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Spatio-temporal multi-modality ontology for indexing and retrieving satellite images

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Abstract. This paper presents spatio-temporal multi-modality ontology for indexing and retrieving satellite images in the high level to improve the quality of the system retrieval and to perform semantic in the retrieval process.

Our approach is based on three modules: (1) regions and features extraction, (2) ontological indexing and (3) semantic image retrieval. The first module allows extracting regions from the satellite image using the fuzzy c-means (FCM) segmentation algorithm. The second module allows indexing the satellite image by a spatio-temporal ontology which represents sensors, spatial objects, visual features (spectral signature, texture, shape, etc.), spatial relation between objects, temporal variation and semantic relation between terms. The last module allows retrieving satellite images by comparing the ontological model of the requested satellite image with the ontological model base. We adopted several algorithms for measuring the lexical and the structural similarity degree between ontological models.

Our approach attempts to fully describe the semantic content of the satellite image and to perform the quality of the retrieval system.

Keywords: Satellite image retrieval, spatio-temporal ontology, multi-modality ontology, ontology matching.

1. Introduction

With the recent advances in image acquisition and sensor technology, the amount of satellite images is constantly increasing at different levels of temporal, spatial and spectral resolution. They are used in a large variety of applications including, geologic, land cover mapping, agriculture, military, environmental assessment, etc. In order to deal with these data, it's necessary to develop appropriate information systems to efficiently manage these collections. Automatic content extraction,

classification and content-based retrieval are highly desired goals in intelligent remote sensing databases.

Satellite image retrieval becomes an active area of research for several years. The goal is to create systems capable of interactively retrieving images that are semantically related to the user's query from a database. Several approaches have been developed such as text-based and content-based image retrieval.

Traditional text-based approaches, based on the keyword matching of the text metadata descriptions of images, are usually relatively simple and easy to use, but the retrieval process requires subtle query expressions, and the task of manually annotating the current volume of satellite imagery would involve a large amount of time and expense [1, 2].

During past few years, Content-based Image Retrieval [1] (CBIR) technique has been proposed to overcome the obstacles of text-based approach methods. This technique uses the visual contents of an image such as color, shape, texture, and spatial layout to index and represent the image [3]. CBIR system provides an intelligent and automatic solution for efficient searching of images. However, the low-level image features are often too restricted to describe images on a conceptual or semantic level. This is due to the 'semantic gap' between the limited descriptive power of low-level image features and the richness of user semantics [2, 3].

Many methods have been developed to reduce the 'semantic gap' between low-level features and high-level image semantics such as relevance feedback [3], using data mining techniques to associate low-level image features with high-level concepts [4], region based techniques [5] which allow the user to specify a particular region of an image and request that the system retrieve images that contain similar regions, and ontology approach [1, 2] to describe the semantic content of the satellite image. It allows an explicit, formal, machine readable semantic model that defines the classes (or concepts) and their possible inter-relations specific to some specified domain.

In this paper, we present a spatio-temporal multi-modality ontology-based approach allowing semantic satellite image retrieval and modeling the spatio-temporal content of the satellite image. Our approach is based on three modules: (1) regions and features extraction, (2) ontological indexing and (3) semantic image retrieval.

The proposed spatio-temporal multi-modality ontology represents sensors, spatial objects, visual features (spectral signature, texture, shape, etc.), spatial relation between objects, temporal variation and semantic relation between terms. Our approach attempts to reduce the semantic gap between visual features and semantic concepts and to fully describe the semantic content of an image.

This paper is organized as follows: section 2 gives an overview of previous works on ontology-based image retrieval; section 3 presents an overview of ontology; section 4 describes the proposed approach and discusses their modules; section 5 presents our conclusions.

2. Related work

In this section, we present some previous works on ontology-based image retrieval. Ontology is designed to capture shared knowledge and overcome the semantic heterogeneity among domains.

In [6], authors proposed a system which combines the use of an ontology annotating images repository and CBIR techniques. The system incorporates an ontology which is built by extracting the term hierarchy ranging under placental in WordNet [7] and separates the leaf synsets in this ontology.

In [8], authors present an ontology-based medical image annotation with description logics for semantics-based reasoning and image retrieval.

