Semantic Preventive Conservation of Cultural Heritage Collections

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Abstract. Semantic knowledge has been proven to be rather efficient on the data management of Culture Heritage domain. Conservation is an important aspect of museum management cycle aiming to preserve cultural heritage objects in the best possible condition for future generations. Since cultural objects are susceptible to environmental changes, sensor data could be of significant importance in automatic environmental monitoring and possible conservation issues. Recently, many approaches have included the SSN (Semantic Sensor Network) ontology in their domain knowledge representation and relevant applications. In this work, we merge the SSN using the CORE (Conservation Reasoning) ontology, an ontology which is based on empirical analysis, scientific knowledge and existing vocabularies of the conservation domain. Incorporating many of the existing properties of both ontologies and proposing additional ones, we integrate the majority of SSN classes in the CORE ontology, creating a new merged ontology that combines conservation procedures data and rules with sensor and environmental information. Furthermore, we create ontology-based rules, using the SWRL (Semantic Web Rule Language), in order to express preventive conservation guidelines and rules based on sensor and object current data.

Keywords: Conservation Reasoning, SSN Ontology, Ontology Integration, CIDOC CRM Development, Cultural Heritage.

1 Introduction

Artworks conservation is an important process of museum collection management cycle, aiming to preserve it in the best possible condition for present and future generations [1]. Conservation procedures[1], such as examination, analysis, diagnosis, preventive or active conservation, require the consistent documentation of diverse information which the museum must organize, manage and potentially share. Furthermore, conservators and scientists of the conservation domain must be aware of related information in order to reach conclusions and take decisions relevant to their work [2].

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[1] Conservation embraces preventive conservation, remedial conservation and restoration.

While the major part of information is generated by the scientists of the domain of Cultural Heritage (CH) conservation, as a result of their observations and activities, there are also valuable data which are produced by sensors or sensor networks in the context of preventive conservation activities. Preventive conservation[2] includes indirect actions taken to avoid and minimize future deterioration of artworks and collections and therefore is related to the management of environmental conditions [1, 3].

Nowadays, metadata standards and schemes, as well as the mapping between them, facilitate the structural and syntactic interoperability and therefore the information organization, search and retrieval of the CH conservation domain [4]. An approach of ontology-based knowledge representation could create a context of intelligent information management, defining concepts and their relations, as well as their use in the semantic web [5].

Taking into consideration the above mentioned statements, semantic knowledge and ontology-based rules could be efficient for the management of conservation information and sensor data. Besides the creation of semantic and interoperable data, the conceptual representation of domain knowledge could support the ontology-based rules generation [6]. The ontology-based rules could express preventive conservation guidelines and rules, combining information related to objects' condition state, production materials and techniques, environmental conditions, damage mechanisms, causes and results.

Therefore, the use of ontology for artworks conservation and environmental monitoring, as well as the expression of ontology-based domain rules which reflect the knowledge of the discipline is considered beneficial. In the remainder of this paper we first describe the information management requirements pertaining to artworks conservation and monitoring, while we provide an overview of related work in the area of conservation knowledge and semantic sensor data management (Section 2). Thereafter we describe the integration between CORE (Conservation Reasoning) and SSN ontology, as well as the expression of ontology-based rules (Section 3). Finally, we conclude with a brief discussion of future trends regarding to the application of ontologies and ontology-based rules in the domain (Section 4).

2 Motivation and Related Work

2.1 Documentation and Environmental Monitoring in the Conservation Domain

Artworks and collections present features inseparable to their creation, use and history, which are neither always known nor stable. All the original features and changes must be examined and documented by the scientists of the conservation domain. Detailed and accurate documentation in textual (reports) or visual (photographs, diagrams, designs etc.) records is necessary [7]. However, different conservation activities require different ways (analytical or brief) and modes of information recording. Generally, the information material that scientists of conservation domain collect and produce may refer to an object condition –before or after conservation treatment– and

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[2] Preventive conservation includes activities about the storage, handling, exhibition, packing and transportation, the security and emergency planning.

pathology, production materials and techniques, applied conservation materials and methods, analysis methods, as well as some administrative information [8].

