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IMPLEMENTATION OF MULTIPLE INTERPRETATION DATA MODEL CONCEPTS IN CIDOC CRM AND COMPATIBLE MODELS

IMPLEMENTACIÓN DE CONCEPTOS DE MODELO DE DATOS DE MÚLTIPLE INTERPRETACIÓN EN CIDOC CRM Y MODELOS COMPATIBLES

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Highlights:

- Cultural Heritage modelling involves two different ontological concepts: reality and information held about it.
- Historical Objects existence is a sequence made by events, stability periods and changes affecting it.
- Multiple Interpretation Data Model mapping to CIDOC CRM and its extension proposal take into account difference between reality and information. They also manage sequence concept.

Abstract:

Modelling cultural heritage is a research topic shared by a broad scientific community. Although this subject has been widely studied, it seems that some aspects still have to be tackled. This paper describes two CIDOC Conceptual Reference Model (CRM) extension proposals (A & B) dedicated to structuring knowledge concerning historical objects and historical events. It focuses on multiple interpretations and sequential reality, this last being a concept which does not exist in CIDOC CRM but was originally developed in another conceptual model, the Multiple Interpretation Data Model (MIDM). To begin, an extensive description of MIDM concepts is given as well as a recall of its main peculiarities. It is followed by a mapping proposed to translate MIDM concepts into ontologies devoted to describe cultural heritage entities and activities, the CIDOC-CRM and compatible models. Unfortunately, some MIDM concepts are not covered by this mapping because they do not match with existing CRM entities and properties, and this paper explains why an extension is necessary. It describes how the two versions of the extension proposal cover the missing MIDM concepts. One of these two versions, the proposal A, has been implemented as an ontology in Protégé and has been tested through an instantiation phase using a real example. This instantiation phase is fully detailed. It shows that proposal A works coherently with CRM ontologies. On another hand, instantiation phase highlights improvements needs such as recording chronology in a structured way.

Keywords: ontology; sequential reality; reasoning process; documentation; virtual archaeology; cultural heritage

Resumen:

El modelado del patrimonio cultural es un tema de investigación ampliamente compartido por la comunidad científica. A pesar de que este tema ha sido ampliamente estudiado, parece que algunos aspectos aún tienen que ser abordados. Este artículo describe dos propuestas de extensión (A & B) del Modelo de Referencia Conceptual (CRM) CIDOC dedicado a estructurar el conocimiento concerniente a objetos históricos y eventos históricos. Se centra en múltiples interpretaciones y en la realidad secuencial, siendo este último un concepto que no existe en CIDOC CRM pero que fue originalmente desarrollado en otro modelo conceptual, el Modelo de Datos de Interpretación Múltiple (MDIM). Para empezar, se da una extensa descripción de los conceptos MDIM, así como un recuerdo de sus peculiaridades principales. Continúa con un mapeo propuesto para traducir conceptos MDIM en ontologías dedicadas a describir entidades y actividades del patrimonio cultural, el CIDOC-CRM y los modelos compatibles. Desafortunadamente, algunos conceptos de MIDM no están cubiertos por esta asignación porque no coinciden con las entidades y propiedades de CRM existentes, y este artículo explica por qué es necesaria una extensión. Describe cómo las dos versiones de la propuesta de extensión cubren los conceptos MIDM faltantes. Una de estas dos versiones, la propuesta A, se ha implementado como una ontología en Protégé y se ha probado a través de una fase de instanciación usando un ejemplo real. Esta fase de la instanciación está completamente detallada. Muestra que la propuesta A funciona coherentemente con ontologías CRM. Por otro lado, la fase de instanciación resalta la necesidad de mejoras tales como el registro de la cronología de una manera estructurada.

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Palabras clave: ontología; realidad secuencial; proceso de razonamiento; documentación; arqueología virtual; patrimonio cultural

1. Introduction

Modelling cultural heritage (CH) and archaeological data is a very popular research topic. It requires digital recording and preserving all kinds of scientific information: besides digital representation of the shape, appearance and conservation condition of an object, virtual reconstruction of an object must provide its semantic content (history, function, users, etc.) (Australia ICOMOS & International Council on Monuments and Sites, 2013; Desjardin, Nogent, & De Runz, 2012; Doulamis, Doulamis, Ioannidis, Klein, & Ioannides, 2017; Van Ruymbeke, Carré, & Billen, 2012).

Moreover, this information is intended to be linked with facts and arguments on which it is constructed. One of the consequences of this basic rule is heavy managing of a continuously growing amount of data. Enabling cross relations between different data facilitates subsequent data access, data re-use and new data creation.

Although the question has been extensively studied, we believe that some aspects still have to be tackled. In that respect, we have pointed two key points out (Van Ruymbeke, Hallot, & Billen, 2017; Van Ruymbeke, Carré, Delfosse, Pfeiffer, & Billen, 2015): the modelling of all available data about a given item, including hypothetical or refuted data; and the management of the entire lifecycle of an item, with the changes which affected, or will affect it. This means taking into consideration not only its past states, but also its current and future states (like treatment, predictive modelling or restoration, for example). Such concepts were introduced in the Multiple Interpretation Data Model (MIDM) as pointed out by (Van Ruymbeke et al., 2015). Two mapping extensions from MIDM to CIDOC CRM (Le Boeuf, Doerr, Ore, & Stead, 2017) and its compatible models were discussed in (Van Ruymbeke et al., 2017). The following paper develops one of these proposals, the proposal A.

The paper is structured as follows: first, we come back on the almost entirely covering of the notions of the MIDM by existing CRM classes, properties and paths (being understood in CIDOC CRM as "set of properties"). We also come back on the reasons why some additions are necessary to complete the coverage, either as proposal A, or as proposal B. Then, we describe the implementation of the CIDOC extension proposal A and we present an instantiation test realized from real data. Finally, we draw future research perspectives and conclusions.

2. MIDM model and its mapping to CIDOC CRM and compatible models

2.1. Multiple Interpretation Data Model (MIDM) background

The MIDM conceptual model has evolved over the years (Billen et al., 2012; Pfeiffer, Carré, Delfosse, Hallot, & Billen, 2013; Van Ruymbeke et al., 2012; Van Ruymbeke et al. 2015; Muriel Van Ruymbeke, Tigny, De Bats, Garcia Moreno, & Billen, 2008). The proposed version was designed in 2014 (Fig. 1). In this model, we worked on the assumption that an historical object is defined by its spatiality, its temporality and its functionality. This definition relies on the object identity definition proposed by D. Peuquet (Peuquet, 1994) for geographical object and re-used for archaeology by (Galinié, Rodier, & Saligny, 2004; Rodier & Saligny, 2007; Rodier & Saligny, 2011). It also relies on "object's identity" concept understood as: "the property intrinsic to each object which allows it to be differentiated from all others» (Hallot, & Billen, 2016).

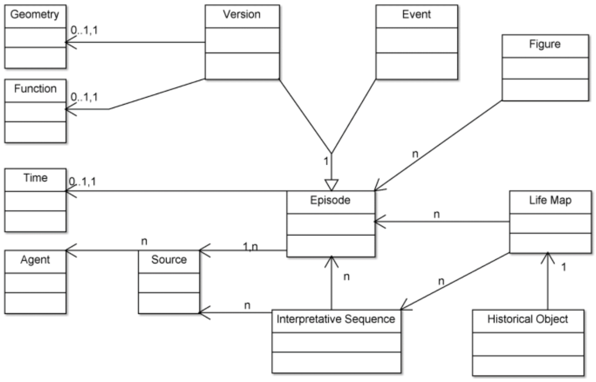

Figure 1: MIDM schema.

We developed a hypothesis that biography of a historical object is composed of several steps (we called them "Episode", each of them being documentable. We called "Version" information regarding "Geometry" and/or, "Function" of an "Episode". We considered that an "Event" affecting these steps is an "Episode" too. We called "Interpretative Sequence" information about an ordered succession of episodes. Lastly, we called "Life Map" the class dedicated to store all information related to the "Historical Object". "Life Map" class ensures the distinction between historical reality and hypotheses describing it.

2.2. From conceptual model to ontology

At that stage, we decided to transform our conceptual model into a Resource Description Framework (RDF) ontology (RDF Schema 1.1, 2014). In parallel, we also wanted to adopt official cultural heritage standards and, thanks to it, taking part in scientists and users' communities.

Recent papers (in particular: Belussi & Migliorini, 2016a; Belussi & Migliorini, 2016b; Le Goff, Marlet, Rodier, Curet, & Husi, 2015; Marlet, Curet, Rodier, & Bouchou-Markhoff, 2016; Ronzino, 2015; Ronzino, Niccolucci, Felicetti, & Doerr, 2016a; Wefers, Karmacharya, & Boochs, 2016, p. 20 - 22) mentioned the significance of CIDOC – CRM in the cultural heritage domain. Moreover, its compatible models offer a wide range of interesting extensions. Considering these facts, we proposed to map the innovative concepts of the MIDM into the CIDOC CRM.

