Towards a Semantic Interpretation of Satellite Images by Using Spatial Relations Defined in Geographic Standards

Samuel Andrés
IRD, UMR Espace-Dev
Montpellier, France
samuel.andres@ird.fr

Christelle Pierkot
IRD, UMR Espace-Dev
Montpellier, France
christelle@pierkot.fr

Damien Arvor
IRD, UMR Espace-Dev
Montpellier, France
damien.arvor@ird.fr

***Abstract*—To work more efficiently, remote sensing applications need to introduce semantic tools which are able to express experts knowledge. One important part is about spatio-temporally which is often used by experts to make their interpretations. We argue that geographic standards could help to formalize spatio-temporal expertise. In this paper, we focus on spatial relations by giving an example on how to fin beaches by using spatio-temporal ontology.**

***Keywords*-Remote sensing; Semantic interpretation; Geographic standards; Spatial relations.**

I. Introduction

Usually, to interpret and recognize objects on satellite images, experts use both remote sensing knowledge (e.g., spectral signature, remote sensing index, etc) which are linked to physical properties of objects (wavelength, texture, etc), and field knowledge (features properties, spatial relations, etc), linked to the application domain such as agriculture, ecology or urban planning. For example, to find *mangrove* in an image of French Guiana, the expert uses knowledge acquired from his field experience (e.g. mangrove grows in salt water, between ocean and continent etc) together with knowledge stemming from remote sensing processes (e.g. NDVI index for vegetation segments, NDWI to find water). However, this way of proceeding often brings some problems. Indeed, because of this knowledge depends on the expert personal experience, it is diverse and non equivalent. First, two experts do not have the same interpretation of one image because they do not use necessarily the same treatments in the segmentation or classification processes. For example, many indexes exist to classify vegetation (e.g., NDVI, VGI, etc) and the expert will probably use the one he has the best knowledge, thus the selected index for this process is not necessarily the same from one expert to another. Moreover, the expert often proceeds by trial and error tests before finding a suitable solution. Finally, a remote sensing expert has not necessarily the sufficient knowledge of the field to well interpret the image in a specific context. Therefore, the interpretation of the same image often leads to different results which are not consensual.

We argue that to have more consistent results, it is necessary to develop new methods which take into account all complex types of knowledge used in the image interpretation process. One way to achieve this is to add more semantics in the interpretation process, by using ontologies which describe both image and field knowledge. Indeed, ontologies are a way to facilitate *knowledge sharing and reuse* and can be formalized with standardized languages as OWL. Thus, they can serve to structure the semantic interpretation of images.

This paper is structured as follows. First, we introduce some relevant works in the field of image interpretation. Then, we discuss on how taking into account image and field viewpoints in the formalization process. Section IV is dedicated to explain why the use of geographic standards can be of interest in this context and introduces the theoretical metamodel that we have specified to take into account this kind of information in both viewpoints. Section V presents our first experimental results by focusing on management of spatial relations. Finally, we conclude and give some perspectives to this work.

II. Some related work in image semantics

Bridging the semantic gap with ontologies is a wide topic which has been studied by many ways.

Ontologies have been used to improve expressivity for both manual and automatic image annotation [1], [2]. Nevertheless, the main purpose of ontologies in image interpretation is to formalize a domain knowledge [3], [4], [5]. Some works mention reasoners and knowledge inference to enrich image information at different steps of image exploitation [6], [7], [8].

Some of other research ways use spatial relationships between objects. For instance we can cite [9] for fuzzy spatial relationships conceptualization in medical images. In [10], RCC-8 based spatial relationships are used for image annotation. At a lower level, [11] uses spatial relationships for identifying the semantic of urban objects by the way of a dedicated algorithm. Finally, [6] uses spatial relationships in image interpretation based on reasoning. This work argues that some academic spatial relationships cannot be distinguished in digital images because of lack of depth information.

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III. Image and field viewpoints

In the process of interpretation of satellite images, image and field are two complementary and indivisible viewpoints, that represent the same features according to distinct perspectives. For example, according to respectivly field and image viewpoints, mangrove can be defined by either biotic or abiotic factors of ecosystems such as leaf type, salinity environment or by physical characteristics such as wavelength or texture (cf. Fig. 1).