In the context of preventive conservation, scientists often use sensors to monitor and control some critical physical parameters related to the degradation of the artworks. Sensors are small sensing devices which change their status according to physical stimulus and can be attached to larger objects or specific location [9, 10]. Nevertheless it must be mentioned that the ideal atmosphere may differ for each item, or group of items, according to their original materials and current condition state [3, 11]. According to the different cases and requirements, data loggers, as well as sensors in wired or wireless sensor networks, have been used in different implementations. The provided measurements can be downloaded to a computer and analyzed from time to time, or in the case of networks communication, data flow from low-powered devices to high-powered systems (also called platforms) for further aggregation and processing [12]. Additionally in potential IoT (Internet of Things) architectures for museums, sensor data are transferred to a cloud by means of gateways [3]. Commonly, the main environmental factors which are monitored are related to the temperature and relative humidity, but in some cases sensors are used for the detection of light and other forms of radiation, the pollution, the pests and the vibration [10].

The combination of documented information and recorded sensor data could improve the conservation specialists' work. In the short-term, the aforementioned sustained supervision aims to the immediate detection of environmental changes. Therefore, by using existing knowledge about an object feature it is easy to estimate whether the condition is harmful, act accordingly and reduce the potential risk [10, 11]. Furthermore the long-term records of sensed data, in relation to other information which have been documented during conservation procedures, may lead to useful inferences about the relation between the material decay and its environment [3].

2.2 Conservation Information and Sensor Data Management

Considering the amount and diversity of information related to conservation procedures, high organization in a concept level is often required for its integration and management. Conceptual Reference Model (CIDOC CRM) is a widely used ontology for CH and conservation domain, though not always effective. It has been noticed that the known information in a particular point of time during conservation documentation, sometimes cannot be expressed by a CIDOC CRM entity [13, 14].

Conservation is an interdisciplinary science, consequently it is useful to include data models and ontologies of related domains, such as chemistry domain. In this context OreChem data model and CRMsci (Science Observation Model) have been very useful for analysis and examination [15, 16]. Nevertheless there are some domain ontologies about conservation science and procedures. The Ontology of Paintings and Preservation of Art (OPPRA) draws existing ontologies such as CIDOC CRM, OreChem and OIA-ORE and aims at the description of chemical analysis/characterization data [17]. Furthermore, PARCOURS is a domain ontology dedicated to conservation and restoration domain [18]. Finally, CORE ontology extends CIDOC CRM with concepts and relations about materials and techniques, condition state and conservation processes of artworks, and particularly byzantine icons [19].

Similarly to conservation information, sensor data may be difficult to be shared, integrated and processed, in order to support knowledge extracting and reasoning capabilities such as intelligent decision making. This is caused because sensor networks are consisted of devices with increased heterogeneity which produce various types of data and measurements. To overcome the lack of semantics in sensor networks, semantic technologies are used to automatically annotate and enrich sensor data, add semantic metadata and information and resolve the heterogeneous of sensor data [9]. In this direction Semantic Sensor Web (SSW) uses declarative descriptions of sensors, networks and domain concepts to search, query and manage the network and sensor data [20].

Sensor ontology is one of the most important components of the SSW [20]. In the past years there have been developed general sensor ontologies, as well as ontologies for more specific applications (such as CSIRO, CESN, OntoSensor etc). However, there were problems in terms of the sensor ontology structure and the expression of processes and systems' composition. Therefore, the W3C Semantic Sensor Network (SSN) Incubator Group proposed a more generic, field-independent model, the SSN ontology. Developed from developers of the CSIRO, MMI and OOTethys ontologies, the SSN addresses many of the problems in the older ontologies. The SSN ontology integrates and upgrades the original ontologies with more detailed classification and a wider range of generality [20, 21].

As proposed in previous works the semantic sensor data can be connected with domain concepts related to a specific scenario where the sensor networks are used [9]. This type of organization may be interesting in order to further analyze data and verify its compliance with domain rules. A very similar idea has been proposed in WISE-MUSEUM project specifying art conservation rules [10].