2.2.1. Characteristics of CIDOC CRM and compatible models (CRMsci, CRMinf, CRMarchaeo, CRMba, CRMgeo and FRBRoo)

CIDOC CRM (Le Boeuf et al., 2017) is an ontology developed more than twenty years ago for museum inventory purposes. It became an international standard in 2006 (ISO 21127:2006). Enriched by several extensions, it now concerns not only the museum domain but the overall cultural heritage field.

A first extension, CRMsci (Doerr, Kritsotaki, Rousakis, Hiebel, & Theodoridou, 2017b) targets scientific observation and measurements methodologies. Another one, CRMinf (Stead, Doerr, & Alii, 2015a), focuses on argumentation and deduction in descriptive and empirical sciences. CRMarchaeo and CRMba (Doerr et al., 2017a; Ronzino, 2017; Ronzino, Niccolucci, Felicetti, & Doerr, 2016b) describe respectively subsurface and building archaeology process while CRMgeo (Hiebel, Doerr, Eide, & Theodoridou, 2015) provides the missing link with GEOSPARQL. Moreover, Functional Requirements for Bibliographic Records ontology (FRBRoo) adds creative process aspects, not only for bibliography or literature, but also for artistic or architectural creation (Bekiari, Doerr, Le Boeuf, & Riva, 2017; Guillem, Bruseker, & Ronzino, 2017).

The CRMinf model provides the ability to link semantic proposals with the steps (observation, inference making and belief adoption) of reasoning leading up to them. A very recent paper proposes using events to express reliability with coefficients (Niccolucci, & Hermon, 2017).

To easily link CIDOC CRM to GEOSPARQL, CRMgeo proposed to separate real world classes (called phenomenal classes) from information classes (called declarative classes) (Hiebel, Doerr, & Eide, 2017). This distinction between the real word and the world described by information concerns time and geometry dimensions only.

CIDOC CRM and its compatible model ensure the modelling of various streams of information. It has been designed to “accommodate alternative opinions and incomplete information” (Le Boeuf et al., 2017). In that goal, most properties are quantified as optional and repeatable for their domain and range (“many to many (0,n:0,n)”). However, other cardinalities may be used and some CIDOC CRM or compatible models properties are very constrained, notably in CRMarchaeo or CRMba.

2.2.2. Main mapping

The main mapping between MIDM entities and CIDOC CRM and compatible models uses existing classes, properties, and paths to encompass most of the concepts of the MIDM (Fig. 2). Several properties succession (named “path” in CIDOC CRM) is a concept rather used to express complex relations. If necessary, they can be shortened by shortcuts which are designated to simplify longer articulated paths (Le Boeuf et al., 2017, p. xvii).

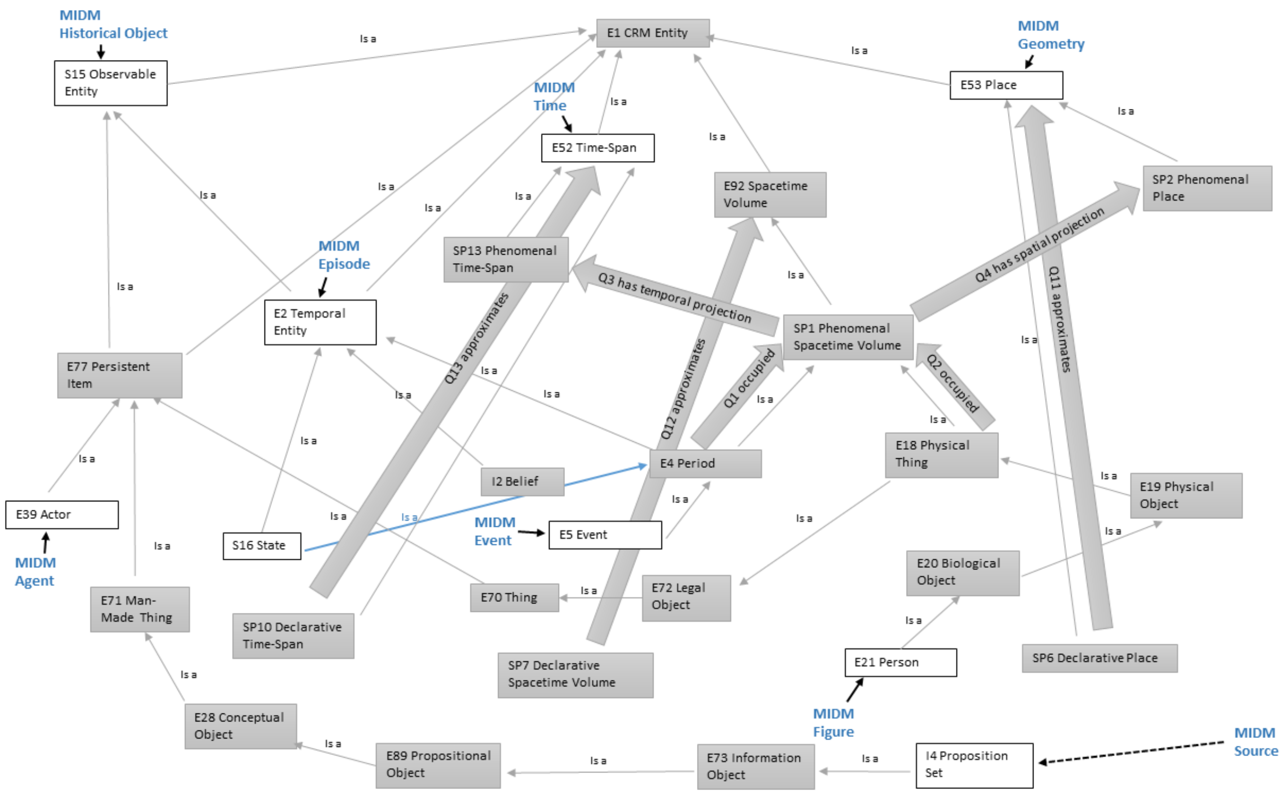

Figure 2: Mapping of MIDM on CIDOC CRM and compatible models, where white boxes designate CIDOC CRM classes equivalent to MIDM concepts.

The main mapping identifies several equivalences between MIDM concepts and CRM existing classes. It constitutes a framework to be completed by the proposal extensions described below, in Section 3.2.

2.2.2.1. Historical Object class

The main class of the MIDM was defined as follows: “a consistent group of elements belonging to the same body from its emergence until its disappearance. The mentioned body can be an architectural body, a professional corporate body, a human body, etc." (Van Ruymbeke et al., 2015). In our opinion, this definition corresponds to an S15 Observable Entity, phrased in CRMsci in these terms: "This class comprises instances of E2 Temporal Entity or E77 Persistent Item, i.e.: items or phenomena that can be observed, either directly by human sensory impression, or enhanced with tools and measurement devices, such as physical things, their behaviour, states and interactions or events" (Doerr et al., 2017b).

In CRM hierarchy, S15 generalizes a wide range of classes and notably CRMba B1 Built Work (Doerr et al., 2017a; Ronzino, 2017; Ronzino et al., 2016b), CIDOC CRM E22 Man-made Object (Le Goff et al., 2015; Marlet et al., 2016), CRMarchaeo A8 Stratigraphic Unit (Doerr, et al., 2017a), but also CIDOC CRM classes like E39 Actor and FRBRoo F21 Person and all classes that descend from E28 Conceptual Object class (Le Boeuf et al., 2017). In CRM hierarchy, it is important to emphasize that all classes that descend from CIDOC CRM E92 Spacetime Volume (subclasses of CIDOC CRM E4 Period and CIDOC CRM E18 Physical Thing) occupy (CRMgeo properties Q1 occupies and Q2 occupies, cardinality many to one, necessary (1,1:0,n)) a CRMgeo SP1 Phenomenal Spacetime Volume (Hiebel et al., 2015).

In accordance with CRMgeo, SP1 Phenomenal Spacetime Volume has a temporal and spatial projection (properties Q3 and Q4, cardinality one to one (1,1:1,1)) which can be described by instances of declarative spatial or temporal classes (Hiebel et al., 2015).

2.2.2.2. Version class

S16 State, Sub-class of CIDOC CRM E2 Temporal Entity is described in CRMsci as follows: "This class comprises the persistence of a particular value range of the properties of a particular thing or things over a time-span." (Doerr et al., 2017b). We assume that it encompasses, but only partially, the MIDM "Version" class. In other words, we see S16 State as the phenomenal side of MIDM "Version", that is to say a real step in the spatiotemporal and functional evolution of an item. Unfortunately, in current version of CRMsci, S16 State is not a subclass of E92. As a result, it does not occupy an SP1 Phenomenal Spacetime Volume. Now, the CRMgeo model centres around SP1 and we want to use it for S16 State. To solve this question, we propose here to see in S16 State a subclass of E4 Period.

