LC3 A Spatial-temporal Data Model to Study Qualified Land Cover Changes

Helbert Arenas, Benjamin Harbelot and Christophe Cruz
Checksem Team, Laboratory Le2i, UMR CNRS 6306,
University of Burgundy
Dijon, France

Land cover changes caused by humans have reached points never witnessed in history before. Consequences of these changes are environmental degradation, pollution of water, biodiversity loss and climate change among others. It is in this frame that the interest of the scientific community for this type of events has increased in the last decades. Nowadays, researchers have access to sophisticated monitoring tools and techniques. However, the new threat is that over abundance of information would hide relevant facts and processes. In our research we use data from the CORINE (Coordination of Information on the Environment) program. This program has compiled land cover information about Europe in a standardized form for the years 1990, 2000 and 2006, allowing comparative studies of land cover evolution. In this chapter we present the LC3 data model to study land cover changes. In our research we use Semantic Web technologies to create a formal representation of the CORINE land cover classification. Later we use the same technologies to create formal representations of the components involved in land cover change. In our research land cover types are organized as a taxonomy. Using this approach it is easy to aggregate and disaggregate land cover types at different levels, allowing a more flexible analysis. An additional benefit is that it is possible to create formal descriptions of particular land cover changes, allowing an easy identification of them at different levels of the land cover classification. Our approach has been implemented as a computer program using a triplestore as its data repository. Our approach enable scientist to easy discover patterns of change that could be hidden due to the large volumes of data.

Key words: Spatial-temporal dynamics, spatial-temporal semantics

1. Introduction

Along thousands of years, humans have modified the environment. In many cases land cover change is the result of a combination of economic opportunities, national policies and markets. However, only until recently, scientists have identified a relation between Land Use/Land Cover Change (LULCC) and medium/long term phenomena like weather pattern modifications (Lambin et al., 2001).

In other cases, the land cover change might pose a more immediate threat not only to the areas where the change had occurred but to adjacent ones. An interesting example is Portugal. This country has a high incidence of forest fires compared to other European countries. Research conducted by Varela (2006), identified that by the year 2003, Portugal had 3,200,000 ha. of forests, which represented near 1/3 of the country surface. If we add to this, the areas covered by shrub land, this percentage is higher than 50% of the country's area. In the same research, the authors identified several conditions that increase fire risk such as: 1)The abandonment of agricultural parcels that become unmanaged shrub and forest lands. This is caused by migration from rural to urban areas, ageing of the rural population, and the loss of value for agricultural products among other things. 2) The existence of large quantities of exotic species such as eucalyptus, which is cultivated for the production of the cellulose pulp. Even the fact that eucalyptus have higher burning rates compared to native species.

In the past, agricultural areas represented a buffer area between urban and forest. However due to the abandonment of farms, this buffer area is disappearing, increasing the risk for urban areas (Paton and Fantina 2013).

A forest fire does not only represent an economic loss in terms of forestry stands burnt up, but also grave disturbances in ecological systems, with loses in fauna and flora, and release of CO2. After the fire the affected area losses the coverage that protects it from erosion, leading to further land degradation.

There are several models currently employed to model LULCC. However, there is a continuous need for new approaches in order to reevaluate current models and improve them (Mahmood et al., 2010).

In this chapter, we present a model designed to keep track of changes in dynamic spatial systems such as LULCC. Our model is based on Semantic Web technologies. Our model represents a dynamic system composed by elements with a spatial representation. In our approach, we conceptualize the system as a graph in which the involved elements are linked by relationships. In our model, we conceptualize different types of evolution, in which objects cease to exist or continue their existence after experimenting changes. By keeping track of the evolution of entities, it is possible to determine changes that might increase certain undesirable conditions, for instance in the case of Portugal, we could detect when fire risk has increased for a certain area.

To show the effectiveness of the model, we implement our ideas using a Java application and a triplestore to store the data of our model. Our approach is flexible in the sense that it can be used with any spatio-temporal system in which entities have a 2D spatial representation. In this chapter, we present our model, using land cover change data for Portugal.