In [9], authors proposed the Visual descriptor ontology which represents the structure of the MPEG-7 visual part. The goal of this ontology is to enable machines to generate and understand visual descriptions which can be used for multimedia reasoning. This ontology contains four main concepts, which are Region, feature, visual descriptor and meta-concept.

In [5] authors proposed an ontology approach to object-based image retrieval. In this system, low-level features describing the color, position, size and shape of the resulting regions are extracted and are automatically mapped to appropriate intermediate-level descriptors forming a simple vocabulary termed *object ontology*. The object ontology is used to allow the qualitative definition of the high-level concepts of the user queries.

In [10], an image retrieval approach based on an extensible ontology is proposed. Querying is achieved by combining ontological concepts (e.g. size, location, color, semantic category). This combination is constrained by a grammar. Mapping between image data and concepts is based on supervised machine learning techniques.

In [11], authors proposed a generic multi-layered ontology to describe key features of urban applications. The ontology contains layers which are composed of a generic functional structure and one or more domain ontologies.

In [12], Authors investigate the design and use of ontology for multimodal similarity matching and ranking for multimedia retrieval on the Web in the animal domain. A new ranking mechanism is proposed to measure conceptual similarity in the ontology, integrating both textual and image features.

Authors in [13] proposed ontology of spatial relation to guide image interpretation. This ontology is enriched by fuzzy representations of concepts, which define their semantics and allow establishing the link between these concepts and the information that can be extracted from images.

Zhou et. al [14] proposed an approach for computing the orientation spatial similarity between two symbolic objects in an image. Wang [15] proposed a new spatial-relationship representation model called two dimension begin-end boundary string (2D Be-string), based on previous research in 2D String [16].

3. Ontology overview

Ontology describes a particular reality with a specific vocabulary, using a set of hypothesis related to the intentional meaning of the words in this vocabulary.

Gruber [17] defines the ontology as “a specification of a conceptualization”. The conceptualization is the couching of knowledge about the world in terms of entities (things, the relationships they hold and the constraints between them). The specification is the concrete representation of this conceptualization. One step in this is the encoding of the conceptualization in a knowledge representation language.

The role of ontology is to capture domain knowledge in a generic way and provide a commonly agreed upon understanding of a domain. The common vocabulary of ontology, defining the meaning of terms and relations, is usually organized in taxonomy. Ontology usually contains modeling primitives such as concepts, relations between concepts, and axioms.

In ontology, concepts are the fundamental units for specification, and provide a foundation for information description. In general, each concept has three basic components: terms, attributes and relations. Terms are the names used to refer to a specific concept, and can include a set of synonyms that specify the same concepts. Attributes are features of a concept that describe the concept in more detail. Finally relations are used to represent relationships among different concepts and to provide a general structure to the ontology [17]. The goal is to create an agreed vocabulary and semantic structure for exchanging information.

An ontology O is a 4-tuple (C, R, I, A) , where:

*C is a set of concepts,
R is a set of relations,
I is a set of instances,
A is a set of axioms*

Concept, sub-concept, depth :

Let Θ be the set of concepts, \leq_Θ is a partial order between concepts. $\forall (C_i, C_j) \in \Theta^2$, $C_i \leq_\Theta C_j$ means that C_i is a sub-concept of C_j , $\rho(C)$ is the depth of the concept C in the hierarchy.

Classes of attribute

Let Φ be the set of attribute classes. A is the set of all attributes. For a set of attribute classes

$\alpha \subseteq \Phi$, $A_\alpha \subseteq A$ is the set of attributes of each class in α

Values and weight of an attribute

Let $a \in A_\alpha$ be an attribute of a class in $\alpha \subseteq \Phi$. We define

$V_c : A_\alpha \rightarrow [\mathcal{R}; \mathcal{R}]$ so that $V_c(a)$ is the range of values for 'a' in the concept $C \in \Theta$.

Let $\omega(a, C)$ be the weight associated to the attribute 'a' for the concept C .

3.1. Ontology levels

Ontologies are classified in four groups, according to their dependence on a specific task or point of view [18]:

Top-level ontologies describe very general concepts like space, time, matter, object, event, action, etc., which are independent of a particular problem or domain: it seems therefore reasonable, at least in theory, to have unified top-level ontologies for large communities of users.