2.2.2.3. Other classes

In the proposed mapping, CIDOC CRM E53 Place coincides with the MIDM "Geometry" class. CIDOC CRM E5 Event encompasses the MIDM "Event" class. Considering class structuring in CIDOC-CRM and compatible models, MIDM "Episode" class can be assimilated with class E2 Temporal Entity. MIDM "Figure" and "Agent" classes match with CIDOC CRM classes E21 Person and E39 Actor.

2.2.2.4. MIDM "Source" mapping class

Assured by CRMinf (Stead et al., 2015a; Stead, Oldman, & Cloud, 2015b), the contribution of the MIDM "Source" class is deeply enriched. Thanks to this model, the entire development of an argumentation can be detailed. It allows for complete traceability, which also includes the formulators of an hypothesis. In a few words, here is what CRMinf proposes: knowledge acquisition process, generalized by CRMinf I1 Argumentation class, holds CRMinf property J2 concluded that. This property's range is CRMinf I2 Belief. This class holds two properties: CRMinf J5 hold to be whose range is CRMinf I6 belief value and CRMinf J4 that, whose range is CRMinf I4 proposition Set. The CIDOC CRM property P14 carried out links I1 Argumentation to CIDOC CRM E39 Actor. CIDOC CRM property P70 documents links CIDOC CRM E31 Document to I4 Proposition Set. In the same way, CIDOC CRM property P67 refers to links CIDOC CRM E89 propositional Object to I4 proposition Set.

To take full advantage of these paths, considering they are lying on CRMinf class I4 Proposition Set, we propose to consider CRMgeo SP5 Geometric Place Expression, SP14 Time Expression and SP12 Space Time Volume Expression to be subclasses of I4.

3. Extension proposal

3.1. Required adjustments for a complete matching

Despite the completeness of CIDOC CRM and compatible models, some specific points from MIDM presented in 2014 are not yet covered.

3.1.1. Semantic distinction between reality and information

Unlike Spatiotemporal properties of phenomena which are difficult to perceive in the real world (Hiebel et al., 2015), their semantic properties can be more easily discerned by contemporaneous observers. Nevertheless, most of the phenomena described in CIDOC CRM occurred in the past. Consequently, our knowledge of their properties depends on historical and archaeological sources.

Dedicated to store semantic contents (covered by the class "Function" in the MIDM), CIDOC CRM and compatible models can give a detailed description of the information about real phenomena through use of properties or relations. These descriptions, however, provide no clear distinction between reality and the information depicting it. On our side, we assumed that it is important to specify whether we model reality or information about it. Reality is supposed to be unique and true while information can be varied, fuzzy and uncertain.

In the MIDM, this difference found expression in the use of different classes: Historical Object was used for phenomenal entities, and Time, Geometry, Function, Episode, Version, Event, Interpretative Sequence and Life Map were used for declarative entities. In the CIDOC CRM and its compatible models, we did not find satisfactory equivalent for Function, Version, Interpretative Sequence and Life Map. This is the reason why we worked on drawing up an extension proposal.

3.1.2. Reality is sequential

Another aspect of MIDM is not yet present in CIDOC CRM and compatible models: the sequence of events. Just as constructed works can be divided into morphological building sections (Ronzino, 2017; Ronzino et al., 2016a; Ronzino et al.,2016b), we assume that all phenomena (for example a building life cycle) can be divided into different moments corresponding to the succession of its different states. We assume that such a succession occurs in reality and must of course be the subject of historical and archaeological hypotheses. Even if we can model different states, different events and different properties in CIDOC CRM and compatible models, there is no class for sequences as such. One could object that CIDOC CRM E4 Period or E5 Events could suit to play that role. It is not the case and we will explain why below. There are two key advantages to having a specific class for sequences: the possibility to discretize reality into smaller entities, and consequently the possibility of linking information to it.

3.1.3. Multiplicity management

With the current state of CIDOC CRM and compatible ontologies, multiple semantic information regarding a given reality can be stored in two ways: keeping the most recent one and therefore losing the previous ones; or adding information layers without real possibility for information classification (Bruseker, Guillem, & Carboni, 2015; Stead et al., 2015b).

In the archaeological domain, research subjects stretch over the long term and produce a huge amount of data because the statements, the analyses, the studies and the interpretations accrue over time. It is thus necessary to organise these data. This organization ensures, notably, data reliability evaluation, semantics' indexation, and linking with sources and arguments. Thanks to that organization, researchers are easily able to find previous information and recycle it into new reasoning.

3.1.4. Objectives of the proposed extension

The extension proposition (actually composed of two concurrent versions) aims at distinguishing reality from positions held about it, breaking down complex phenomenon's evolution into sequences and ensuring documented versioning for the knowledge accumulation. Both extension proposals ensure statement for MIDM concepts absent from the mapping (Version, Function, Interpretative Sequence and Life map). It is expressed as extension proposals added on top of CIDOC CRM and its compatible models with classes and properties (Van Ruymbeke et al., 2017).

To point out difference between reality and the discourse held about it, and to model interpretative sequences, we propose to follow the track opened by Hiebel et al. 2015; Hiebel et al. 2017 and to add (proposal A), or to select in CIDOC CRM and compatible models (proposal B) declarative classes to model functional (or semantic) parts of information. In both cases, a new class is also proposed for sequential aspects of phenomena. Only proposal A is fully described and instantiated below, while proposal B is shortly presented. In both versions of the proposal, new classes are identified by numbers preceded by the letter M; new properties are identified by numbers preceded by MP.

3.2. Extension proposal A

The extension proposal A endeavours to differentiate reality from views held about it by adding new classes (Fig. 3). It consists in creating five classes (M) and five properties (MP), namely M1, M2, M3, M4, M5, MP1, MP2, MP3, MP4 and MP5. Most of them were conceived for semantic modelling. The MIDM "Function" notion is epitomized by M1 Semantic Dimension. MIDM "Version" is obtained when instances of M3 Declarative Semantic Content concern instances of S1 State of an Historical Object. The whole of Declarative Semantic Contents affecting a same S15 Observable Entity covers the MIDM Historical Object's "Life Map" concept. Lastly, when a declarative Semantic Content describes an M5 Sequence, it corresponds to the MIDM "Interpretative Sequence concept".

3.2.1. M1 Semantic Dimension

Semantic Dimension comprises all the semantic contents of a material or immaterial phenomenon. These semantic contents may be explicit or implicit, known or unknown, unique or multiple. It can be described as all the real facts making up a phenomenon. To take an example, the semantic content of the event: "the murder of Caesar" would include all real facts and real persons implicated in the event: the exact location and date, the murderers, the witnesses, the weapons, Caesar's last words, the fatal issues and so on. M1 gathers all significant contents of entities and activities constituting a complex entity. In a way, it can be understood as the semantic equivalent of E92 Spacetime Volume. To ensure this semantic dimension for as many classes as possible, we propose that M1 be superclass of S15 Observable Entity.

3.2.2. M2 Phenomenal Semantic Content

Phenomenal Semantic Content represents the global contents carried by a phenomenon during its existence. This class corresponds to the real semantic contents of an instance. In historical and archaeological domains, it is impossible to describe these contents in their entirety. At the very least, one can approximate them by way of hypothetical discourses. In the case of Caesar 's murder, Phenomenal Semantic Content encompasses the whole set of real phenomenon embedded in this historical event such as the colour of Caesar's clothes, the size of the weapons, the number of the murderers…

3.2.3. M3 Declarative Semantic Content

Declarative Semantic Content includes all information describing the semantic dimension of an object. We propose to use this class to store hypotheses relative to an item or its evolution. Historical and archaeological discourses could find their place in this class. If, declarative semantic contents are most often expressed in the form of text, they can also be pictures, or movies or instances of ontological relations. Like declarative classes in CRMgeo, we propose to see M3 as a subclass of CIDOC CRM E89 Propositional Object. It is also a subclass of M1 Semantic Dimension. For example, all the statements related to Caesar's murder included in historical sources, scientific publications or visible on pictorial works are instances of M3.

3.2.4. M4 Semantic Expression

Semantic expression is a normalized content, marking out the contents of M3 Declarative Semantic Content. Like SP5 Geometric Place Expression, SP12 Spacetime Volume Expression and SP14 Time Expression, it is a subclass of CIDOC CRM E73 Information Object. We see it also as a subclass of CIDOC CRM E62 String and I4 Proposition Set. We propose to add I4 as superclass to expressive classes of CRMgeo, because this hierarchical dependence is of importance for the argumentation tractability exposed above in Section 2.2.2.4.