In Section 2, we identify previous relevant research in the field of Spatial temporal modeling. Later in Section 3, we refine our quest focusing on work carried out in the field of modeling the dynamics of LULCC. In Section 4, we present the formalisms of our model, later in Section 5, we present the model implementation. Finally, in Sections 6 and 7, we discuss our results and present our conclusions.

2. Advances on Spatio-Temporal modeling

Several spatial and temporal approaches have been proposed to model environmental processes. This type of models generate complex relationships in space and time. Objects that take part on a dynamic process can move, change shape while maintaining their identity, or evolve into new objects.

In order to handle the vast number of relations between evolving entities, it is required the help of software mechanisms capable to analyzing complex networks of relations and infer new implicit knowledge. Gruber (1995) defined ontologies as conceptualizations of a domain, in a formal, explicit form that can be easily shared among potential users. An ontology modeler, attempts to identify concepts and relations that exist within an specific domain. By using formal specifications, it is possible to use inference mechanisms on them capable to identify incoherences (Gruber 1995).

Ontologies are based on notions of individuals, classes, attributes, relations and events. In an ontology, entities can be treated as individuals and grouped in defined classes. The definition of a class can be further specialized, creating subclasses. It is possible to define subsumption relations between classes, establishing in this way a hierarchy. The characteristics of entities are modeled as properties. It is also possible to model relations between entities. Any change in the properties or the relations is modeled as an event.

The representation of the real world objects is composed of an identity, descriptive and spatial properties. While an identity property describes a fixed component of the entity, alphanumeric and spatial properties can vary over time and are its dynamic part. When the identity of an entity varies, there is a particular type of evolution in which the spatial-temporal entity is transformed into a new one. In the literature, there are two main types of spatial-temporal entities: 1) objects moving, like for example a a boat sailing, and 2) changing objects, for example, a region which boundaries evolve in time (Meskovic, Zdravko, and Baranovic 2011).

There are two main philosophical theories behind models of spatio-temporal dynamic objects: 1)*endurantism* and 2) *perdurantism*. The first approach *endurantism*, consides that objects (endurants) exist wholly at any given point of time during their lifespan. An alternative modeling approach follows the *perdurantism* paradigm. This approach represents objects as entities composed of several timeslices. Each timeslice is a representation of the object during a finite time. A complete representation of the evolving object is the sum of all its timeslices (Harbelot, Arenas, and Cruz 2013a).

An interesting research using an *endurantism* approach can be found in Bittner, Donnelly, and Smith (2009). In his research, the authors identified three classes of entities, 1) Individual entities, 2) Endurant universals and 3) Collections of individual endurants. In the ontology developed by Bittner, Donnelly, and Smith (2009), to declare that two entities sustain a relationship, it is necessary to indicate the valid time of the relation.

The alternative *perdurantism* approach can be found in other works such as O'Connor and Das (2011), Batsakis and Petrakis (2011) and Harbelot, Arenas, and Cruz (2013a). In Al Debei (2012), the authors compare the *perdurantism* and *endurantism* aproaches. The authors concluded that a *perdurantism* approach when using ontologies offers better expressiveness, handling of time, flexibility and objectivity.

A *perdurantism* dynamic model requires mechanisms for the representation of dynamic properties. However, the two main Semantic Web languages are OWL and RDF, provide limited support for temporal dynamics, having been designed to define binary relations between individuals (O'Connor and Das 2011). In order to overcome these limitations, different ideas have been proposed.

Klein and Fensel (2001) presents an approach based on *versioning*. In this case, the model constructs multiple variants of the objects in order to represent their evolution. However, the major drawback of the *versioning* approach is the redundancy generated by the slightest change of an attribute. In addition, any information requests must be performed on multiple versions of the ontology affecting its performance.

In Gutierrez, Hurtado, and Vaisman (2007), the authors present an extension of the standard RDF to name properties and to assign them corresponding time intervals, allowing explicit management of time in RDF. The limitation of this approach is that it only uses RDF triples, lacking the expressiveness of OWL. For example, it is not possible to define qualitative relationships.