Domain ontologies and *task ontologies* describe, respectively, the vocabulary related to a generic domain (like medicine) or a generic task or activity (like image interpretation), by specializing the terms introduced in the top-level ontology.

Application ontologies describe concepts depending both on a particular domain and task, which are often specializations of both the related ontologies. These concepts often correspond to roles played by domain entities while performing a certain activity.

4. Proposed approach

We consider a satellite image base and a image query as shown in figure 1; we aim to retrieve the similar satellite images to the query taking into account the quality of the system retrieval, the size of the data base, the speed of the retrieval process, the image semantic, etc.

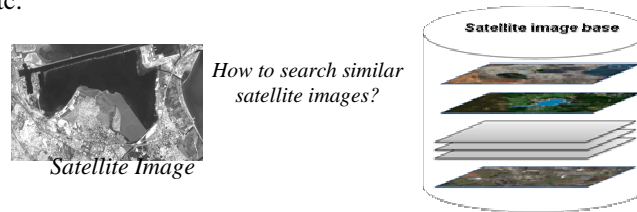


Fig.1. Satellite Image retrieval

We propose an ontological approach for modeling the spatial content of the satellite image and providing semantic in the system retrieval. The goals of our system are:

- Extraction of the salient regions from the satellite image using a segmentation algorithm.
- Extraction of visual features from the extracted regions.
- Index the satellite image by ontological models which describe its semantic content: regions and spatial relation between them, visual descriptors of each region, etc.
- Retrieve satellite images in the semantic level by measuring the similarity between ontological models.

Our system (figure 2) works in two modes which are the off-line and the on-line mode. In the first mode, the whole satellite images base are indexed by developing an ontological model base. In the second mode, similar satellite images are retrieved. Our system is based on three modules which are region extraction, ontological modeling and semantic satellite image retrieval.

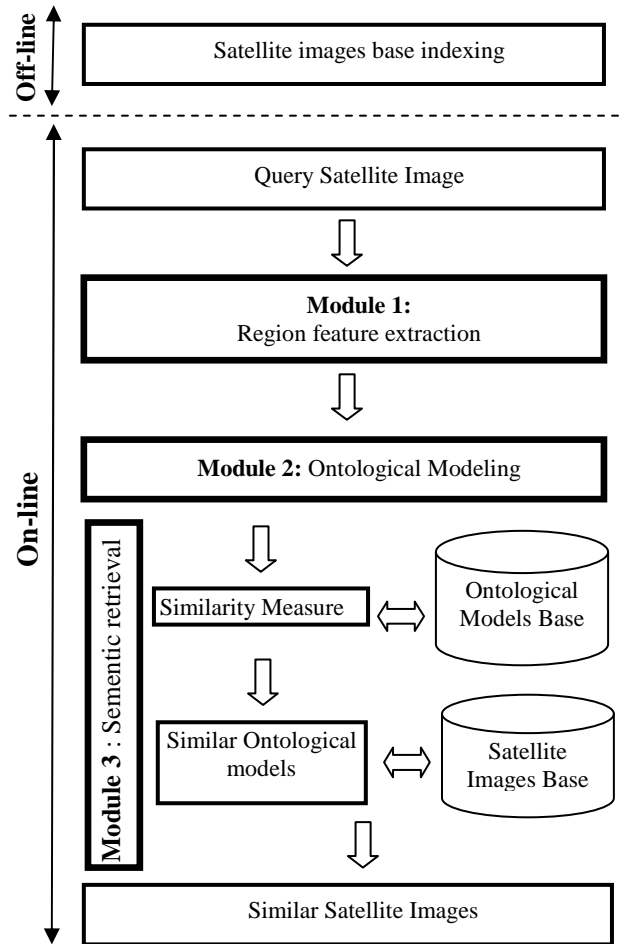


Fig.2. Proposed System Retrieval

4.1. Satellite image base indexing

The first step in our system is to index each satellite image in the satellite images base. The idea is to develop ontological models for each satellite image in order to constitute an ontological model base.