3.2.5. M5 Sequence

Sequence is the new class for a sequence of events constituting a phenomenon in the real world. It is built by one or more instances of S16 State, and E5 Event. Its creation is necessary because neither E5 Event nor E4 Period can play that role. Indeed E4 Period is defined in CIDOC CRM (Le Boeuf et al., 2017) as the class comprising: «sets of coherent phenomena or cultural manifestations occurring in time and space». The examples given in the definition are historical or artistic periods. Obviously, E4 Period regards coherent and constants phenomena. On the contrary, E5 Event is defined as «changes of states» (Le Boeuf et al., 2017). Though, Sequence is an alternation of stability and changes. The chain of facts and events having led to Caesar's dead is, in our opinion, a perfect example of Sequence.

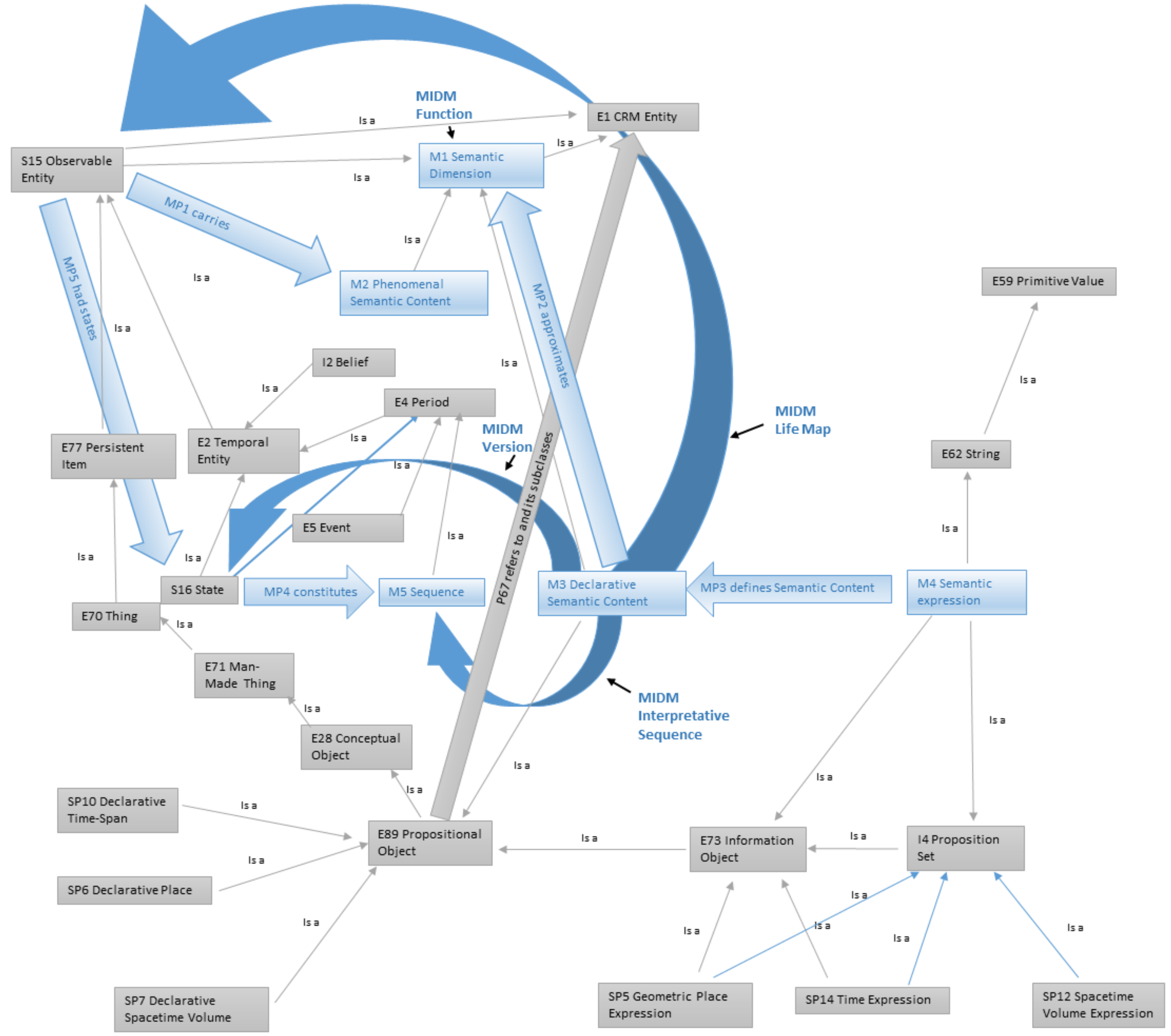

Figure 3: Mapping of the extension proposal A.

3.2.6. MP1 carries

M2 Phenomenal Semantic Content is the range of property MP1 "carries (is carried by)" whose domain is S15 Observable Entity. This property can be seen as equivalent to CRMgeo properties Q1 and Q2 "occupied". Considering the character of the state of MP1, we conjugate it at the present time (Le Boeuf et al., 2017). Q1 and Q2 are quantified: many to one, necessary (1,1:0, n). We assume that this should not be the same for MP1: each phenomenon could have an unlimited quantity of semantic contents, but must have at least one. We would quantify this property as many to many, necessary (1,n:0,n). To get back to Caesar's murder example, this historical fact "carries" several Phenomenal Semantic Content: the murderer, the weapon, Caesar's clothes and so on.

3.2.7. MP2 approximates

M3 is the domain of MP2 property "approximates" whose range is an M1 Semantic Dimension. Along the lines of CRMgeo Q11, Q12 and Q13 (Hiebel et al., 2015), this property approximates the semantic dimension of an item. It does not state the quality or accuracy of the approximation, but states the intention to approximate the semantic dimension. Consequently, the cardinality of MP2 should be many to one (0,1:0,n). If we take the clothes worn by Caesar when he died, they "approximate" the global Semantic Dimension of the event.

3.2.8. MP3 defines Semantic Content

M4 is the domain of property MP3 "defines Semantic Content". Like CRMgeo properties again, (Q10, Q14, and Q16), it associates an expression with its content. Considering that different expressions may lead to a same meaning (Hiebel et al., 2015), the cardinality of MP3 should be many to one, necessary, dependant (1,1:1,n). There are for example numerous paintings of Caesar's murder but most often they show the same toga and tunic.

3.2.9. MP4 constitutes

The domain of MP4 property "constitutes" is E2 Temporal Entity. MP4 creates the membership between instances of S16 State or E5 Events and M5 Sequence (its range). Considering the fact that an unlimited number of states may constitute a single sequence, we assume that cardinality of MP4 should be many to one, necessary, dependent (1,1:1,n). For example, successive stages of Caesar's murder (entrance of Caesar in Pompée's curia, Caesar sitting down, etc.) constitute murder's sequence.

3.2.10. MP5 had states

On theoretic bases, we had imagined that the link between object and state could be expressed by an existing property. But during the implementation phase, we did not find any suitable property, and thus we created MP5 "had states", with S15 Observable Entity as domain and S16 State as range. We conjugate it at past time because we consider it as a property related to event. We confer it cardinality many to one, necessary, dependent (1,1:1,n). This property suits for example to link the global historical fact "Caesar's murder", with its successive steps.

3.2.11. Proposal B: short description

In contraposition with proposal A approach, proposal B (Fig. 4) works on the principle that most of CRM classes include a semantic dimension. Thus, to separate reality from information held about it, we started from the assumption that E89 Propositional Object could be seen as the semantic declarative class, and that I4 Proposition Set could be considered as the semantic expression class. In other words, E89 should take M3 Declarative Semantic Content's place while I4 should take M4 Semantic Expression's place. At the end, this proposal consists of only one class (M5 Sequence) and two properties (MP4 constitutes and MP5 had states).

