c$ or Physical Things$_c$ over the Phenomenal Spacetime Volume$_{cg}$ that they occupy as illustrated in Figure 1.

We want now to illustrate the importance of the Reference Space concept for events taking place on moving objects using as example the Battle of Trafalgar between the English and allied French-Spanish fleet and Lord Nelson's death on the HMS Victory. For an historian interested in Lord Nelson's death the events on board of the HMS Victory are important. For an archaeologist interested in the remains of the Trafalgar battle on the seafloor it is important to formulate hypothesis in relation to the seafloor, where we would expect to find debris of the fight. Therefore, depending on the research question, the same event may be projected either on the ship as Reference Space$_{cg}$ or on the seafloor as Reference Space$_{cg}$. Each projection creates one Phenomenal Place$_{cg}$ resulting in two Phenomenal Places$_{cg}$ of one unique Space Time Volume$_{cg}$. The Phenomenal Place$_{cg}$ on the ship ceases to exist when the ship as base for the Reference Space$_{cg}$ ceases to exist. The Phenomenal Place$_{cg}$ on the seafloor ceases to exist when the seafloor disappears under the continental plate (this is relevant for palaeontology). Figure 3 illustrates the projection of the one unique battle Spacetime Volume$_{cg}$ on two Reference Spaces$_{cg}$ resulting in two Phenomenal Places$_{cg}$.

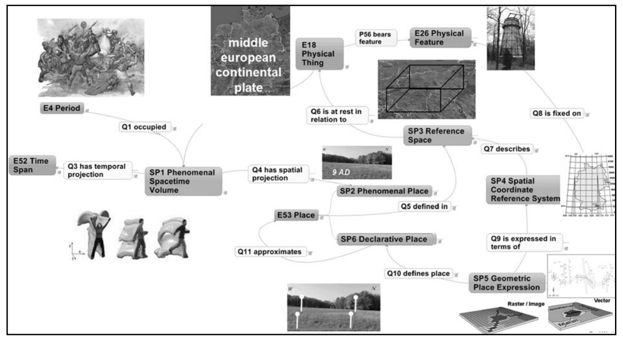

Figure 3. Introducing Geometric Place Expression$_{cg}$ and Declarative Place$_{cg}$ as approximation of a Phenomenal Place$_{cg}$.

2.2 *Declarative Places$_{cg}$ based on Spatial Coordinate Reference Systems$_{cg}$ and Geometric Place Expressions$_{cg}$*

After introducing the Phenomenal Place$_{cg}$ as the real place of the Varus battle we want to provide the concepts to approximate its spatial position and extent with Declarative Places$_{cg}$ that are defined by humans. Locations within the Reference Space$_{cg}$ can be described using some kind of Spatial Coordinate Reference System$_{cg}$ that is related through reference points (features) to the real world. Geometric Place Expressions$_{cg}$ are expressed in a Spatial Coordinate Reference System$_{cg}$. A Geometric Place Expression$_{cg}$, which can be seen as a prescription to find the intended place in the real world, may be created from an observation with a measurement device or the simple drawing of a line on a map. Both actions create a Declarative Place$_{cg}$ that can be visited in the corresponding Reference Space$_{cg}$ of the real world. A Declarative Place$_{cg}$ derives its identity through the description in the Geometric Place Expression$_{cg}$ and not through a Phenomenal Place$_{cg}$ that it may approximate. Figure 3 shows the relations between Phenomenal$_{cg}$ and Declarative Places$_{cg}$ and their related concepts.

3. Geoinformation Standards

The standards in the ISO 19100 Series for Geographic Information (ISO 2013) provide the backbone for the development of Geodata Infrastructures like INSPIRE - Infrastructures for Spatial Information in the European Community (European Commission 2014). The development of these standards is realised by the Open Geospatial Consortiums (OGC) which is an international voluntary consensus standards organisation with more than 400 partners. OGC standards are submitted to the ISO process through the ISO/technical committee 211. They can be grouped in Abstract Specifications defining conceptual models to represent geographic information and Implementation Specifications defining how to implement these conceptual models.