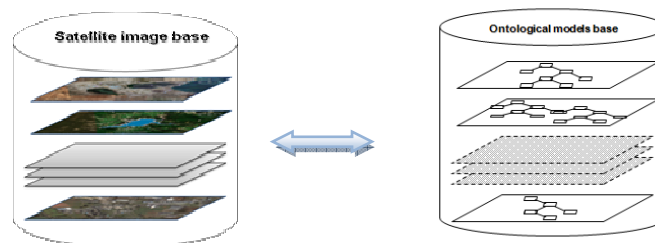


Fig.3. Satellite Image base Indexing

4.2. Regions and features extraction

This step aims to extract salient regions from the satellite image using the Fuzzy C-Means method (FCM) which is proved to be very well appropriate to deal with the satellite images. We obtain a set of homogeneous regions as shown in figure 4. Next, we extract several features from regions such as spectral signature, texture, moments, etc.

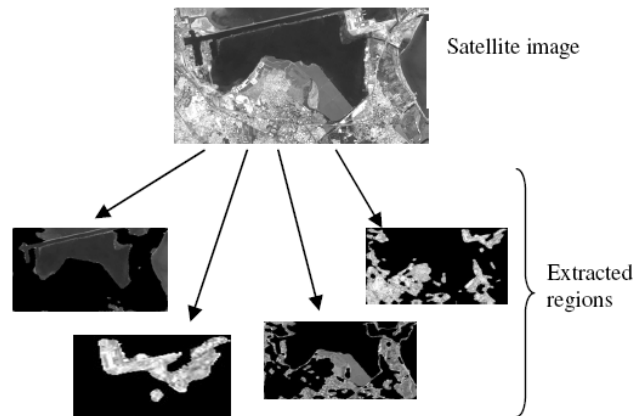


Fig.4. Satellite image segmentation

4.3. Ontological Modeling

The goal of this step is to index the satellite image by developing ontological models which describe its semantic content, basing on the extracted regions from the satellite images.

In order to integrate both the low level image features and the high level images objects, we propose to develop spatio-temporal multi-modality ontology (figure 5) which describes:

- Sensors
- Spatial objects
- Spatial organization
- Visual features: spectral signature, texture, shape
- Shape information as area, perimeter, moments, orientation, etc.
- Spatial relation between objects
- Temporal relation between objects
- Semantic and lexical relation between terms

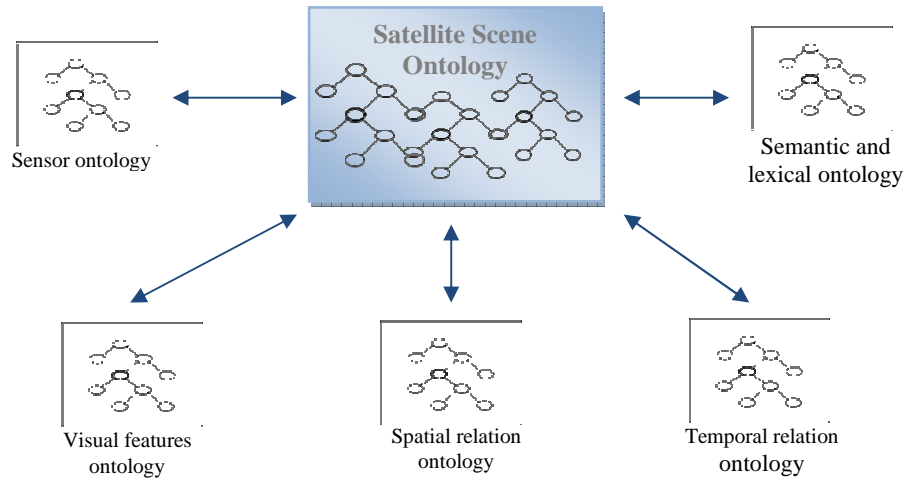


Fig.5. Spatio-temporal multi-modality ontology

Satellite scene ontology

This ontology represents spatial objects in the satellite image and their semantic hierarchy [19] such as land zone, humid zone, river, urban zone, etc. the typical relation between objects is the “is-a” taxonomic relation which describe the semantic hierarchy between them. Each object has a set of attributes such as name, length, area, orientation, etc.