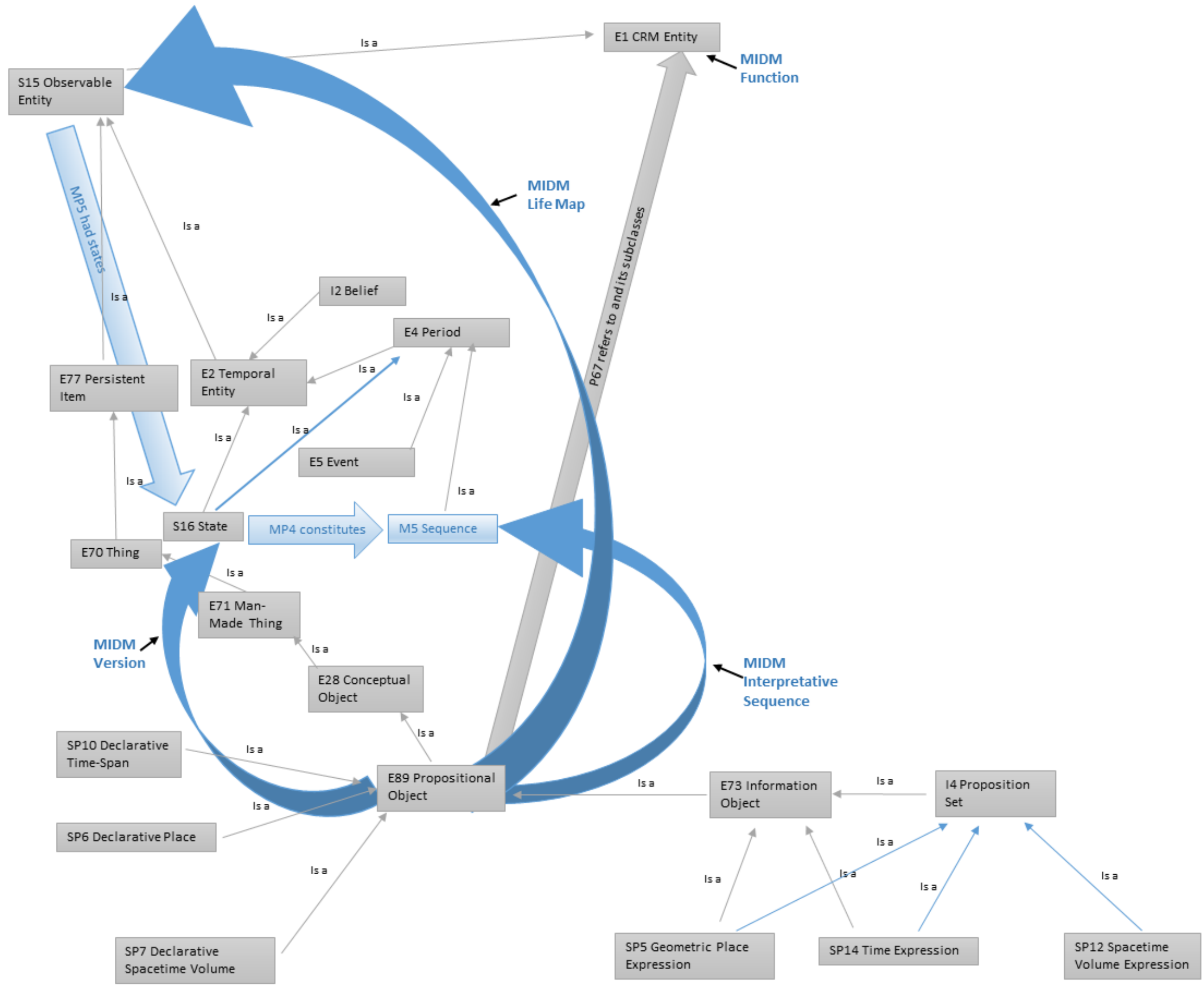

Figure 4: Mapping of the extension proposal B.

Here, the MIDM "Function" notion is included in E1 CRM Entity. MIDM "Version" is obtained when instances of E89 Propositional Object concern instances of S1 State of a Historical Object. The whole of Propositional Objects aiming at a same S15 Observable Entity covers the MIDM Historical Object's "Life Map" concept. Lastly, when a Propositional Object describes an M5 Sequence, it corresponds to the MIDM "Interpretative Sequence" concept. It should be noted that this proposal has been implemented but not instantiated yet.

4. Proposal implementation and instantiation

4.1. Methodology

Implementation and instantiation were the necessary steps to validate and consolidate our mapping and extension proposal. Implementation consisted in creating an OWL file of the proposal (with new classes and new properties) and to link it with CIDOC CRM and compatible models. Instantiation consisted in creating instances of classes and properties to check the mapping and the ontology's feasibility and validity.

4.2. Implementation

To implement our ontology and to graft it on CIDOC CRM and compatible extensions, we used Protégé, a "free, open-source ontology editor and framework for building intelligent systems" (Musen, 2015).

4.2.1. Ontological roots setting-up

Implementation began with downloading the most recent CIDOC CRM and compatible models RDFS files and saving them locally. After using a reasoner, we noticed some inconsistencies (annotation properties recorded instead of object properties, lacks in hierarchy or erroneous IRI (Internationalized Resource Identifier)). We modified them on our local files. We also added, on these local files, the disjunctions described in official releases. Finally, we added, also on local files, the specializations exposed above: S16 State subclass of E4 Period and SP5 Geometric Place Expression, SP14 Time Expression and SP12 Spacetime Volume Expression subclasses of I4 Proposition Set.

4.2.2. Proposal A implementation

We then implemented the proposal A ontology (Fig. 5). We called it EPA and created it with the following IRI: http://www.geo.ulg.ac.be/MVR/. We annotated it, according to Dublin Core recommendations (DCMI, 2012), with the date, the creator, the contributors, the title and the CIDOC CRM and compatible ontologies with which it is compatible. Thus we created the five classes, the five properties and their dependencies with other ontologies classes. To implement the fact that M4 Semantic expression is a sub class of String, we had to create the data property "MP6 has content" whose range is data type Literal. Indeed, String entity is not included in the CIDOC CRM existing implemented ontology.

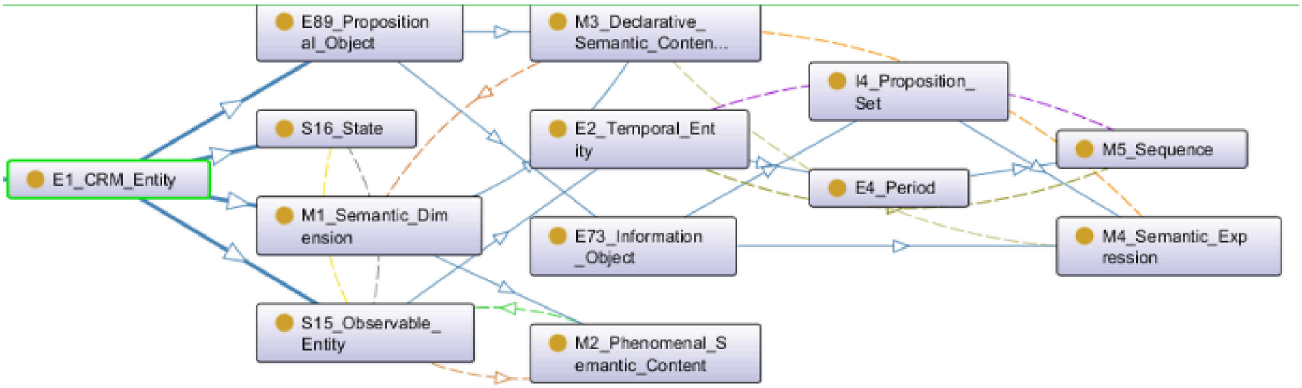

Figure 5: Implemented proposal A classes (boxes). Blue lines are hierarchical links, dotted lines are properties.

After this implementation of proposal A, we gathered it with CIDOC CRM and compatible models and we checked overall consistency with reasoner Pellet.

4.3. Instantiation

To test the complete appropriateness between our theoretic proposal A and the MIDM model, we decided to use an example published in a previous paper (Van Ruymbeke et al., 2015). It targets the evolution of a single building, currently a church named "*Saints Hermes et Alexandre*" or "Theux's church" (Fig. 6).

Figure 6: Theux's church ©KIK-IRPA, Bruxelles.

4.3.1. Data contextualization

The listed monument has a long story. It has been studied since the 19th century and many interpretations regarding its development's phases have been published. (See notably but not extensively Bertholet, 1968; Bertholet,1971; Genicot, 1972; Henaux, 1846; Lemaire, 1952; Limbourg, 1874; Winants, 1968). In 1986, new scientific data (i.e. archaeological excavations and dendrochronological analysis) were produced (Bertholet & Hoffsummer, 1986). They showed that the building was older than previously thought and they lead to imagining a long and complex evolution. In 2009, a new publication presenting artefacts flat glass analysis suggests revising the dating of the two first building's states (Van Wersch, Mathis, & Hoffsummer, 2009).

To make things simpler to understand here, we simplified the whole of the scientific studies and interpretations and we just kept information displayed in 3 of them: Henaux (1846), Bertholet & Hoffsummer (1986) and Van Wersch, Mathis, & Hoffsummer (2009). To test the model in a plausible situation, we instantiated the data in a chronological way: Henaux's data, then Bertholet & Hoffsummer data, then Van Wersch & al. data. For clarity reasons, we will describe very shortly below these data content.

When he visited the church, around 1845, Ferdinand Henaux thought that the structure had known three states: a first one before year 800, a second one at the beginning of the 16th century, and a last one around 1626 (Fig. 7).

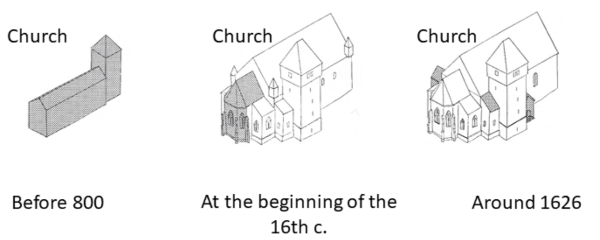

Figure 7: Henaux's interpretations, drawn from Bertholet & Hoffsummer (1986).