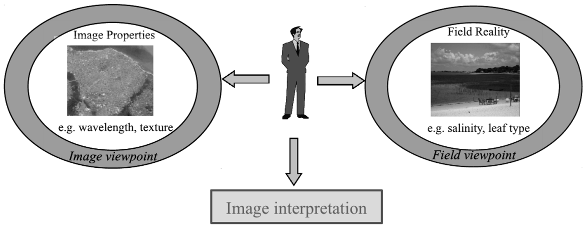

Figure 1. Image and field viewpoints.

However, to be used widely, matching must be established between concepts related to the field and the image points of view (e.g. we must recognize that mangrove defined in the field's point of view apparent to a vegetation segment in the image perspective). To facilitate these gateways, first of all it is necessary to represent knowledge in a common formalism.

Ontologies that [12] defined as a *formal specification of a shared conceptualization*, specify a set of concepts, relations and properties that are relevant for modeling a domain of study [13]. To be used in a process, these ontologies must be formalized in a common language such as the OWL semantic web standard. Furthermore, OWL standard based on description logics, allows reasoning on resources, on the one hand to check the consistency of conceptualized information, and on the other hand to find new knowledge. Formalize knowledge from two points of view by ontologies specified in OWL, will therefore facilitate matching between the different knowledge and allow inferring new knowledge that can be used into a semantic interpretation process.

Moreover, in both points of view, spatio-temporal concepts are commonly used to define features. For example, we can use spatial relations to define features relative position from each other (e.g. Mangrove is located *between* ocean and continent in field, or vegetal segment is *between* water and soil objects in image). Furthermore, geometry can also be used in both viewpoints to define shape or location properties. This consideration also applies with temporal characteristics. Thus, we also must take into account the spatio-temporal dimension in the modeling of knowledge.

As a result, we need to formalize three ontologies: One dedicated to image perspective, another one for field viewpoint and a transversal one to specify spatio-temporal concepts (cf. Figure 2).

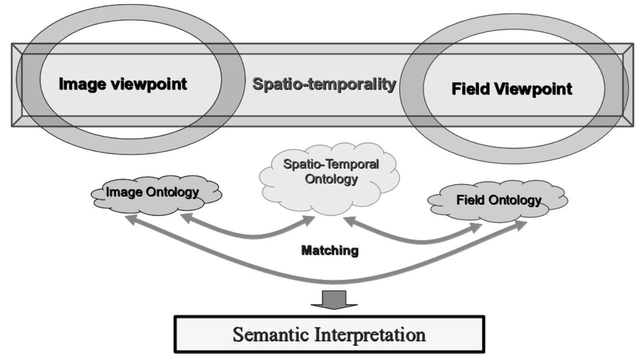

Figure 2. Matching different viewpoints.

IV. Formalizing spatio-temporal concepts

Because of spatio-temporal concepts exist in both viewpoints, it seems to be useful to formalize them into a framework ontology. Indeed, specifying a framework ontology will give a common basis for describing the different viewpoints, thereby helping the implementation of bridges between the various elements to be described, which, therefore, leads to reduce this which is usually called the *semantic gap* [9]. We also see another advantage which is to unify definitions and to reuse concepts that appear redundantly in different application contexts (e.g. spatial relationships between objects in land cover mapping or Amazonian coastal dynamics).

A. Using geographic standards to represent spatio-temporal knowledge

GIS community has been very active for many years in terms of modeling spatiotemporal knowledge [14], [15], [16], [17], [18], [19]. A number of these studies have led to the specification of standards and recommendations from the OGC (Open Geospatial Consortium) and ISO (International Organization of Standardization), the two major standard organisms in terms of geographic Information [20], [21], and are now widely used by GIS and spatial DBMS. Thus, it seems interesting to use standards and recognized work to define spatio-temporal concepts.

B. Spatio-temporal metamodel

A metamodel for describing spatio-temporal knowledge using geographic standards has been defined [22]. An overview of this metamodel is given in Figure 3, where eight components have been identified.

The *Core package* is the central element of the metamodel. It is used to characterize the geographical feature as a whole which have a direct or indirect dependency with the other packages. The *SpatialDimensionPackage* contains information about spatial references of the feature such as shape or location. The *TemporalDimensionPackage* includes concepts, which characterize time such as instant or period.