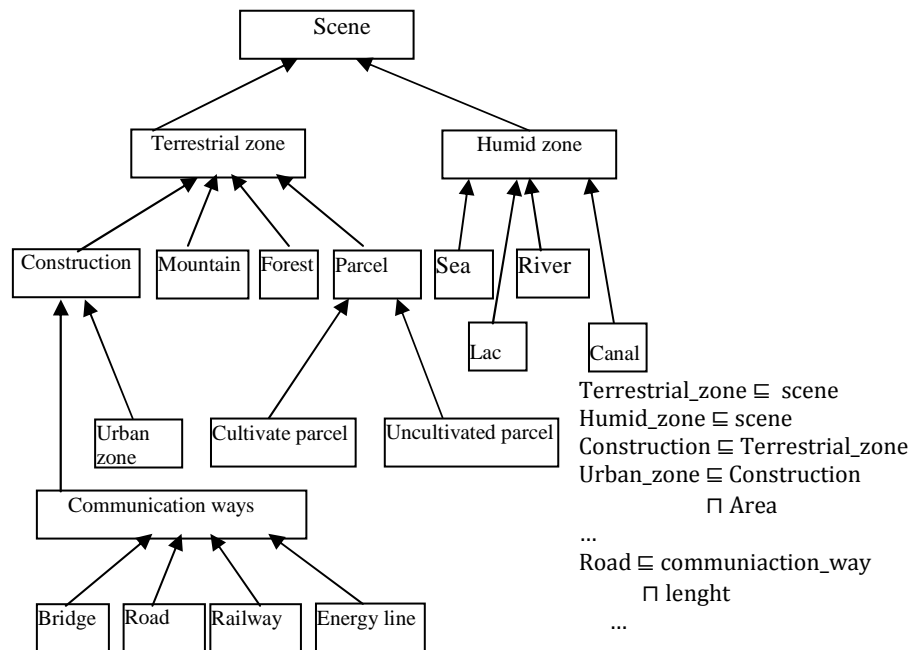


Fig.6. Spatial Objects Ontology

Sensor ontology

This model allows representing types of sensor according to their functioning mode [19].

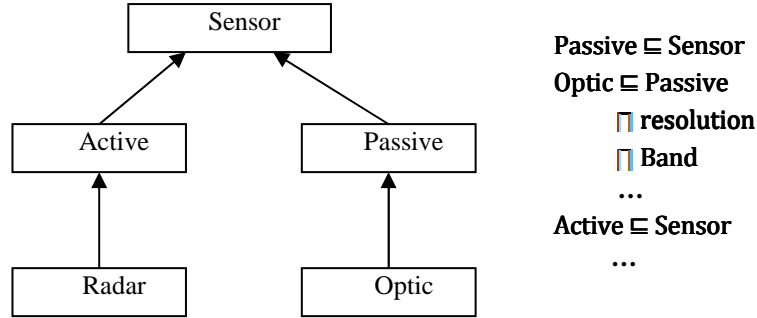


Fig.7. Sensor Ontological Models

Visual features ontology

This ontology allows representing the visual features of objects (regions) in the satellite image such as spectral signature, texture and shape, etc. in the high level. We propose this ontology:

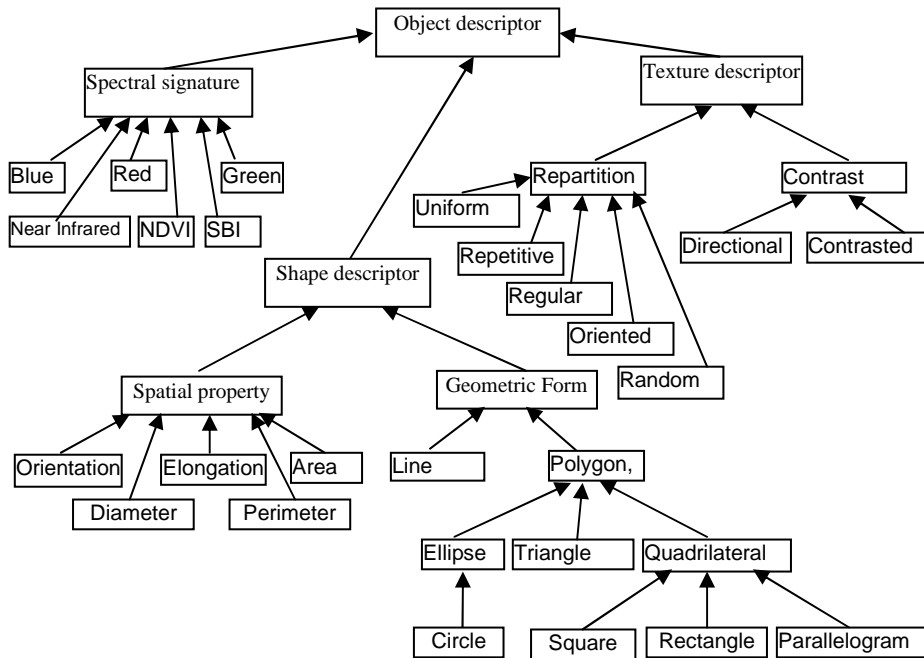


Fig.8. Visual feature Ontology

Each concept in the visual feature ontology contains the low information value. For example, the forest object has green color, circular form and area of 30 cm².

Spatial relations ontology

This ontology allows representing spatial relations between objects in the satellite image. Table 1 shows some topological relations in the RCC-8 [20] calculus.

Spatial relation	Meaning	Graphical representation
DC(x,y)	X disconnected from Y	
EC(x,y)	X externally connected to Y	
PO(x,y)	X partially overlapping Y	
EQ(x,y)	X equals Y	
TPP(x,y)	X tangential proper part of Y	
NTPP(x,y)	X has tangential proper part Y	

Tab.1. RCC-8 Topological spatial relation

Other types of relation can be cited such as distance relation (the river is near from the forest), position relation (the bridge is on the river) and the direction relation (the forest is at the left of the urban zone). We proposed in [19] an ontology describing these types of spatial relations (Figure9):

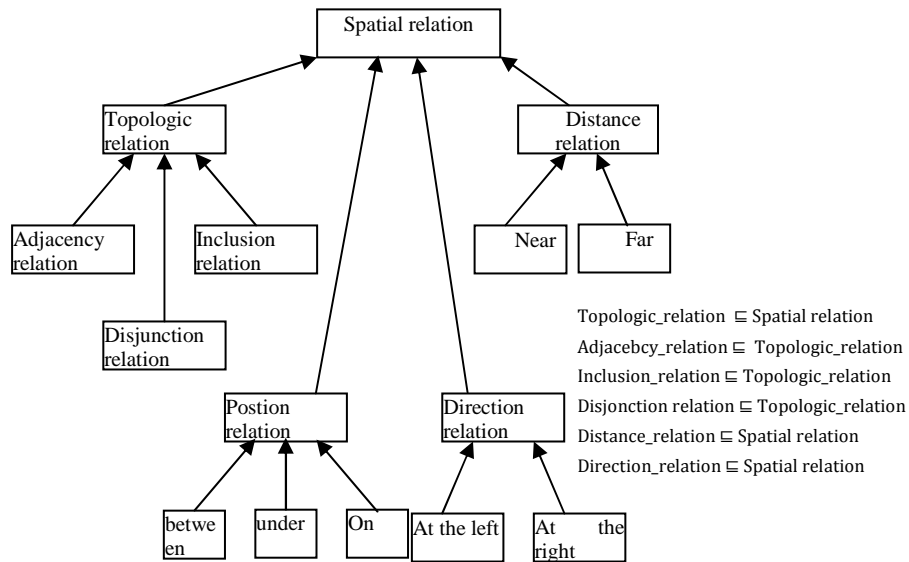


Fig.9. Spatial Relation Ontology

For example, the forest zone is adjacent to the Madjerda River and it's at the left of the urban zone.