After their archaeological excavations, Paul Bertholet and Patrick Hoffsummer proposed a new evolution of the building's reconstruction divided into nine steps (Fig. 8).

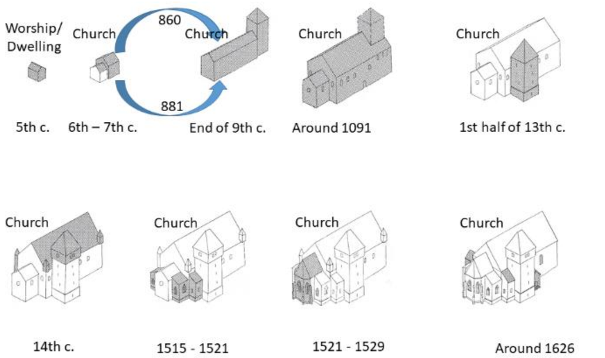

Figure 8: Bertholet & Hoffsummer's interpretations, drawn from Bertholet & Hoffsummer (1986).

They date the very first building of the structure, a house, or a pagan Place of Worship back to the fifth century. Secondly, during the 6th or 7th century the authors think that the building was extended to become a Christian church, probably dedicated to Saint Pierre. In the second half of the 9th century the authors suggest that this building was replaced by a bigger one. According to them, two events could explain this new building: the receipt of St Hermes' relics (around 860) end the new church's dedication, or a fire caused by a Norman's incursion in 881. Around 1091, the authors believe that a new church, three times bigger than the previous one, was erected and also dedicated to Saint Alexander besides Saint Pierre.

More than one century later, in the beginning of the 13th century, a tower would have been added against the north wall. During the 14th century, important fortification works would have been achieved: the tower would have been equipped with hoardings (currently still preserved), naves roof repaired and wooden turrets surmounting the angles and the entrance.

At the beginning of the 16th century, two transformation phases would have modified the east part of the building to give it a gothic shape. Lastly, around 1626, the nowadays porch would have been built.

The new analysis undertaken in 2009 brought the following new interpretations (Fig. 9): the dating of the two first states have been revised and the authors suggest that the first state would have occurred at the end of the 8th century and would have been quickly followed by the second state, still at the end of the 8th century or at the beginning of the 9th century.

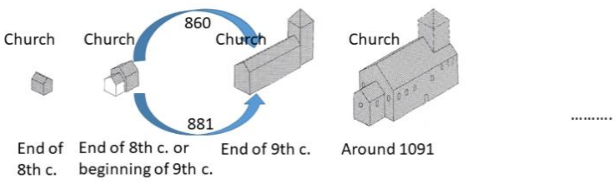

Figure 9: Van Wersch & alii's interpretations, drawn from Bertholet & Hoffsummer (1986).

4.3.2. Instantiating

This step consisted in creating examples of classes and properties described above. For this purpose, we first created instances for classes and properties related to Historical Object, then we created states, events and sequences as and when they appeared in the publications chronology.

4.3.2.1. Historical Object

We began the instantiation test with Historical Object recording. The Historical Object studied (Theux's church) has been considered as an instance of B1 Built Work and received the ST-0101 code. We followed by creating instances of phenomenal classes and properties related to it:

- SP1 Phenomenal Time-Span Volume: ST-0101PTSV
- SP2 Phenomenal Place: ST-0101PP
- SP 13 Phenomenal Time-Span: ST-0101PTS
- M2 Phenomenal Semantic Content: ST-0101-PSC
- Q2 occupied: ST-0101 occupied ST-0101PTSV

- Q3 has temporal projection: ST-0101 has temporal projection ST-0101PTS
- Q4 has spatial projection: ST-0101 has spatial projection ST-0101PP
- MP1 carries: ST-0101-PSC

4.3.2.2. States, Events, Sequences and the publications which mention them

The next step consisted in creating instances of the authors (FRBR F10) and their publications (F2). It should be noted that the use of F2 Expression class is a shortcut for Bibliographic instantiation. We exceptionally used it in this test, for a sake of simplicity. Actually, the complete FRBRoo and the FRBRpress model allows a richer way to describe documentation data.

- F10: François_Mathis, Line_Van_Wersch, Patrick_Hoffsummer, Paul_Bertholet
- F2: Bertholet_P, Hoffsummer_P., _1986; Henaux_F.,_1846,_p._42-43; Van_Wersch_L.,_Mathis_F.,_Hoffsmmer_P.,_2009.

After that, we created instances of the states (S16) and the sequence (M5). We did it in three phases in order to respect the publications chronology.

Indeed, we began with recording Henaux's interpretation. Three states have been created: ST-0101-EP1, ST-0101-EP2 and ST-0101-EP3. The first one occurring before (P120), the second one occurring before (P120), and the third one (Fig. 10). These states constituted the sequence ST-0101-S (instance of M5).

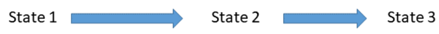

Figure 10: First recording of ST-0101-S.

We pursued with creating instances for the data published in 1986: we created 6 new states (ST-0101-EP4, ST-0101-EP5, ST-0101-EP6, ST-0101-EP7, ST-0101-EP8, ST-0101-EP9) and one event, recorded in E81 Transformation, a sub class of E5 Event (ST-0101-EP5-to-EP1) (Fig 11). We had to change the previous flow by the new one and replace, for example "state 1 occurs before state 2" by "state 1 occurs before state 6".

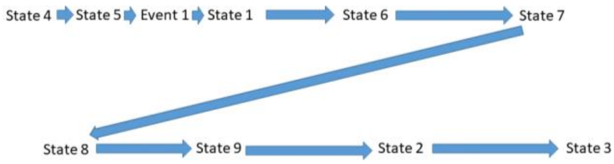

Figure 11: Second recording of ST-0101-S.

No more states, events or relation have been added regarding the information collected by the 2009 study. Indeed, it tackled elements previously identified.

Once instantiated, we created phenomenal instances of states, events and sequence, and we linked them by properties Q1, Q2, Q3, Q4 and MP1 like it has been done for Historical Object (Fig. 12). We also linked Historical Objects with its states, events and sequence by P12, P10 and MP5.

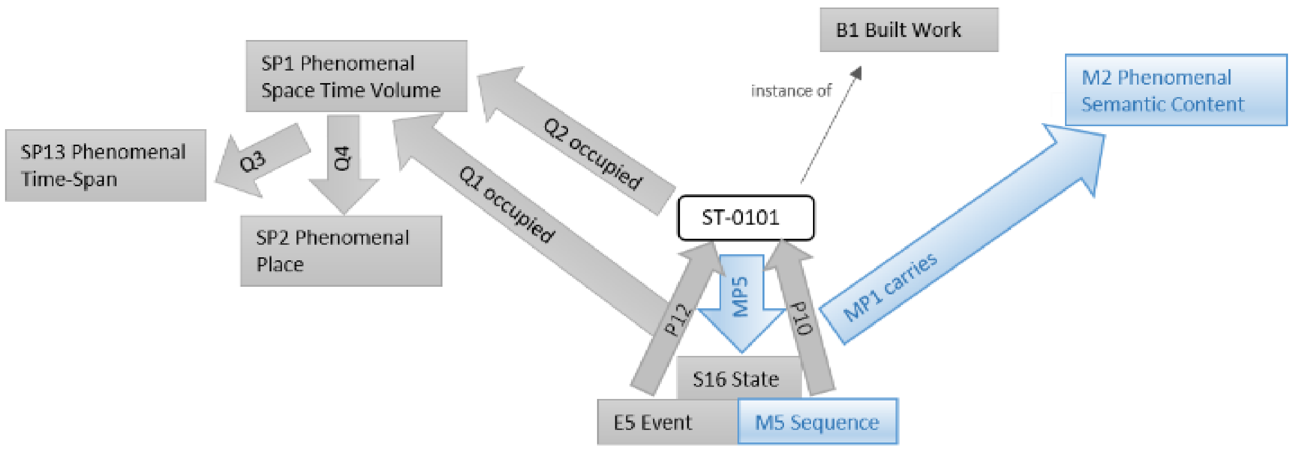

Figure 12: Phenomenal instantiation protocol; In grey: existing classes and properties, in blue: proposal A classes and properties, in white: HO instance.

4.3.2.3. Declarative classes instantiation for States, Events and Sequence

First, we created instances of expressive classes SP14, SP5 and M4 (Fig. 13). Considering the different opinions expressed by authors, we have 15 semantic expressions being relevant to the 9 states recorded in S16: ST-0101-EP1v1 (for Henaux's statement about Roman Theux's church), ST-0101-EP1v2 (for 1986's statement about Roman church), and so on with ST-0101-EP2v1, ST-0101-EP2v2, ST-0101-EP3v1, ST-0101-EP3v2, ST-0101-EP4v1, ST-0101-EP4v2, ST-0101-EP4v3, ST-0101-EP5v1, ST-0101-EP5v2, ST-0101-EP6v1, ST-0101-EP7v1, ST-0101-EP8v1 and ST-0101-EP9v1.