3 Knowledge Semantic Representation

3.1 Methodology and Tools

The domain ontology for the representation of conservation domain knowledge and sensor networks concepts was achieved with the integration of CORE and SSN ontology. The CORE ontology builds upon and extends the CIDOC CRM ontology, while is based on empirical analysis, scientific knowledge and existing vocabularies of the conservation domain. The CORE ontology consists of a base of 11 classes, each of which branch into subclasses with semantic consistency. CIDOC CRM top-level classes capture the provenance information about an artwork while the CORE extensions capture the domain related knowledge [19]. On the other hand SSN ontology consists of 41 concepts and 39 object properties, and can describe sensors, the accuracy and capabilities of such sensors, observations and methods used for sensing [21]. Furthermore, it is built around a central Ontology Design Pattern (ODP) describing the relationships between sensors, stimulus, and observations, the Stimulus-Sensor-Observation (SSO) pattern [1].

CORE development and its integration with SSN entities are achieved with the free open source software Protégé (Protégé Desktop version 5.2.0) of Stanford University [22]. Entities attributes and inference rules were also included to support a finer level of granularity for the domain. In some point the efficiency and consistency of the ontology was tested by the reasoners “Pellet” and “Hermit”. In addition, rules which express knowledge of the domain of preventive conservation were formulated in SWRL rule language and were expressed through SWRL tab of Protégé.

3.2 CORE-SSN Entities and Relations

Considering the amount and diversity of information related to conservation procedures, high organization in a concept level is often required for its integration and management. In order to model conservation information and sensor data which derived from monitoring of environmental conditions, CIDOC CRM, CORE domain ontology and SSN sensors ontology were combined. CIDOC CRM is the top-ontology which CORE entity extends, while the SSN entities are manually mapped and integrated with the rest of the other two ontologies.

CORE ontology is based on CIDOC CRM classes and furthermore includes entities which aim to model more accurately the knowledge relating to artworks and collections (a) physical and material structure, (b) pathology, (c) conservation procedures, (d) environment and (e) information resources. Therefore, there are CORE concepts which organize and represent types of measurement activities related to the processes of monitoring and material analysis or modification activities related to processes of sampling and conservation. Furthermore, there are concepts about properties such as temperature, physical features such as types of material or structure attributes and deterioration, information objects and so on. An interesting aspect of CORE concepts structure is the fact that the entities about a damage cause, mechanism and result are separately defined. Therefore, it is possible to capture the information about what is observed and what is concluded or could potentially appear as a consequence. Additionally, the aforementioned possible conclusions or consequences in some cases were captured as axioms of the ontology.

Some of these concepts are semantically related to the classes of SSN ontology. As a result it was possible to integrate SSN classes in CORE structure either as subclasses, for example SSN class ‘Stimulus’ is the subclass of ‘E5 Event’. Moreover some SSN classes were defined as equivalent to some CIDOC CRM or CORE classes, for example SSN class ‘Observation’ was equivalent to CORE class ‘Monitoring’, maintaining the semantic consistency. In Figure 1 the main integration and correlation between SSN and CORE entities is presented.

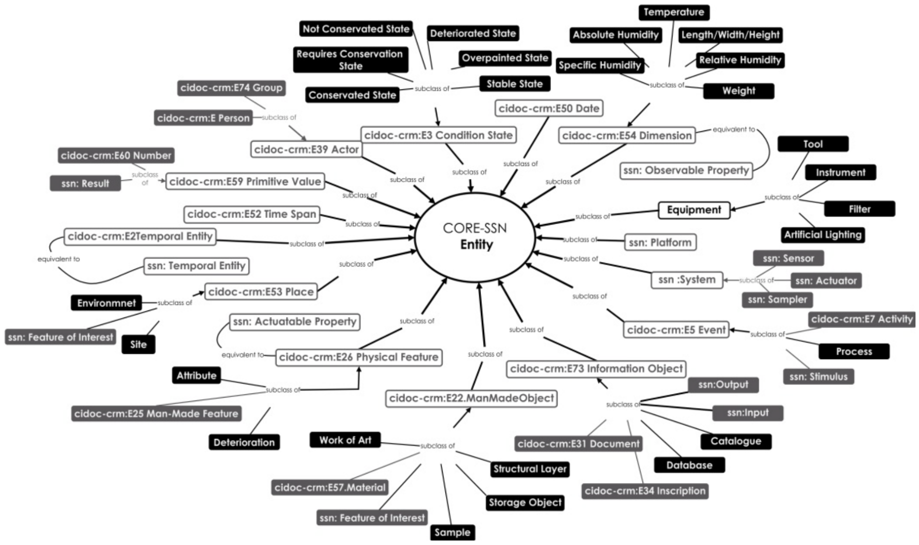

Fig. 1. Main classes and subclasses of CORE-SSN integration.

