A Multi-level Ontological Approach for Change Monitoring in Remotely Sensed Imagery

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Abstract: Land-use/cover change, climate change, sea level evolution are examples of application that are associated with change detection. Actually, we use satellite image time series to monitor the change where entities are often dynamic along time. Moreover, knowledge associated to these spatio-temporal objects can evolve when changes occur. Thus, for modeling this kind of knowledge it is necessary to deal with four aspects: spectral, spatial, temporal and semantic. Such approach can be modeled by ontologies in many levels. Thereby, a shared ontology can be an ontology or a combination of some ontologies based on some mechanisms of linking. Such link process should maintain consistency between represented knowledge. In this paper, we propose a multi-level ontological approach for monitoring dynamics in remote sensing images. The proposed methodology aims to link our domain ontology to an upper level ontology thus enabling to represent existing change processes.

1 INTRODUCTION

Change detection is one of the main applications of remote sensing community. Singh (Singh, 1989) defined change detection as the process of identifying differences in the state of an object or phenomenon by observing it at different times. The remotely sensed data become a major source for change detection and monitoring studies because of its high temporal frequency, digital format suitable for computation, synoptic view, and wider selection of spatial and spectral resolutions (Hussain et al., 2013). Geographic objects in these data images are often dynamic. Indeed, objects with spatial representation might grow, shrink (the case of the urban space), change their shape (for example when a city changes its borders), divide (in the case when a forest is divided into urban zone and forest), disappear (a lake can disappear) or merge into a new object (sub-parcels are merged into one parcel) in time. Knowledge associated to spatio-temporal object can evolve when changes occur on thematic attributes of objects. The semantic dimension of an entity aims to describe the knowledge associated with the entity. Adding semantic capabilities to GIS tools is one of solution that allows handling the semantics of the spatial-temporal objects. However, this solution does not offer the capacity to perform inference or reasoning on information from spatio-temporal dynamic phenomena (Harbelot et al., 2013).

Thus, a better framework must be able to represent the description of the knowledge in an enhanced way that can be used to perform reasoning on dynamic phenomena. Such approach is offered by ontologies. Ontology allows a formal representation of knowledge as well as on the reasoning on this knowledge. This paper is organized as follows. In Section 2, we start by introduce the basic principle of ontology as a knowledge representation technology and presents the different types of ontologies, then we present a state of the art of different existed ontology-based approaches for modeling dynamics of objects and finally, we describe the dynamics in remote sensing. In Section 3, illustrate the proposed approach for modeling change in remote sensing images. Finally, we present our conclusions in Section 4.

2 MODELING DYNAMICS

2.1 Ontology

Recently, ontology is considered as one of the better

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techniques used for the interpretation of images. Gruber (Gruber, 1995) defines ontology as a formal specification of a shared conceptualization. Ontologies specify a set of concepts, instances, relationships, and axioms that are relevant for modeling a domain of study (Gruber, 1995) and permit the inference of implicit knowledge. Nevertheless, ontologies can be very different both in terms of their "top-level" as at the level of the treatment of their basic components such things, process, relationships, etc. Thus, ontologies can be classified according to two dimensions: level of detail and degree of dependence relative to a particular task or a point of view. Precisely, (Guarino, 1998) classifies ontologies according to their generality levels. At the top level, *upper ontologies* describe general concepts or sense knowledge such as space, time, materiel, objects, events, actions, etc., which are independent to a defined problem or to a particular application domain. These ontologies provide general concepts to which all terms of existing ontologies must be linked. *Domain ontologies* are specialized for a certain type of artifact. They describe the vocabulary related to a generic domain (such as medicine or automobiles) by specializing the concepts presented in high level ontologies. *Task ontologies* describe vocabulary related to a task or a generic activity (such as diagnosis or sale). These ontologies provide a systematic lexicon of terms used to solve the problems associated with particular tasks (dependent or not to the domain).