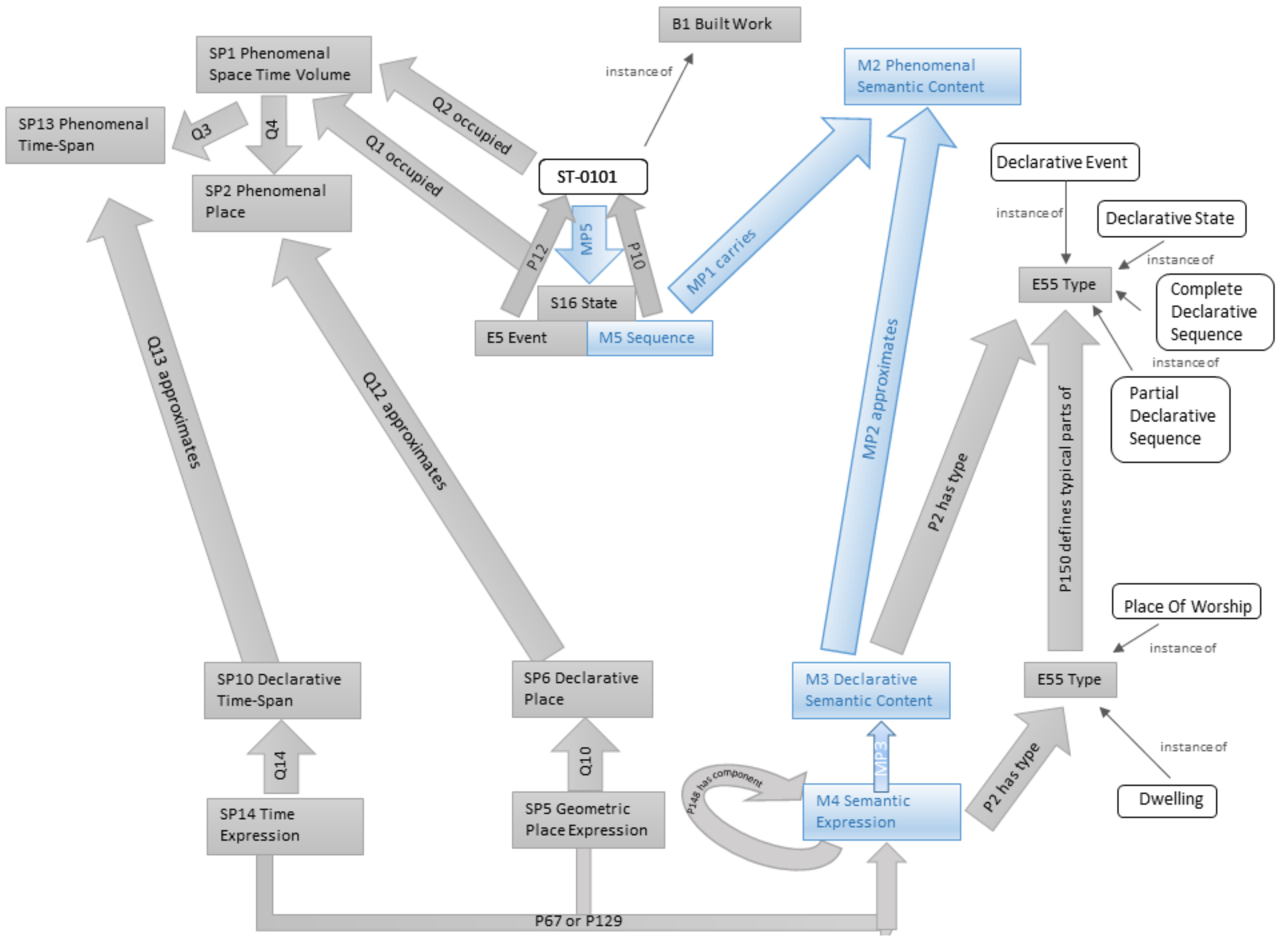

Figure 13: Declarative instantiation protocol; In grey: existing classes and properties, in blue: proposal A classes and properties, in white: instances.

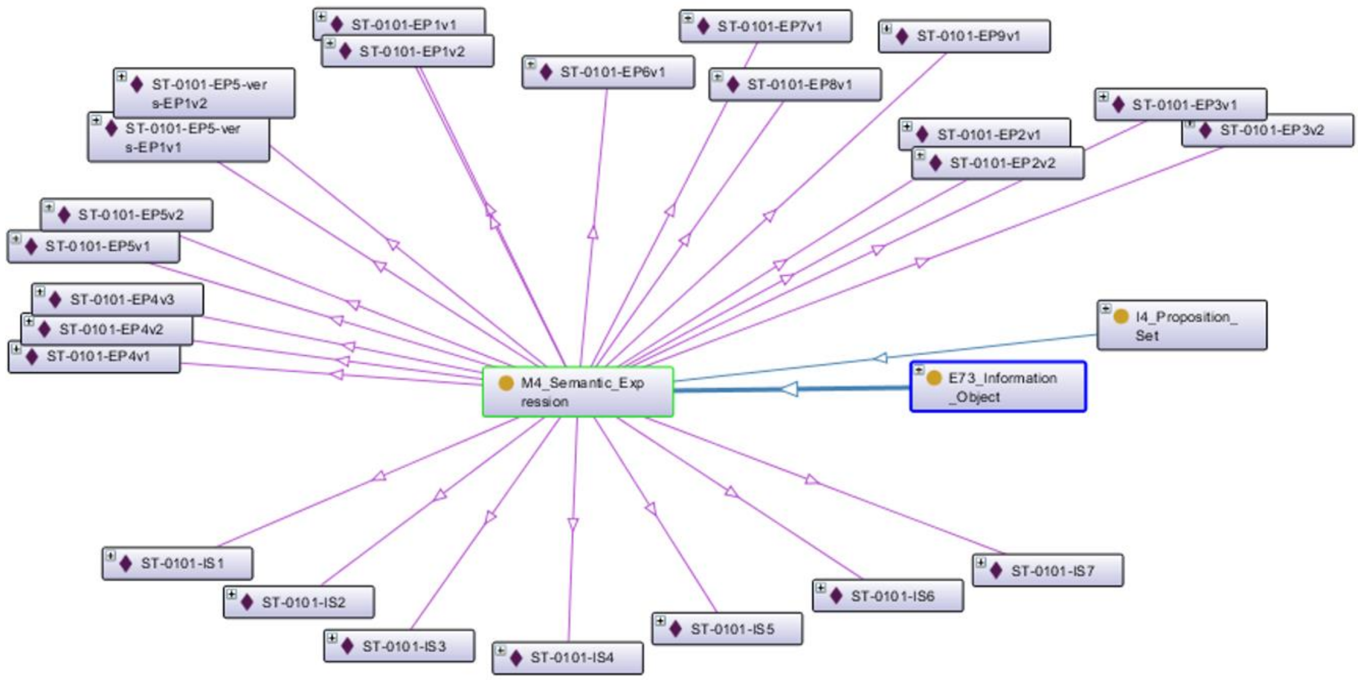

Figure 14: Declarative instances of M4 Semantic Expression class.

We have also, in M4, seven semantic expressions instances concerning the building sequence (or biography): ST-0101-IS1, ST-0101-IS2, ST-0101-IS3, ST-0101-IS4, ST-0101-IS5, ST-0101-IS6 and ST-0101-IS7. Lastly, we have two semantic expressions for the transformation event between state 5 and state 1 ST-0101-EP5-to-EP1v1, ST-0101-EP5-to-EP1v2. (Fig. 14).

We chose to instantiate the function expressed in statements with the P2 property "has type" linking M4 and E55 Type. In this case study, there is only two possible function instantiated in the E55 Type class: Dwelling or Place of worship. To link states' expressions with sequences' expressions, we used CIDOC CRM P148 has component. For the test, we instantiated Time expression as: a year (860,881) or an interval (From 01/01/1085 to 31/12/1095). It gives:

- 1626
- 860
- 881
- From_01_01_1085_to_31_12_1095
- From_01_01_1200_to_31_01_1250
- From_01_01_1345_to_31_12_1375
- From_01_01_1500_to_31_12_1525
- From_01_01_1515_to_31_12_1521
- From_01_01_1522_to_31_12_1529
- From_01_01_1600_to_31_12_1655
- From_01_01_400_to_31_12_499
- From_01_01_400_to_31_12_800
- From_01_01_500_to_31_12_699
- From_01_01_750_to_31_12_800
- From_01_01_785_to_31_12_850
- From_01_01_875_to_31_12_899

To instantiate Geometric Expression, we recorded the coordinates following the GML standards introduced by GeoSPARQL recommendations. To avoid very long IRI, we stored them in data annotation, RDFs: isDefinedBy_Literal (Fig. 15). For test simplicity, we created a unique instance for historical object and states. Future developments will consist in using GeoSPARQL to further enhance geometry management.