Research conducted in Batsakis and Petrakis (2011), uses the so called 4D-fluent model. Using this methodology, it is possible to express the existence of an entity using multiple representations, each corresponding to a defined time interval. In the literature 4D-fluent model is the most well known method to handle dynamic properties in an ontology. It has a simple structure allowing to easily transform a static ontology into a dynamic one. However, the approach of the 4D-fluent model has also some limitations: 1) It is difficult to maintain a close relationship between geometry and semantics; and 2) It increases the complexity for querying the temporal dynamics and understanding the modeled knowledge. Furthermore, this approach does not define qualitative relations to describe the type of changes that has occurred or to describe the temporal relationships between objects. Thus, it is difficult to identify entities that change, and new entities that might emerge as a result of these changes. In Batsakis and Petrakis (2011), the authors developed SOWL, which uses 4D-fluent to extend the ontology OWL-time making it able to handle qualitative relations between intervals, such as *before* or *after* even with intervals with vague ending points.

In O'Connor and Das (2011), the authors developed a lightweight model using *Reification*. The proposed model, can be deployed using existing OWL ontologies, extending their temporal support. This work also proposes the use of the Semantic Web Rule Language (SWRL) operators. Using *reification* it is possible to use a triple as the object or the subject of a property. Unfortunately this method has some limitations: 1) The transformation from a static property into a dynamic one increases substantially the complexity of the ontology, reducing the querying and inference capabilities; 2) The approach is prone to redundant objects which reduces its effectiveness.

The filiation relationship defines the succession link that exists between representations of objects at different instants of time. The analysis of these relations allows us to identify processes such as the division or the merge of entities. Other spatial changes more complex would require the identification of multiple *parents* and *children* entities involved. At this level, filiation relationships are based only on spatial relationships. Therefore, they can be characterized as spatial filiationships in the context of spatial changes. In addition, these spatial changes may reveal an evolution in the nature of the entity. Because of this, the filiation relationship is intimately linked to the notion of identity. This relationship is essential to maintain the identity of an entity that evolves and to follow its evolution along time. In this process, it is also necessary to identify new entities that can emerge from an evolution.

An important concept regarding the evolution of entities is the identity. It can be defined as the uniqueness of an object, regardless of its attributes or values. It is the feature that distinguishes one object from all others. The identity is essential in the conceptualization and modeling of a phenomenon. Its importance while modeling dynamic systems has been identified by previous research such as Del Mondo et al. (2013), Del Mondo et al. (2010) and Muller (2002). However, this concept is very subjective because it depends on the criteria selected by the user to define the identity of an entity. Usually the criteria for the definition of the identity depends on the domain of study.

Research presented in Del Mondo et al. (2010) describes relationships between objects that exist at different points of time, and how some objects can originate others creating filiation relationships. The approach used on the paper can not be strictly described as *perdurantistic*, because they do not implement any timeslices. However, it contributes to the formal definition of filiation relationships. In Del Mondo et al. (2010), filiation relationships must respect two constraints: 1) a temporal constraint, the child object must exist after the parent object; 2) There must be a spatial relationship between parent and child objects.

Previous work presented such as Hornsby and Egenhofer (2000), Stell et al., (2011), Harbelot, Arenas, and Cruz (2013b) and Del Mondo et al., (2013), have identified two general types of filiation relationship: *continuation* and *derivation*. In the first case *continuation* the identity remains the same. The entity continues to exist, but undergoes a change. While in the second case *derivation* a new entity is created from the parent after a certain evolution.

In Del Mondo et al., (2013), the authors further extend the research conducted in Del Mondo et al. (2010), by providing mechanisms to establish filiation relationships at non consecutive times, allowing the combination of different graphs. Due to the constraints proposed, the system is not able to deal with geometries defined by multipolygon spatial representations. Del Mondo et al. (2013) implements these ideas in a relational database. In their work the researchers present an experimental evaluation of their ideas, using cadastral information of the Canton de Neufchatel, in Switzerland, composed by seven snapshots.