2.2 Modeling Dynamics with Upper Ontologies

Spatial-temporal representations are offered, by so-called upper ontologies (foundation ontologies), such as DOLCE (Masolo et al., 2003), BFO (Grenon and Smith, 2004), GFO (Herre, 2010) and others. Foundation ontologies provide a meta-language (Mizoguchi et al., 1995) to ontological approach which allows to model spatio-temporal phenomena.

In these ontologies, there exists a fundamental distinction between static entities (continuants or endurants) and dynamic entities (occurrents or perdurants). Endurants are objects which persist over time. They include physical objects, for example: tree, lake, and river. Perdurants are objects which are "happening" at the time. They include events or processes, but some systems, like BFO, extend the list by adding temporal and spatio-temporal regions.

Probst (Probst, 2006) have presented an ontological analysis of observations and measurements for assessing semantic interoperability between geospatial information sources. This approach consists to align the observations and measurements domain ontology to the foundation ontology DOLCE. The alignment is performed by the interpretations of the central elements of the observations and measurements conceptual model in the DOLCE context and establishes explicit relations between categories of real world entities and classes of information objects. For example, a phenomenon is described by an observed property in the the observations and measurements specification. In DOLCE, only qualities are entities that can be observed. In this case, the category *Observed Property* in the observations and measurements model subsumes the category *Quality* in DOLCE (Figure 1).

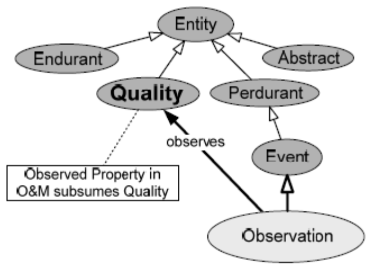

Figure 1: Aligning the domain concept observation to the concept quality of DOLCE (Probst, 2006).

In the medical domain, Camara (Camara et al., 2012) has proposed an ontological approach for monitoring and preventing the propagation of infectious diseases. The conceptual framework adopted for building the propagation ontology of infectious diseases is structured in three layers: (i) *foundation layer* which contains the upper ontology BFO, (ii) the *core layer* that constitutes the IDO-core ontology where IDO (Infectious Domain ontology) is a domain ontology, and (iii) the *specific layer* contains the subdomains ontologies. To align those three layers, authors start by a categorization of the domain entities as continuants or occurrents. Then, based on the IDO-core ontology, they have linked categorized concepts to their equivalent or parent concepts on the IDO-core which are in turns connected to BFO. In the same domain, Weichert (Weichert et al., 2013) has introduced a temporal domain ontology for biomedical simulations. Aligning the domain ontology to BFO allows to monitor the dynamics of blood flow simulations. The correlating categories from both ontologies (BFO and domain ontology) are identified and connected by newly inserted is_a relations.

To facilitate mutual understanding between researchers, managers and local communities, Duce (Duce, 2009) has proposed an informal ontology for reef islands. Such ontology allows to aid the application of information technologies to the forecasting and monitoring of climate-change-related to impact in reef islands environments. Indeed, the author has developed a small, prototypical reef island domain ontology, based on informal, natural language relations, for 20 fundamental terms within the domain. Then, in order to create a coherent, systematic and complete ontology, the domain ontology have been aligned to DOLCE as a top level ontology. To align domain ontology to upper ontology, the author has selected a subset of particulars from the reef island domain in accordance with classes categories of the upper-level DOLCE ontology.

In a similar way, Devaraju (Devaraju and Kuhn, 2010) propose a process-based ontology for representing dynamic geospatial phenomena. The proposed approach aims to improve water planning and management through continuous monitoring and forecasting of river flow. This approach allows to use DOLCE top-level ontology to ease and guide the representation of foundational entities needed to represent dynamic phenomena. Authors have aligned the domain concepts describing precipitation and evapotranspiration (evaporation and transpiration) processes to the general categories defined in DOLCE. Thus, the entities will be identified and assigned to perdurant, endurant and quality notions in the top-level ontology.