Temporal ontology

This ontology allows representing time between objects in the satellite images. Allen [21] introduced an interval-based temporal logic, which considered objects/events along a 1D time axis as a set of temporal intervals based on comparative relations. Allen [21] defined 13 mutually exclusive relations which hold between two intervals: *before* (<), *after* (>), *during* (d), *contains* (di), *overlaps* (o), *overlapped-by* (oi), *meets* (m), *met-by* (mi), *starts* (s), *started-by* (si), *finishes* (f), *finished-by* (fi), and *equals* (=)

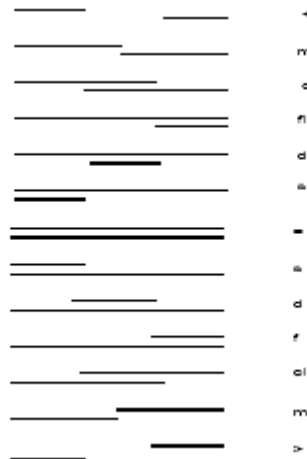


Fig.10. Allen's temporal Ontology

We choose to adopt Allen's approaches to model the temporal relation between objects.

Semantic relation between terms

This ontology allows representing lexical and semantic relation between terms in the spatial ontology using several lexical resources such as WordNet [7], GeoNames [22], etc. WordNet is a lexical resource about English words, which is often used in natural-language processing and information retrieval application. The core concept in WordNet is the synset which groups words via a number of semantic relations such as *hypernyms*, *hyponyms*, *holonym*, *meronym*, and lexical relation including *antonyms*, etc. Genames [22] is a geographical database which provides information about places in the world such as name place, country, geographic coordinates, etc. For example the term River in WordNet has this structure:

Sense: *a large natural stream of water etc.*

Coordinate terms: *rivulet, rill, run, runnel, streamlet -- (a small stream) etc.*

Hypernyms: *stream, watercourse--(a natural body of running water flowing on the earth)*

Hyponyms: (has instance) *Amazon, Amazon River -- (a major South American river, etc.*

Meronyms: (has part): *waterfall, falls -- (a steep descent of the water of a river)*

Nabhana River in Geonames:

Name: Oued Nebaana, Oued Nebana, Wadi Nabhanah, Wādī Nabhānah,

Country: Tunisia, **Geographic coordinate:** N 35° 57' 0"E 10° 3' 0"

We consider a satellite image which contains a river, an urban zone and a forest. The river is adjacent to the urban zone and the forest, forest and the urban zone are disconnected. The forest has a polygon shape, green color, etc. Figure 11 shows the ontological model of this scene.