A related research is Stell et al., (2011). Here, the authors use bigraphs to model spatial temporal dynamics. In this research, the authors apply their ideas to track the evolution of crowds of people, implementing rules to identify splitting and merging of crowds.

There are examples of works in which the authors did not use Semantic Web technologies. For instance: Worboys (1994) presents modeling approaches for spatio-temporal information using relational databases. Similar work is presented in Claramunt, Theriault, and Parent (1997) with the introduction of ideas for the representation of spatio-temporal processes using an object-relationship data model. While in Hornsby and Egenhofer (2000), the authors present a language designed to follow the identity of objects that represent geographic phenomena. Another kind of models such as Egenhofer and Al-taha (1992) use the intersection matrix to identify changes in topological relations between evolving features.

Some models for spatial dynamics are based on discrete approaches such as: the snapshot model found in Armstrong (1988) and in Chen et al. (2013), the Space-Time Composites model (STC) presented in Langran and Chrisman (1988) and the Spatial-temporal Object model introduced in Worboys (1994). However, there are disadvantages with these approaches. They represent only sudden changes then it is difficult to identify processes such as movement of an entity in a geographical environment.

Another type of models is the so called *event and process-based* approach. This approach considers that spatial entities operate under the impetus of an event or a process, the aim of this approach is to analyze the causes and consequences. An example of this type of models is the Event-Based Spatio-temporal Data Model (ESTDM) introduced in Peuquet and Duan (1995). The ESTDM model describes a phenomenon through a list of events; a new event is created at the end of the list whenever a change is detected. However, this model takes into account only raster data and the causal links between events are hardly highlighted in this model. An alternative to ESTDM is the composite processes as introduced in Claramunt, Theriault, and Parent (1997). The composite process model deals with some of the limitations of the ESTDM. It is designed to represent the links between events and their consequences; moreover, the author argues that the data model must differentiate what is spatial, temporal and thematic. Another example, is the model of topological change based on events presented in Jiang and Worboys (2009). This model represents change of a geographic environment as a set of trees. Each tree is connected to the next and the previous through its nodes. The link between two trees is a topological change that reveals the creation of an entity on the geographical environment, the deletion of an entity, division or merger of entity or no change. The succession of these topological changes enables the representation of complex changes.

The weakness of the later set of models is that they do not use any formal semantics, therefore the applicability of formal rules or inference mechanisms is limited.

In the next section we will describe models specifically used in the field of LULCC for spatio temporal dynamics.

3. Spatio-temporal Models for Land Use Land Cover Change

The field of Land Use Land Cover Change (LULCC), due to their data gathering methods and traditional tools, has developed alternative approaches. A significant part of the information used in LULCC comes from remote sensing platforms. Currently the prevailing approach for the analysis of remote sensing data uses pixel based methods. However, in recent years this approach has been criticized as new tools with an *object based* approach become more available. Much of the initial work related to Object Based Image analysis (OBIA) can be traced back to a well known software called *eCognition*, later renamed as *Definiens* (Blaschke (2010)). However, the term OBIA was perceived by some researchers in GeoSciences as too broad, given the fact that similar techniques are used in the medical field. Because of these concerns a new term Geographic Object Based Image analysis (GEOBIA) was introduced.

The goal of GEOBIA is to develop automated methods to partition remote sensing imagery into image objects, and analyze their spatial, spectral and temporal characteristics (Arvor et al., 2013). As a result, it would be possible to generate geographic information from which new spatial knowledge can be obtained. Most of the methods for image classification currently in use, were first developed in the early seventies (Blaschke 2010). They are based on the classification of pixels using a multi dimensional feature space. In these methods the spectral values of the pixels are the most relevant characteristics to be considered for a any given classification. A pixel is the smallest entity for Remote Sensing (RS). Image objects are generated by grouping pixels, with similar values. Then it is possible to link these groups to real world objects. When the spectral characteristics of an object are homogeneous, the classification can be straightforward. However, it is more difficult to use this approach when there is heterogeneity among the pixels that compose an object. For instance an object of the type *urban* could include pixel values of elements that represent *vegetation* (parks, gardens) or *water* (pools, fountains).