An interesting work that shows the effectiveness of the upper ontologies, in the remote sensing domain, has been performed by Kauppinen and de Espindola (Kauppinen and de Espindola, 2011). In their work, they are interested in giving an ontological foundation to essential land change trajectories, and to modeling them with formal semantics. To achieve this they propose the Process-oriented Land Use and Tenure Ontology (PLUTO), built as an alignment to the top-level ontology DOLCE, for semantically integrating several data sets related to deforestation and land change trajectory in the Brazilian Amazon.

2.3 Dynamics in Remotely Sensed Images

Geographic objects such as lakes, rivers, and storm fronts have very spatial dynamic properties. It is possible that an object changes their attributes and spatial representation along time. This observation is particularly true on the case of the remote sensing because major applications are associated with change detection such as land-use or land-cover change. Land-cover refers to the observed biotic and abiotic assemblage of the earth's surface and immediate subsurface (Meyer and Turner, 1992). Examples of major land-cover types are forests, shrublands, grasslands, croplands, barren lands, ice and snow, urban areas, and water bodies. Such information is obtained from ground surveys or through remote sensing. Land-cover change can be characterized as land-cover conversion and modification processes. Land-cover conversion is a change from one land-cover category to another, and modification is a change in condition within a land cover category (Meyer and Turner, 1994), i.e., the more subtle changes that affect the character of the land cover without changing its global classification. An example of the former is change from cropland to urban land, and an example of the latter is degradation of forests. Forest degradation may be due to change in phenology, biomass, forest density, canopy closure, insect infestation, flooding, and storm damage.

Remotely sensed images provide measurement and observation that can be used for monitoring dynamics change. Indeed, indices derived from satellite data are widely used for land-cover change studies. NDVI (Normalized Difference Vegetation index) values strongly correlate with green vegetation, and changes in NDVI indicate changes in biological activities (Verbesselt et al., 2010). NDVI decreases significantly after green biomass is removed, so it is widely used for mapping and monitoring fire disturbance, forest clear-cut activity, urbanization, and other land-cover changes (Verbesselt et al., 2010). The EVI (enhanced vegetation index) has been used for postfire forest regeneration and phenological analysis during change detection (Liang et al., 2011). Normalized Difference Fraction Index (NDFI) (Jr. et al., 2005) is a new spectral index for enhanced detection of forest canopy damage caused by selective logging and forest fires. High NDFI values indicate the presence of intact forest, whereas a degraded forest is obtained by a decreased value of this indice. Other spectral indices are also used for detecting changes in remotley sensed images, for more we can refer to (Chandra, 2012).

Thus, it is necessary to model this information in order to monitor and detect the type of change presented in satellite images. In following section, we present the adopted architecture for modeling dynamics objects of remotely sensed images.

3 THE MULTI-LEVEL ONTOLOGICAL APPROACH

As we have mentioned above, change detection is the process of identifying differences in the state of a feature or phenomenon by observing it at different times. In remote sensing it is useful in land use/land cover change analysis such as monitoring deforestation or vegetation phenology.

Thus, we propose to represent and model the change process in remote sensing images while basing on the cited works that adopt multi-level ontological architecture for modeling the dynamics. The conceptual framework of our suitable multi-level ontological architecture, as we illustrate in Figure 2, is structured on three layers: (1) Fundamental-layer, (2) Core-layer and (3) Domain-layer. These layers are described on following.

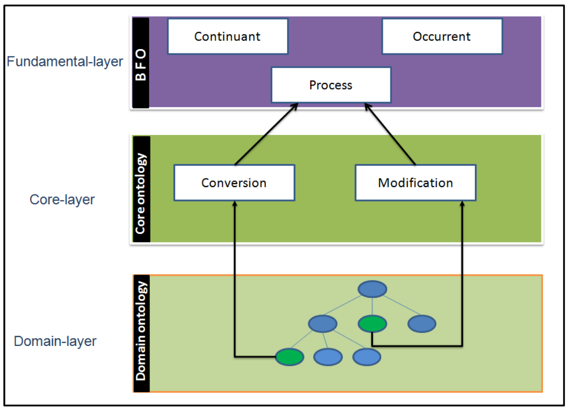

Figure 2: Multi-level ontological approach.