The logical association between the CORE and SSN classes was further achieved by using the existing relations of the ontologies, as well as by adding some new. For example, an object property was created in order to correlate the SSN class ‘Feature of Interest’ with a CORE class which corresponds to a concept of object or place of observation, such as ‘Site’ or ‘Work of Art’. Therefore, the object property ‘equals to’ and its inverse object property ‘is equaled to’ was added (Fig. 2).

In order to test the scope and integrity of CORE-SSN ontology a number of individuals of entities and object property assertions between them was created. Therefore, some expressions related to the temperature monitoring of an exhibition hall were captured. Particularly using the SSN classes and relations, alongside these of CORE, we could define that the Exhibition Hall was observed, the property of observation was specifically the temperature, the particular environmental factor of Exhibition Hall was heat and that the stimulus by which the observation was originated was triggered by heat change (Fig. 2). The above mentioned information tends to be more expressive since it captures technical information about sensors function and scientific information about environmental conditions. Moreover, these concepts and relations could express the potential mechanisms which could be triggered and the damages which could be caused, since the factors and phenomena concepts are included in CORE conservation science ontology.

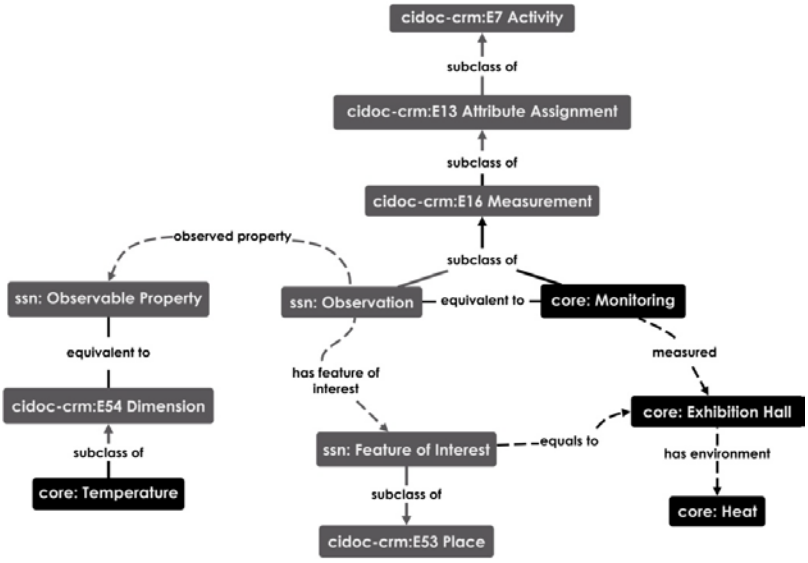

Fig. 2. A conceptual mapping between entities and relations of CORE-SSN integration.

3.3 Reasoning and Ontology-Based Rules

The aforementioned semantic organization of concepts and relations was used for the definition of rules and therefore the generation of inferring information. Initially, we formulated rules in order to further define the relations between concepts. For example, in cases of temperature monitoring of a site, in particular an exhibition hall, it is possible to use both the concepts of heat and temperature. However the first is referred to the environmental factor while the second to its measured dimension. Therefore, having defined some basic relations between individuals and formulating the rule S1, we could have the inferring information that the temperature actually refers to the heat of the place and that it was observed particularly by a temperature measurement activity. Using the SWRL syntax, the above mentioned rule can be expressed as shown in Table 1.

Table 1. SWRL Rule 1 (S1).