Approaches that use only the pixel spectral characteristics do not consider the context and patterns. For instance, considering what exists in the neighborhood of the pixel in spatial and temporal dimensions would provide further information for a given analysis.

The use of classification schemas that are based mostly in pixel spectral values, does not take advantage of domain knowledge. For any domain, it is possible to identify the main existing concepts and the relations between them. For instance relations such as *is part of*, *is more specific than*, *is instance of* would provide insights regarding the land use of certain area. These semantics can be formalized allowing inference mechanisms to operate with the information.

According to Blaschke et al. (2014), the core characteristics of a GEOBIA are: 1) Data is Earth centric; 2) Analytical methods are multi source capable; 3) Geo object based delineation is a pre-requisite; 4) The methods are contextual, allowing for surrounding information; 5) Highly customizable, allowing human semantics and hierarchical networks.

Most of the previous work on GEOBIA focus on the segmentation of images and temporal analysis (for instance Sheeren et al., 2012 or Herold et al.,2012). However, the use of semantic technologies is more scarce.

One area in which Semantic Web technologies have been used is on the field of interpretation of remote sensing imagery. Such is the case of Morshed, Aryal, and Dutta (2013) or Aryal, Morshed, and Dutta (2014), where the authors capture knowledge from different sources at different scales using RDF.

Another interesting field of use for Semantic Web technologies is for data integration. It is common that GEOBIA practitioners use different classification systems, based on particular conceptualizations of the world. In order to compare or merge products from different sources, it is necessary to find harmonization tools. Ontologies can fill this gap, having formal description of classes. Then it is possible to link two different classification systems, this process is called mapping or matching. Therefore, there is a need for standardized conceptualizations that would enable the comparison of results from different users, geographic areas (Blaschke et al., 2014).

In Arvor et al. (2013), the authors identify six areas for further research in GEOBIA: 1) The alignment of real world concepts to image objects, 2) The management of qualitative and quantitative information, 3) The handling of fuzzy geographic entities, 4) The handling of scale, 5) The handling of change and evolution and 6) The dichotomy of open world vs. closed world assumptions.

Our proposal fits in the fifth research area identified by Arvor et al. (2013). The objective of our model is to provide LULCC practitioners with tools to keep track of evolving land cover entities, allowing researchers to perform queries considering concepts like vicinity in time and space.

4. The LC3 Model Specification

In this section, we proceed to describe the use of Description Logic for the model, and First Order Logic for the constraints on the model.

4.1 Basic Components

4.1.1 Temporal Points

We can think of the temporal domain composed by a set of temporal points. The components of the set follow a strict order $<$, which forces all points between two temporal points *p1* and *p2* to be ordered using the approach presented by Artale and Franconi (1998).

$$\mathcal{P} \tag{1}$$

4.1.2 Time Intervals

By selecting a pair *[p1,p2]* of temporal points, we can limit a closed set of ordered points (Artale and Franconi 1998). We represent this concept as:

$$\mathcal{I} \equiv \forall\, hasInit.\mathcal{P} \;\sqcap hasEnd.\mathcal{P} \tag{2}$$

constraint:

$$\forall\, i \rightarrow \exists t_o, \exists t_f \,\middle|\, (t_o < t_f) \wedge hasInit(i, t_o) \wedge hasEnd(i, t_f) \wedge (t_o, t_f \in \mathcal{P}) \wedge (i \in \mathcal{I}) \tag{3}$$

4.1.3 Time

We can define a generalized class, called Time, which we define as:

$$\mathcal{T} \equiv \mathcal{P} \sqcap \mathcal{I} \tag{4}$$

4.1.4 Geometries

The spatial representation of an object is given by the coordinates representing its geometry. It is represented by G. The spatial topological relations between geometries are defined by the Extended Nine-Intersection model (DE-9IM) (Strobl 2008).