3.1 The Fundamental Layer

The fundamental layer contains the upper ontology that we have used in our model. We have chosen the fundamental ontology BFO (Basic Fundamental Ontology) as a suitable upper ontology that provides concepts and relations that may be reused for the construction or for the enrichment of domain ontology. Consequently, we have reused these abstract concepts and relations for modeling the ontology of change processes (core-layer). The choice of the BFO is based on three criteria: (i) BFO extends the list of occurrents (event or process) by temporal and spatio-temporal regions, (ii) the coherence of the categorization of the concepts of process, event, state and object towards their semantic in the domain of remote sensing, and (iii) the consistency of the reuse of relations between these concepts to cover the specific relations in our domain.

3.2 The Core Layer

The core ontology models general concepts and relations related to change processes in remote sensing images. The definitions and the classification of these concepts are based on the categorical classes defined in the BFO ontology. In the following, we present the different steps for the construction of the core ontology of change processes.

- *Identify and Categorize Changes Processes:*

This step consists for understanding and detecting modifications process in addition to conversions. Indeed, as we have mentioned in Section 3.2, there are generally distinctions between land cover conversion process, namely the complete replacement of a type of cover by another and the land cover modification process i.e., the more subtle changes that affect the character of the land cover without changing its global classification. Deforestation, urbanization and desertification are examples of land cover/land use change processes.

Deforestation is the ***conversion*** of forested areas to non-forest land use such as arable land, urban use, logged area or wasteland. According to FAO (Food and Agriculture Organization), deforestation is the conversion of forest to another land use or the long-term reduction of tree canopy cover below the 10% threshold. Desertification is a specific expression of land degradation processes. The degradation is a process leading to a "temporary or permanent deterioration in the density or structure of vegetation cover or its species composition" (Grainger, 1993). In this case, changes affect soil characteristics, then we consider desertification as a ***modification*** process.

So, in this step we have categorized the changes as conversion and modification processes and, then each example of change is classified to one of these categories. In Figure 3, we illustrate an example of a change process classification.

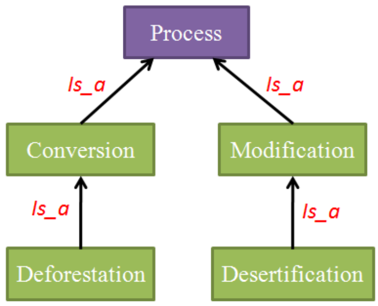

Figure 3: Process categorization and classification.

- *Categorize Domain Entities:*

This step aims to identify and classify domain entities that participate in such change process, i.e., to know what are the main ecological and socio-economic variables which drive the land-cover change process. In other words, what are the basic features required for modeling dynamic phenomena and how they are classified? Indeed, entities can be biophysical objects, features such as biomass, state of vegetation, soil moisture, fire, etc. These entities will be classified into two categories of concepts: *Continuants (Endurants)* and *Occurrents (Perdurants)*. Continuants correspond to entities without temporal part. They include physical objects that persist in time such as tree, lake, river, etc. The concepts of occurrents correspond to entities taking place in the time during different phases. They are objects that occur in time and they include events (such as fire) and processes (cutting down trees) that involve the continuants.

- *Identify Categorical Relations:*

This step consists to know what are the categorization relations that hold between concepts (continuants and occurents). Examples of these relations are :

Participation: A continuant participates in a occurrent (Grenon and Smith, 2004). A fire participates in a deforestation.

Parthood: It reflects the notion of relationship "part-of" and it applies to both continuants and occurrents. For example, an event is constituted of processes.

The Hierarchy: It models the inheritance relationships. As example, a desertification is_a modification process.

The Causality: It expresses, for example, the fact that an event "causes" another event. Less soil moisture causes a less soil canopy.