Core:Heat (?h), core:Exhibition_Hall(?eh), sosa:Observation(?o), core:measured(?o, ?eh), core:Temperature(?t), core:has_environment(?eh,?h), core:has_dimension(?eh,?t) -> core:has_dimension(?h,?t), core:Temperature_Measurement (?o)

Activating the reasoner Pellet some useful information is inferred, according to rules and relations. Particularly, the individual Observation1 whose type is the SSN entity Observation, is inferred that can be equally be defined by the type Temperature_Measurement which is a CORE entity. The aforementioned inference is due to the fact that Observation1 is correlated to other individuals which verify the rule S1.

Therefore, SSN and CORE concepts can be equally used for the definition and querying of relevant individuals.

Moreover, the ontology-based rules could express preventive conservation guidelines and rules, such as the definition of a temperature “set point” for a sensor of the system. However, we have to take into account that in practice the set point for an environmental factor may differ according to the needs and the general condition of an item, group of items, site etc. For example, the below SWRL expression (S2) uses the built-in atom “swrlb:greaterThan” to compare the temperature measurement of an observation with a threshold *(ex. 35 °C)* and infer that there is a change in heat factor (Table 2).

Table 2. SWRL Rule 2 (S2).

sosa:Observation(?o) , sosa:Result(?r), core:Heat(?h) , core:Heat_Change(?hc) ,
sosa:has_result(?o, ?r), core:has_temperature(?r, ?num) ,
swrlb:greaterThan(?num, 35)
-> core:has_environmental_change(?h, ?hc)

In the context of CORE ontology some axioms about the mechanisms and the results of environmental changes had been formulated. For example, axioms have expressed the fact that heat change triggers the physicochemical mechanism of heating and that heating effects mechanical damage, such as swelling. Furthermore, the expressivity of the ontology allows the definition of the artworks which may be exhibited in the place under observation. The structure and production materials of the object can be expressed with CORE entities and relations. Using CORE ontology classes and relations, as well as the included axioms, we could formulate rules about the potential impact of the heat change on the materials and structural layers of an artwork. For example, we could correlate the potential damage of swelling, which is effected by heating, with an artwork, which has a textile support layer.

In this case, we used the CORE relation *“has the tendency to”* in order to express a rule about the potential presentation of swelling on an artwork with textile support (Table 3). The information that had been inferred, using the axioms and rules, about the environmental change of the Exhibition Hall, the possibility of a damage mechanism activation and the impact of this change on an artwork that is exposed in this condition, could be useful in the context of querying in order to support recommendations or decision-making.

Table 3. SWRL Rule 3 (S3).

core:Work_of_Art(?w), core:places(?eh,?w), core:Textile_Support(?ts),
core:Exhibition_Hall(?eh), core:has_structural_layer(?w, ?ts), core:Swelling(?sw)
-> core:has_tendency_to(?w,?sw)

Taking into consideration additional information about sensor measurements, observations and samples, we can create a system which provides predictions about the risks and deterioration of the objects regarding environmental conditions such as heat and humidity.

4 Conclusion and Future Work

In this work, the CORE, an ontology for conservation domain, is integrated with the SSN ontology in order to combine information about the artworks' condition state and environmental conditions, and express preventive conservation guidelines and rules. In our approach, we integrate the majority of the SSN classes into the CORE structure either as subclasses, or as equivalent to CORE classes, while also we use the existing object properties of both ontologies and add a few new, to achieve the logical association between them.

The CORE - SSN integration is developed in the open source software Protégé, and the reasoners "Hermit" and "Pellet" are used for rules implementation. Nevertheless, further work is necessary for the validation of the integration and the testing of the rules efficiency. Furthermore, in regards of the rule language, the SWRL syntax was used at this stage, though other rule languages are considered to be tested as well in the future, such as Jena Rule. It is probable that the requirements of real-time processing, ontology's complexity and the amount of the processed semantic data could potentially lead to the use of a different rule language [23].

Future research could mainly focus on the design and development of a recommendation system that will provide users useful advices and suggestions based on the semantic rules and information derived from sensor data and objects' features. By incorporating systems like Wireless Sensor Networks (WSN) and context-aware services and using the CORE-SSN ontology approach, we aim in designing a conservation system that automatically control environmental conditions according to sensor data and support decision-making in compliance with art conservation rules and semantic knowledge.

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