Figure 15: Coordinates recording.

We continued with creating instances of declarative classes M3, SP6 and SP10, where instances are translations of sentences found in the publications. After that we created the relations between: instances of SP10 and SP13 (Q13), SP14 and SP10 (Q14) SP6 and SP2 (Q12), SP5 and SP6 (Q10), M3 and M2 (MP2), M4 and M3 (MP3), SP14 and M4 (P67), SP5 and M4 (P67), M4 and M4 (P148: has component), M4 to E55 (P2).

4.3.2.4. Information's source classes instantiation

This path constitutes the essential link between declarative information, their creators and facts, or the arguments on which information is based on. Firstly, we instantiated the argumentation sources: S4 Observation (for Henaux's church visiting), A9 Archaeological excavations (for Bertholet & Hoffsummer's excavations), E16 Measurements (for 2009 analysis) or I7 belief adoption. Then, we related them to the F10 person (subclass of E39 Actor) who carried out the argumentation.

Secondly we created instances of I2 belief. We had to create one instance for each occurrence of belief value (in our test they can be true, false or likely) regarding each declarative expression. Indeed, instances of I2 belief are links between argumentation, creator and propositions tackled. J5 property "holds to be" is not an object property but a data property. Consequently, if an instance of belief is regarded as true by somebody, and likely by somebody else, we have to create two different beliefs for the same declarative expression, one belief holds to be true, and the other one holds to be likely.

To complete the documentation of instances we used P67 which refers to between F2 expression and I2 Belief.

5. Reasoning and requests

A semantic reasoner, or a semantic engine, is a software able to infer information from a set of axioms or asserted information. The problem within the use of such a piece of software is that when you catch an error, the whole engine is blocked and the inferred ontology is inconsistent. A three years old paper (Ciccarese & Peroni, 2014) proposed a solution to avoid this problem; it is possible to set up a set of rules in SWRL (Semantic Web Rule Language) to infer errors, expressed as Literals within an individual attribute. This rule will enclose the expression of the error within a Data Type Property and always explain what happened by creating this attribute.

Because of its strong explanations on inferences and Jena (a wide-used Java library) support, the reasoner Pellet has been preferred. Furthermore, Pellet can deal with many formalism as RDF, OWL, turtle and SWRL.

At this stage of our work, we used Pellet for three purposes: 1) to check the consistency of the proposal itself and between our proposal and the CRM ontologies, 2) to complete the asserted model and obtain an inferred model, and 3) to detect mistakes in recording instances. In several cases, Pellet reported bad property use, enabling us to make appropriate adjustments. Indeed, each manual instantiation can lead to unexpected combination of domain/range in the declaration of a property between concepts. Without reasoning through a reasoner or a good inspection, such an error could remain in the model and bring problems in later uses. The reasoner will then call attention on the reasons of the inconsistency and detect misunderstandings in an automatic way: for example, the instantiation of a

Sequence is made of an instance of M5_Sequence, MP4i_is_constitued_by and E2_Temporal_Entity. An easy typo is to invert the MP4i_is_constitued_by and MP4_constitutes. Because of the domain/range restrictions, the reasoned will raise an error flag and explain the fault.

Moreover, thanks to this reasoner, inferred relations were added. Indeed, the idea was to simplify the manual recording and to specify a minimum of relations, then to use Pellet to obtain an auto-completed model. In this respect, Pellet worked only on basis of class and properties hierarchies. As a result, all inferred relations showed in Figure 16 are outputs of this "simple" reasoning based on hierarchies. They enrich the belief adoption recorded instances by instances of P12 carried out by, P15 was influenced by, P116 starts, P11 had participants and P16 used specific object.

Figure 16: Inferred relations (in yellow).

In a second phase, we tested the querying with SPARQL (SPARQL Protocol and RDF Query Language) ('SPARQL 1.1 Overview', 2013). Specifying the structure of the wished triples, the graph extracts subgraphs to answer the query. The answers could be only subjects, predicates, and all the possible combinations.

It is important to say at this point that the selected model is the inferred, which is allowed by the use of the Protégé-Plugin (Snap SPARQL Query) and the exploitation of the newly created triples. Below, there is an example (Fig. 17) of a query in SPARQL on the inferred model. Its purpose consists in finding the M3 Declarative Semantic Content instances according to the building ST-0101 and to justify its declared type: Place of worship or dwelling.

As specified in the ontology, the instance of B1 Built Work "Theux's church" is linked to an instance of S16 State and so on to the M3 Semantic Declarative Content. The query will run through the graph step by step and answer the encountered items. In Figure 17 are selected the building, its type and the declarative semantic content in which there is an information on the particular building.

Beyond these first examples, we think that a lot of further interesting reasoning and requests could harvest the data instantiated.

```
PREFIX rdf: <http://www.w3.org/1999/02/22-rdf-syntax-ns#>
PREFIX rdfs: <http://www.w3.org/2000/01/rdf-schema#>
PREFIX cidoc-crm: <http://www.cidoc-crm.org/cidoc-crm/>
PREFIX MVR: <http://www.geo.ulg.ac.be/MVR/>
PREFIX : <http://ALL#>

SELECT DISTINCT (<http://ALL#ST-0101> AS ?Building) (?y AS ?TypeOfBuilding) (?M3 AS ?DeclarativeSemanticContent)
WHERE {
          ?M4 cidoc-crm:P2_has_type ?y.
          ?M4 MVR:MP3_defines_Semantic_Content ?M3.
          ?M3 MVR:MP2_approximates ?M2.
          ?S16 MVR:MP1_carries ?M2.
          <http://ALL#ST-0101> MVR:MP5_had_state ?S16
}
```

?Building	?TypeOfBuilding	?DeclarativeSemanticContent
:ST-0101	:Place_of_Worship	:PH_and_PB_building_6
:ST-0101	:Place_of_Worship	:PH_and_PB_building_5
:ST-0101	:Place_of_Worship	:PH_and_PB_building_4
:ST-0101	:Place_of_Worship	:PH_and_PB_building_2
:ST-0101	:Place_of_Worship	:LVW_and_FM_and_PH_building_2
:ST-0101	:Place_of_Worship	:PH_and_PB_building_7
:ST-0101	:Place_of_Worship	:LVW_and_FM_and_PH_building_1
:ST-0101	:Dwelling	:PH_and_PB_building_1_house
:ST-0101	:Place_of_Worship	:PH_and_PB_building_1_church
:ST-0101	:Place_of_Worship	:PH_and_PB_building_9
:ST-0101	:Place_of_Worship	:Porch_added_in_1626
:ST-0101	:Place_of_Worship	:PH_and_PB_building_8
:ST-0101	:Place_of_Worship	:second_church_repaired_at_the_begining_of_the_sixteenth_century
:ST-0101	:Place_of_Worship	:First_church_before_800

Figure 17: Example of query in SPARQL.

6. Conclusions

Going from a theoretic phase to experimental implementation and instantiation, we wanted to check if our extension proposal was working coherently with CIDOC CRM and compatible extensions such as CRMsci, CRMinf, FRBRoo or CRMgeo. Even if we simplified some paths for a sake of convenience, we achieved the transforming of our MIDM model into an ontology extension and we instantiated it.

The next step will consist in instantiating the same example with other extension proposal (proposal B) in order to compare, on practical bases which one is the most suitable. On the other hand, the test showed us some improvement tracks:

Semantic expressions are, for now, linked with SP5 Geometric Place Expression and SP14 Time Expression by P67 “refers to”. We will have to find (or create) a more suitable link with the one to many (0,n;0,1) cardinality.

We will also have to make other improvements regarding SP14 Time Expression. Our recording way cannot classify chronologically the events relating to a building. Moreover, it is not able to detect inconstancy in a declarative view from a set of views. For example, if an event, according to someone’s belief, occurs before another, the links with the real states of the building would express the error. The reasoner could catch and then explain the reasons of the error and highlight the fact that someone may witness a misunderstanding. The complementarity between the different beliefs could also be established. A new source of information would complete a view of an events succession, in an automatic way.

We will also have to improve the way (and more specifically the place where) we will manage geometric information. We already know that we will use GeoSPARQL which allows the expressivity of geometries through the GML format and the expression of topology relations. Through these geometries, it can describe points, lines, surfaces… Regarding implementation and links, we will follow the approach proposed by Hiebel & al. (2017). Thanks to it, we aim to obtain cartographic outputs and spatial analysis.

Acknowledgements

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