3.1 *Abstract Specifications*

The Abstract Specifications use UML (Unified Modelling Language) to describe the classes with their attributes and relations. The fundamental unit of geospatial information within the geoinformation community is the 'Feature' which is defined in ISO 19101 as an 'abstraction of a real world phenomenon'. It is a geographic feature if it is associated with a location relative to the Earth. Feature instances derive their semantics and valid use from the meaning of the corresponding real world entities. A layered model abstracts from the real world to a so called 'Project World' which is a world view for a specific task (e.g. cartography, cadastre or pavement management). The categories of features captured in a Project World are feature types. The model describes the relations between real world entities, features and their representations. There are three popular approaches for the modelling of geospatial features and each is specified in a separate abstract specification standard. The first is called 'Features with Geometry' and models the spatial extent of a feature with point, lines, polygons, and other geometric primitives that come from a list of well-known types. The abstract specification standard is ISO 19107. The second approach is called 'Feature as Coverage' as specified in ISO 19123, including images as a special case. The third approach is 'Feature as Observation' as specified in ISO 19156, where an observation is an action with a result which has a value describing some phenomenon. An observation feature binds a result to the feature upon which the observation was made. The observed property is a property of the feature of interest. All these primary feature types are intimately related, yet have distinct concepts (OGC 2009).

ISO 19136 Geography Markup Language (GML) is one Implementation Specification that is based on the conceptualisations and classes defined in the Abstract Specifications.

3.2 *GeoSPARQL*

SPARQL is a protocol and query language for the Semantic Web defined in terms of the W3C's RDF data model in much the same way as SQL is a query language for relational databases. In 2012 the OGC adopted the 'OGC GeoSPARQL – A Geographic Query Language for RDF Data' standard. It defines spatial extensions to the W3C's SPARQL protocol and RDF query language. GeoSPARQL provides now a framework how to implement OGC Standards with semantic technologies through RDF/OWL encoding. Its introduction allows the integration of RDF specified information models with the OGC/ISO standards developed in the geoinformation community. The OGC GeoSPARQL standard supports representing and querying geospatial data on the Semantic Web. It provides the foundational geospatial vocabulary for linked data involving location and defines extensions to SPARQL for processing geospatial data. GeoSPARQL comprises five modules:

1. The Core Component defines top-level RDFS/OWL classes for spatial objects.

2. The Geometry Component defines RDFS data types for serialising geometry data, RDFS/OWL classes for geometry object types, geometry-related RDF properties, and non-topological spatial query functions for geometry objects.

3. The Geometry Topology Component defines topological query functions.

4. The Topological Vocabulary Component defines RDF properties for asserting topological relations between spatial objects.

5. The Query Rewrite Component defines rules for transforming a simple triple pattern that tests a topological relation between two features into an equivalent query involving concrete geometries and topological query functions (OGC 2012).

3.3 *Core Component and Geometry Component*

The Core Component contains two main classes. The root class within the hierarchy of the GeoSPARQL ontology is SpatialObject$_{g}$ representing everything that can have a spatial representation. Its

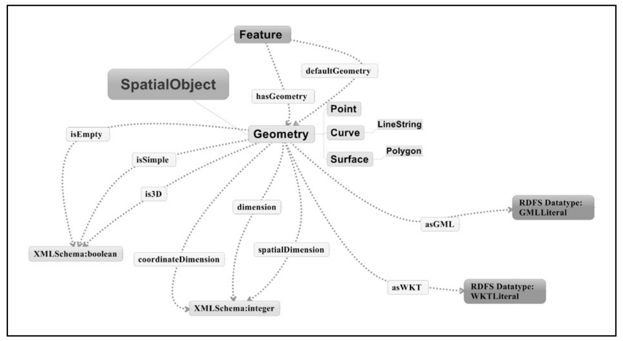

Figure 4. GeoSPARQL Core component classes (SpatialObject$_{g}$, Feature$_{g}$) and the Geometry$_{g}$ class with their basic relating properties.