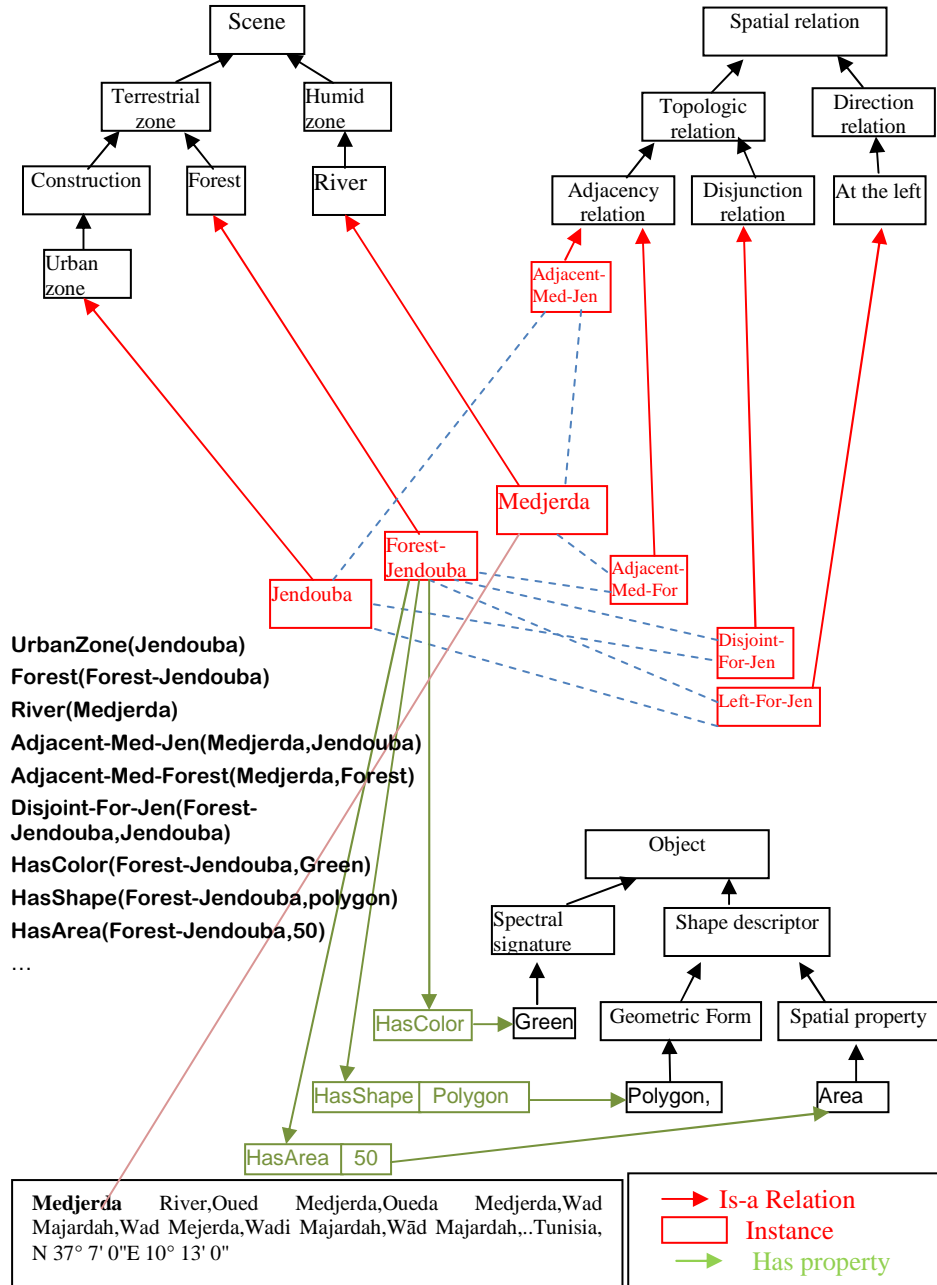


Fig.10. Ontological Model of Jendouba Scene

4.4. Semantic retrieval

This step allows retrieving similar satellite images to satellite image query basing on their ontological models: two images are similar if their ontological models are similar. To retrieve similar images, we compare the ontological model of the satellite image query with each ontological model in the database. Therefore, we need to measure similarity degree between ontological models.

The measures for similarity computation can be divided into two general groups [23] including lexical measures which compare entity labels, and structural measure which compare taxonomic hierarchy. Several approaches have been developed such as ASCO [24], Anchor-Prompt [25], OLA [26], S-Match [27], Glue [28], etc.

In our system, we choose to compare ontological models using ASCO algorithm which measure the linguistic and structural similarity. This algorithm identifies the pairs of corresponding elements in two different ontologies. These pairs may be pairs of concepts (classes) or relation in the two ontologies.

The matching process of ASCO is composed of several phases. The linguistic phase applies linguistic processing techniques, and uses string comparison metrics, and lexical databases to compute the similarity of two concepts or two relations. The computed linguistic similarities are input for the structural phase. In this phase, ASCO tries to exploit the structure of ontology taxonomy for modifying or asserting the similarity of two concepts or relations.

The similarities of classes or of relations are iteratively propagated to their neighbors in the tree of ontology which is built from the hierarchy of classes and the hierarchy of relations. When the propagation terminates, if the similarities between classes or relations exceed a threshold, they are considered as similar.

After applying this algorithm, we arrange the computed similarity degree of ontological models. Then, the system displays satellite images corresponding to these ontological models.

5. Conclusion

In this paper, we presented spatio-temporal multi-modality ontology for modeling and retrieving satellite images in the high level to improve the quality of the system retrieval and to perform semantic in the retrieval process.

Our system works in two modes which are the off-line and the on-line mode. In the first mode, the whole satellite images base are indexed by developing an ontological models base. In the second mode, similar satellite images are retrieved. The system is based on three modules which are region extraction, ontological modeling and semantic satellite image retrieval. Our ontology allows indexing the satellite image by a spatio-temporal ontology which represents sensors, spatial objects, visual features (spectral signature, texture, shape, etc.), spatial relation between objects, temporal variation and semantic relation between terms.

Our approach attempts to reduce the semantic gap between visual features and semantic concepts and to provide an automatic solution for efficient satellite image retrieval.

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