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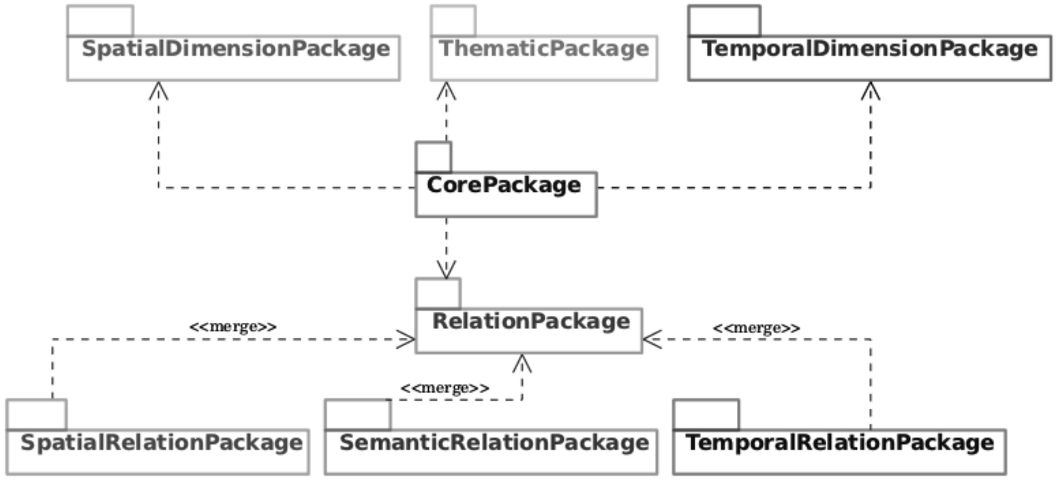

Figure 3. Global view of the metamodel.

The *Thematic package* aim is to describe the other nature of a feature, such as image characteristics or landscape properties. The *Relation package* contains all the required concepts for describing a relationship between features. It is specialized into three sub-packages in order to refine it in terms of *Spatial, Temporal and Semantic relations*. The *TemporalRelation package* includes concepts to define temporal relationships between features, such as ”before” or ”four months ago”. The *SpatialRelation package* includes concepts to define spatial relations between features, such as ”near” or ”50m away”. Finally, the *SemanticRelation package* includes all the others relations that can exist between features such as *part of*, *is a*, *grow*, etc. More details about each package can be found in [22].

For most concrete aspects of the work, our metamodel can be instantiated into a framework ontology which import all ontologies defined by the packages into the metamodel.

C. Focus on spatial relations

As the experiments given in the next section, focuses on spatial relations, we detail here this package in Figure 4.

Many directions have been taken to define spatial relations, and are currently used in the standards [15], [20], [21], [23], [24]. In our metamodel, we have chosen to use the types defined in [25] to specify three classes of spatial relations. Thus, three types of relation have been defined: *topological, projective and metric*. *Metric relations* are of distances or angles [16]. They can be defined by measurable methods (e.g. the town is located 5km away from the beach), cognitive methods (e.g. forest is near river), or fuzzy methods.*Topological relations* are about connections between objects. These relationships are generally defined by measurable methods (e.g. via the DE9IM matrix [15]), but can also be expressed by terminologically cognitive methods (e.g. next to, touches, within). Three approaches are regularly cited in the literature, namely, the *point set based model of nine intersection* by [15] (*EhRelation*), the *Logic based Model connection calculus regions* of [24] (*RCC8Relation*), and the *Calculus based model* of [23] (*CBMRelation*). We choose to explicitly define these three classes in our metamodel, because they are commonly used by several communities and they can be easily linked to each other [26]. *Projective relations* are described by space projections such as cardinal relationship (e.g. east of, north of) [16], or orientation relations of the objects against each other (e.g. left, down, front) [27]. Finally, we choose to represent reference systems used with the relation by an attribute, whose type is defined in [28] (i.e. intrinsic, extrinsic and deictic).

V. EXPERIMENTS ON SPATIAL RELATIONS

We propose to illustrate relevance of this metamodel integrating some spatial relationships to satellite image interpretation by reasoning. Accordingly, we use spatial relation knowledge by focusing on the RCC8 topological relationships [24].

Our example concerns a calibrated (in reflectance and temperature) Landsat 5-TM image of the surroundings of the city of Santarem (in the Brazilian Amazon) from December 7, 2009. In this case, we attempted to detect segments with different semantics (*cf.* Figure 5).

Image processing is performed using the free software *Orfeo Toolbox* which proposes an implementation of RCC8 spatial relationships. Above all, we ensured the image objects are meaningful. For this purpose, we produced a so-called *good segmentation* [29] based on the preliminary semantic mapping of pixels of [30].