subclass Feature$_{g}$ represents the top-level feature type and is equivalent to GFI_Feature as defined in ISO 19156-Observation and Measurement. In an implementation this abstract class shall be substituted by a concrete class representing a feature type from an application schema associated with a domain of discourse. The Geometry Component defines a vocabulary for asserting information about geometry data, and it defines query functions for operating on geometry data. A single root class Geometry$_{g}$ is defined as a subclass of the SpatialObject$_{g}$ class defined in the Core Component. As part of the vocabulary, an RDFS data type is defined for encoding detailed geometry information as a literal value. A literal representation of a Geometry$_{g}$ is needed so that geometric values may be treated as a single unit. Such a representation allows geometries to be passed to external functions for computations and to be returned from a query. In addition, properties are defined for describing geometry data and for associating geometries with features. To represent the actual coordinates of a Geometry$_{g}$, a so called Serialisation is used. That means that the coordinates are stored in a format which defines the sequence of the characters. Two formats are specified. One is Well Known Text (WKT) Serialisation as defined in ISO 19125 Simple Feature Profile and the other is a GML Serialisation as defined in ISO 19136 Geography Markup Language. These specifications (ISO 19125, ISO 19136) are also the base for subclasses of the geometry class. An RDF/OWL class hierarchy can be generated from the WKT or GML schema that implements GM_Object from ISO 19107- Spatial Schema as illustrated in Figure 4 for a simplified GML schema. Coordinate reference system information is encoded in the WKT or GML Serialisation. In future there is

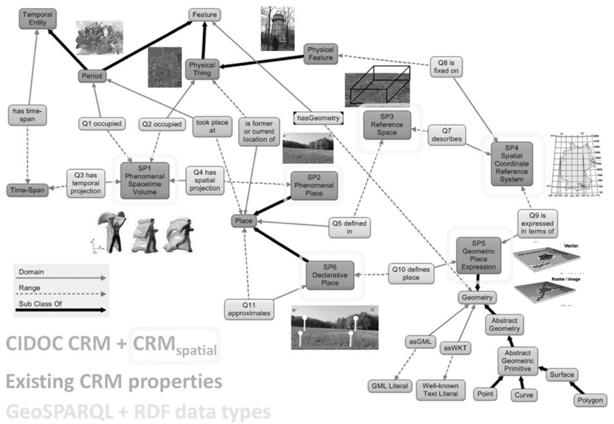

Figure 5. *Integration of CIDOC CRM and GeoSPARQL through CRMgeo.*

the perspective for further extensions covering KML or GeoJSON Serialisations (OGC 2012).

4. CRMgeo Extension

The concepts and relations developed in the integration process have been explained and specified in the CRMgeo extension (Doerr, Hiebel and Eide 2013) and implemented in RDFS. Through the explicit modelling of different identities of Phenomenal$_{cg}$ and Declarative Places$_{cg}$ we can link CIDOC CRM conceptualisations which are targeted at the phenomenal world with GeoSPARQL concepts. Figure 5 provides a graphical view of CIDOC CRM, CRMgeo and GeoSPARQL classes. The link to the GeoSPARQL class Feature$_g$ is realised through Period$_c$ (as superclass of Event$_c$) and Physical Thing$_c$ making them subclasses of Feature$_g$ while the link to GeoSPARQL Geometry is through the Geometric Place Expression$_{cg}$. A representation of spatial content with GML or WKT Literals within the CRM is possible through the GeoSPARQL properties *asGML*$_g$ or *asWKT*$_g$. It shows that the existing CRM property of *is former or current location*$_c$ relating Physical Things$_c$ to Places$_c$ is a shortcut of the fully developed path from Physical Thing$_c$ through *occupied*$_{cg}$, Phenomenal Spacetime Volume$_{cg}$, *has spatial projection*$_{cg}$ to Phenomenal Place$_{cg}$. In case the destination of *is former or current location*$_c$ is a Declarative Place$_{cg}$ the fully developed path has to be extended from the Phenomenal Place$_{cg}$ through *approximates*$_{cg}$ to the Declarative Place$_{cg}$. The same construct is true for Events$_c$ (being a subclass of Period$_c$) and the property *took place at*$_c$. In GeoSPARQL the property *hasGeometry*$_g$ which connects a Feature$_g$ directly to a Geometry$_g$ develops in our model to a path that passes through the concepts of Phenomenal Spacetime Volume$_{cg}$, Phenomenal Place$_{cg}$ and Declarative Place$_{cg}$ to the Geometric Place Expression$_{cg}$. These concepts are needed to make explicit that the proposition about the place of an object holds only for a specific time represented in the Spacetime Volume and the geometry is only an approximation of the real place (Phenomenal Place$_{cg}$) of the object.