$$G \tag{5}$$

4.1.5 Object

This component of the model represents the elements that evolve along time.

$$\mathcal{O} \tag{6}$$

4.1.6 Timeslice

In our model, a TS (timeslice) is a temporal representation of an evolving object. Each timeslice has four components: 1) An identity that links it to the object it represents, 2) A Geometry, that contains its spatial representation, 3) A temporal component, that indicates the time point or interval, in which this representation is valid, 4) A set of properties that describe the characteristics of the object during the corresponding temporal component.

$$TS \equiv (= 1\; hasIdentity.\mathcal{O}) \sqcap (= 1\; hasGeometry.G) \sqcap (= 1\; hasTime.\mathcal{T}) \sqcap \forall\, hasProperties.\overline{\mathcal{TS}} \tag{7}$$

4.2 Filiation relationships and Evolution processes

When a change occurs a new timeslice would be generated from a previous one in a parent-child relationship, denominated *filiation* relations. For a filiation relationship it is necessary to compute the existence of a spatial relationship between parent and child. In the case of timeslices whose geometries are polygons, the spatial relationship must be an intersection of the type polygon, while the existence of the parent must be previous to the existence of the child.

$$\exists\, Intersection(p.geo, c.geo) \wedge (p.t < c.t) \rightarrow hasFiliation(p, c) \tag{8}$$

where *p*, *c* are instances of Timeslice TS, and *p.geo* and *c.geo* are their geometries and *p.t* and *c.t* are their respective time properties.

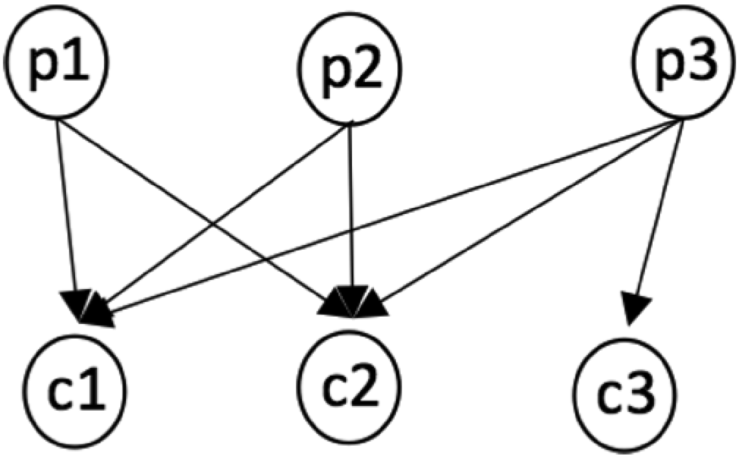

Figure 1: Filiation relationships between timeslices.

Figure 1 depicts the filiation relationships between a set of parent timeslices *[p1,p2,p3]* and a set of children timeslices *[c1,c2,c3]*. In the example depicted in Figure 1, the geometry *p1* would intersect the geometries of *c1* and *c2*, while the geometry of *p3* would intersect the geometries of *c1*,*c2* and *c3*. Each parent has its own identity, that might or might not be inherited by one of their children, based on domain specific rules.

The filiation relationship can be used to describe evolutions of objects along time. An important component of the evolution is the identity inheritance. Previous research, such as Hornsby and Egenhofer (2000), Stell et al. (2011), Harbelot, Arenas, and Cruz (2013b) and Del Mondo et al. (2013) has identified two basic types of Evolution based on the inheritance: *Continuation* and *Derivation*. In Figure 2 we propose a taxonomy of processes based on the filiation characteristics.