Once the segmentation done, we begin the ontological image description without paying attention to semantics from pixel classification. In the ontological image description approach we detailed in [31], ontologies have two purposes.

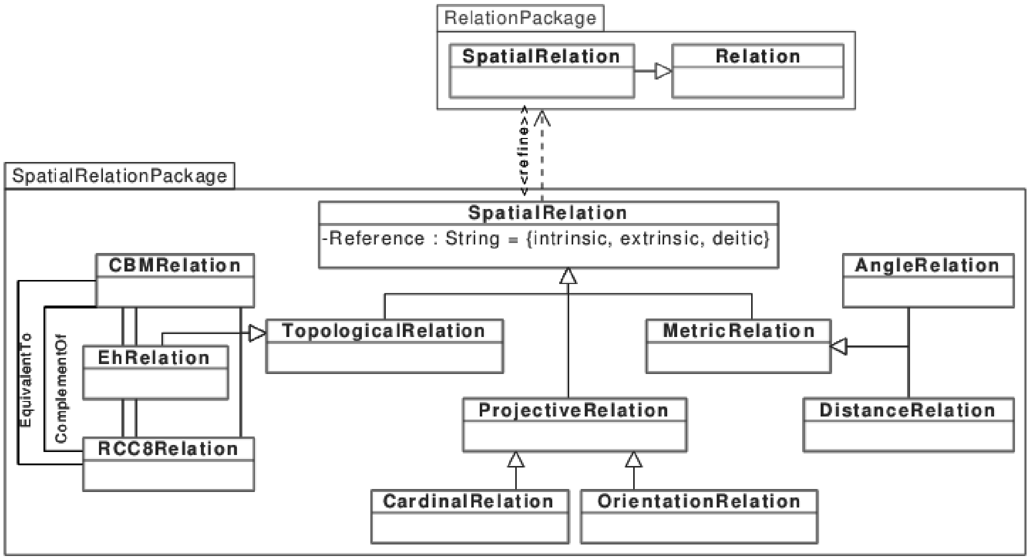

Figure 4. Focus on spatial relations.

Figure 5. Landsat 5-TM calibrated image extract.

(A) (B)

Figure 6. Segments retrieved (in white) by reasoning for two remote sensing semantics: water (A) and built-up and mineral (B).

On the one hand, we use ontologies to automatically describe only low-level image features with a *satellite image reference conceptualization* [6] (framework ontologies). Image description is a set of assertions based on the reference conceptualization, using image concepts, references to remote sensing processing and spatial relationships.

On the other hand, the reference conceptualization is also necessary to express a few expert concepts, which is called *remote sensing contextual knowledge* [6] (domain ontology). We began defining concepts like *vegetal segment*, *water segment* and *mineral segment* using radiometric characteristics (*cf.* Figure 6). These definitions are image-based rather than based on the field point of view.

Concepts like *water segment* and *mineral segment* are defined by intrinsic characteristics which often are spectral or textural indexes. But some other expert concepts need extrinsic characteristics like spatial relationships to be defined. For example, we can define the *beach segment* concept from the mineral one, specifying that a *beach segment* **is a** *mineral segment* **externally connected** to a *water segment*. The RCC8 *externally connected* is an instance member of the spatial relation ontology.

Finally, image segments are automatically classified using a reasoner based on description logics. This allows producing semantics using reasoning based on intrinsic and extrinsic characteristics. The Figure 7 illustrates our approach on the *beach segment* example, taking topological spatial relationships into account.

It is not easy to evaluate the results. We proposed in [32] some confusion matrices to evaluate reasoning on intrinsic characteristics. This is not an absolute solution because the result depends on the whole processing, including segmentation step.

We do not propose quantitative evaluation concerning extrinsic characteristics. However, it is possible to qualitatively compare Figure 5 and Figure 7: the coastline seems to be

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well detected.

Figure 7. Segments of beach retrieved (in white) by reasoning, using spatial relationships.

VI. CONCLUSION

We showed in this article how spatio-temporal conceptualization based on reliable standards can be usefully applied to remote sensing.

We presented a proposal of spatio-temporal metamodel and we specifically focused on spatial relations package. We partially create models which conform to the metamodel, using spatial topological relationships for satellite image description.

Finally, we illustrated our work by preliminary example about coastline detection. This concerns the image side and other concrete aspects concerning field point of view are in progress so to include all knowledge areas of remote sensing.

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