3.3 The Domain Layer

The domain layer contains the domain ontology of remote sensing images (Messaoudi et al., 2014) that represents the domain concepts and their relations. This ontology allows interpretation and representation of objects existing in the scene of satellite image. The remote sensing provides observation and measurement of indicators associated to these objects. Indicators such as NDVI, NDFI, and derived variables (entities) of surface composition (soil moisture, biomass, etc.) are relevant information for detecting participated concepts to each change process. Figure 4 presents an example of the association of the domain concept *forest* to each of both change processes (deforestation or degradation) in function of the measure of its indicator NDFI. In this example, the property NDFI of the concept *forest* indicates that there is a deforestation process with an NDFI value *val1*, although it is a degradation process with an NDFI value *val2*.

3.4 Alignment of the Three Ontological Layers

As we have presented in Figure 2, the proposed model is structured in three layers. The fundamental-layer contains the upper ontology BFO, the core-layer describes the core ontology of change processes and the

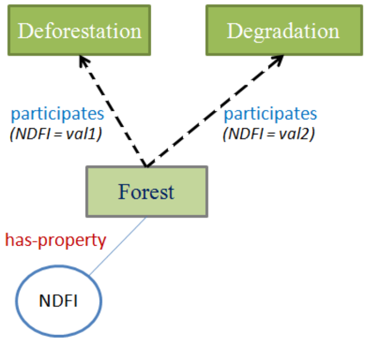

Figure 4: Association of participants entities.

domain-layer that contains the domain ontology of remote sensing images. It is necessary to link those layers for representing changes processes in satellite images. Thus, to align these three layers, we have followed the same principle of alignment proposed in the previously cited works. Indeed, the alignment mechanism consists to identify relations ***R*** that can hold between different concepts ***C*** in the three levels. Given the following formalization of our model, we adopt the procedure described below for linking the three levels.

Model = $\{O_f, O_c, O_d, \mathbf{C}, \mathbf{R}\}$; where:

- O_f, O_c and O_d represent respectively the fundamental, the core and the domain ontology.
- **C** = $\{C_f, C_c, C_d\}$; where C_f,C_c, C_d represent respectively a set of fundamental, core and domain concepts.
- **R** = $\{$*subsumption*, *inherence*, *parthood*, *participation*$\}$ (the set of relations) *(cf. subsection 3.2)*

procedure alignment(O_f, O_c, O_d)
 // alignment of O_c and O_d
  for each change process in O_c
  {
   participants (C_d, C_c)
   // the set of participants concepts (domain concepts) that participates on the definition of a process (core concept) C_d in the C_c
   hold_relation (C_d, C_c, R) // Identify type of relationship between concepts (causes, equivalent, participate, etc)
   // create the relation link
  }
 // alignment of O_c and O_f
  for each C_c in O_c
  {
   hold_relation (C_c, C_f, R)
   // create the relation link
  }

An example that illustrates the mechanism of alignment has been presented in Figure 2 and Figure 3. Indeed, the Figure 3 shows the alignment of the domain layer to core layer. In this figure, the domain concept *forest* participates in the change process *deforestation* (respectively *degradation*). Then, the concept *forest* is linked to the concept *deforestation* with the relationship *participates*. Figure 2 shows how the core layer is linked to the fundamental layer. Indeed, concepts like *conversion* and *modification* have been classified as two types of processes based on the categorical classes defined in the BFO ontology (cf. subsection 3.2). Thus, the basic concept *process* in BFO subsumes respectively the concepts *conversion* (a process) and *modification*. This implies that the relation that holds between these concepts is a subsumption (is_a) relationship.

4 CONCLUSIONS

Remote sensing is a unique monitoring tool that provides access to dynamic environments. The essential, however, is the understanding of processes such as deforestation, desertification, urbanization, etc. A semantic description of each process enables to identify concepts, features and relations that hold between them implying as well that process. In this paper, we have used a multi-level model based on ontologies for representing this knowledge enabling thus to reason on change processes in remotely sensed imagery. This model is based on a domain ontology of remote sensing, core ontology and the upper ontology BFO. The core ontology represents classification and categorization of different processes of changes.The domain ontology provides observations and measurements that allow reasoning on such change process represented in the core ontology. Finally, the ontology BFO provides concepts and relations that are used to construct and enrich the core ontology.

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