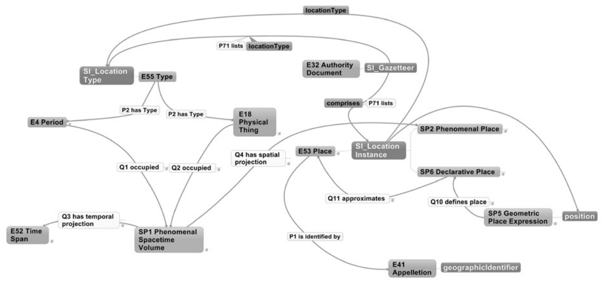

Figure 6. *Representing concepts of ISO 19112, Spatial referencing by Geographic Identifiers with CIDOC CRM and CRMgeo.*

5. Representing Geographic Identifiers and Gazetteers

References to places are often encountered in placenames that can be standardised and made available through gazetteers. Although GeoSPARQL does not include explicitly gazetteers they are defined in ISO 19112 - Spatial referencing by Geographic Identifiers.

The standard defines a model for geospatial references that relate the features and information represented in data or texts to positions in geographic space. Geographic Identifiers are used to refer to geographic locations as an alternative to coordinates and may be names of towns or settlements or addresses with zip codes and street names. As ISO 19112 is in line with other ISO 19100 series standards, Geographic Identifiers can be expressed in GeoSPARQL. The Location Type (e.g. countries, cities, physiographic features, mountains) defines the nature or semantics of a Location Instance, which has a geographic identifier. Depending on the Location Type, placenames in Gazetteers identify places that are phenomenal, declarative or a mixture of both. The CRMgeo extension creates the link to

the CIDOC CRM which provides the possibility to model sources and (implicit) assumptions that lead to the definition of a placename or geographic identifier. In ISO 19112 Gazetteers may contain coordinates of a representative point for the location instance within the 'position' field. In the CRMgeo extension positions in Gazetteers are Geometric Place Expressions$_{cg}$ that create Declarative Places$_{cg}$. Figure 6 shows the relation of ISO 19112 concepts with CIDOC CRM and CRMgeo concepts

6. Conclusions

The proposed extension CRMgeo that links CIDOC CRM with GeoSPARQL provides the ontological foundation for an integration of CIDOC CRM encoded datasets with datasets represented in GIS. The introduction of new classes offers an explicit modelling of concepts that have been hidden until now within the Place class. Within the CIDOC CRM it would not have been possible to relate hypothesis (Declarative Places$_{cg}$) of the Place$_c$ of the Varus battle to the real place of the battle (Phenomenal Place$_{cg}$). Neither it would have been possible to define geometries for these hypothesis in spatial coordinate reference systems making explicit how they relate to Places$_c$ through a Reference Space$_{cg}$ that is fixed in relation to a Physical Thing$_c$. The OGC/ISO models are very sophisticated in dealing with geometric representations of real world phenomenon, but do not differentiate between the phenomenon and the spacetime volume that has been occupied by the phenomenon. It would not be possible to model the Varus Battle, the place of the Varus Battle and the return of Roman troops to this very place a few years later. The direct relation *hasGeometry*$_g$ between Features$_g$ and Geometries$_g$ again gives no possibility to differentiate between the real place of the battle and the hypothesis about this place. Through the linkage of CIDOC CRM and GeoSPARQL with the introduction of the presented classes it is now possible to model:

- real world phenomenon
- the spacetime volumes that are occupied by them
- their spatial projections
- the geometries created by humans to approximate these spatial projections.

The model makes explicit relations of different substance and identity between these four categories.. This has not previously been done, neither in CIDOC CRM nor in GeoSPARQL. CRMgeo may be the basis for the use and development of different kinds of applications. Query engines for semantic networks that are able to process geometric and temporal information may now perform spatiotemporal queries on CRM encoded data, like finding spatiotemporal overlapping areas of battle remains, the spacetime volumes referred to by historical sources, and hypothesis for the true place of the Varus Battle. Geoinformation systems can be developed or used to analyse or visualise the complex relations that semantic networks of cultural data contain, including the provenance of data.

The visualisation of graph networks related to a geometry within a GIS is still a research issue. Future work will have to define different kinds of approximation (like includes or overlaps) relating Declarative Places$_{cg}$ to Phenomenal Places$_{cg}$. An elaboration of the property *approximates*$_{cg}$ is necessary to develop sophisticated spatial reasoning and inferences based on geometric and topological relations.

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