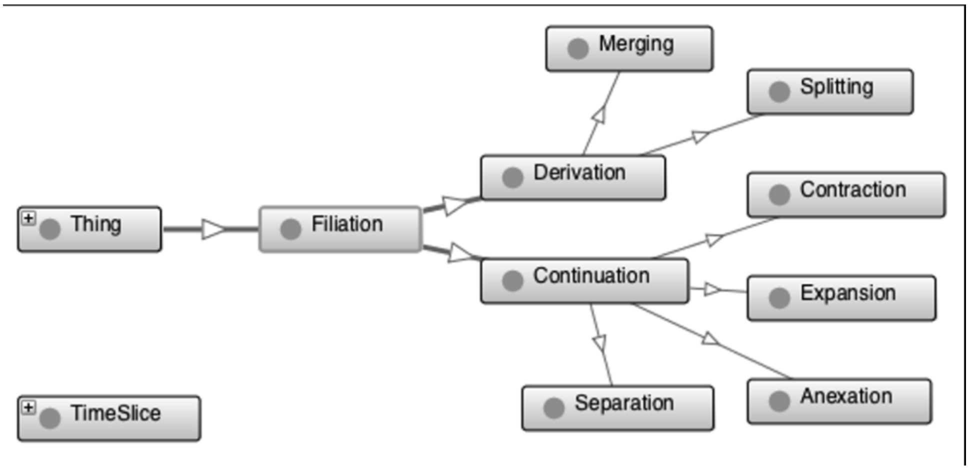

Figure 2: Evolution types.

For the definition of the different types of evolution we use the relations defined in DE-9IM (Equal, Within, Contains) as defined in Strobl (2008).

4.2.1 Continuation

In this type of relationship the identity is constant between a parent and a child.

$$hasFiliation(p, c) \land (p.o = c.o) \rightarrow hasContinuation(p, c) \tag{9}$$

where $p.o$ and $c.o$ are the identities of the parent and child timeslices.

Expansion

$$hasContinuation(p, c) \land Within(p.geo, c.geo) \rightarrow hasExpansion(p, c) \tag{10}$$

Contraction

$$hasContinuation(p, c) \land Contains(p.geo, c.geo) \\ \rightarrow hasContraction(p, c) \tag{11}$$

Separation

This type of process is not limited to a single child. A separation process can result in multiple children timeslices. However, only one of them maintains a *Continuation* relationship with the parent.

$$hasFiliation(p, [c_1, c_2 \dots c_n]) \land Equals\big(p.geo, Union(c_1.geo, c_2.geo \dots c_n.geo)\big) \\ \land (\exists_{=1} hasContinuation(p, c)) \rightarrow hasSeparation(p, [c_1, c_2 \dots c_n]) \tag{12}$$

In this case, the process involves multiple parents that result into one single child. However, only one parent has the same identity as the resulting child, thus maintaining a *Continuation* relationship.

$$hasFiliation([p_1, p_2 \dots p_n], c) \\ \land Equals(\ Union(p_1.geo, p_2.geo \dots p_n.geo), c.geo) \\ \land (\exists_{=1} hasContinuation(p, c)) \rightarrow hasAnnexation([p_1, p_2 \dots p_n], c) \tag{13}$$

4.2.2 Derivation

This kind of relation involves parents and children, who do not share the same identity.

$$hasFiliation(p, c) \land (p.o \ \neq c.o) \rightarrow hasDerivation(p, c) \tag{14}$$

where $p.o$ and $c.o$ are the identities of the parent and child timeslices.

Derivation processes involving multiple parents or children are Splitting and Mergin:

Splitting

This process is similar to *Separation*. However, in this case none of the children shares the same identity with the parent, and the identity of the parent ceases to exist (Del Mondo et al. 2013).

$$\begin{aligned} & hasDerivation(p, [c_1, c_2 \dots c_n]) \\ & \quad \wedge Equals\big(p.geo, Union(c_1.geo, c_2.geo \dots c_n.geo)\big) \\ & \quad \rightarrow hasSplitting(p, [c_1, c_2 \dots c_n]) \end{aligned} \tag{15}$$

Merging

In this case multiple parents combine into a child. The identity of the child is new, different from the involved parents (Del Mondo et al. 2013).

$$\begin{aligned} & hasDerivation([p_1, p_2 \dots p_n], c) \\ & \quad \wedge Equals(\ Union(p_1.geo, p_2.geo \dots p_n.geo), c.geo) \\ & \quad \rightarrow hasMerging([p_1, p_2 \dots p_n], c) \end{aligned} \tag{16}$$

4.3 Identification of the evolution process without *a priori* information

In systems in which no *a priori* filiation lineage information exists, it is necessary to identify the relationships between timeslices from scratch. Those cases are not unusual if you consider all the systems that rely on Remote Sensing observations for regular update. In these cases, the new dataset represent a snapshot describing the area of interest at a discrete point of time. However, no link other than geometry, is given between the new dataset and previously recorded status of the area of interest. To facilitate the analysis of systems without *a priori* filiation information we propose the creation of the class *Filiation*. This class links a parent and child timeslices and stores information regarding the quantification of their relationships (See Figure 3).

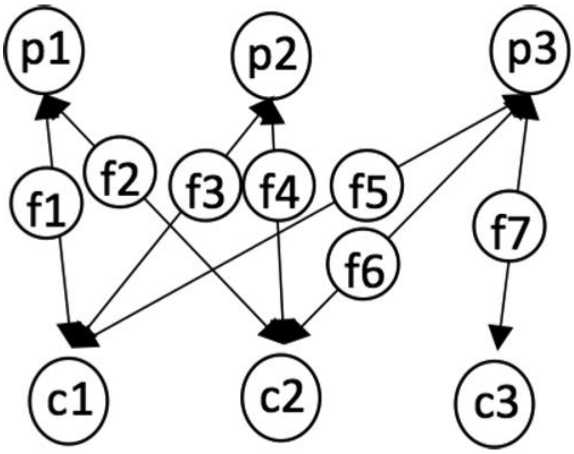

Figure 3: Instances of the class Filiation.

$$\begin{aligned} Filiation \equiv\ & \forall hasParentTS.TS\ \sqcap \forall hasChildTS.TS\ \sqcap \forall has\rho.Double \\ & \sqcap\ \forall has\chi.Double \end{aligned} \tag{17}$$

constraint:

$$\forall[p,c] | hasFiliation(p,c) \rightarrow \exists Filiation(f) | \; hasParentTS(f,p) \\ \wedge \; hasChildTS(f,c) \\ \wedge \; has\rho\left(f, \frac{Area\big(Intersection(p.geo, c.geo)\big)}{Area(p.geo)}\right) \\ \wedge \; has\chi(f, \frac{Area(Intersection(p.geo, c.geo))}{Area(c.geo)}) \tag{18}$$

In an evolving system, a parent timeslice can originate one or many children timeslices, while it is also possible that a child timeslice can be the result of multiple parents. In this case, it would be necessary to identify the most suitable candidates for the identity inheritance. A rule of thumb to solve this problem would be to identify the *parent-child* relationship in which there is the highest spatial similarity between parent and child.

To have a better understanding of this type of relationships we can analyze the values of the *hasχ* and *hasρ*. In the case of a parent with multiple children, we can identify the *parent-child* relationship in which the child comprises most of the geometry of the parent. This relation would be the one with the highest value for the property *hasρ*.

On the other hand, we can have the case of a child with multiple parents. In this case, we can identify the *parent-child* relationship that corresponds to the one in which the most of geometry of the child corresponds to a certain parent. This relation would be the one with highest value for the property *hasχ*.

The identification of the maximum values for *hasρ* and *hasχ* does not resolve the problems of unknown identity inheritance. In some cases, the identity might evolve regardless of the geometric relationships. However, the comparison of the values of *hasρ* and *hasχ* helps to implement domain specific rules. Using this information it is possible to implement rules such as:

The identity is only inherited when there is a filiation for which both hasρ and hasχ are maximum values.

Which would identify the strongest relation between a parent and a child in an environment where there are multiple parent and children involved.

$$\forall Filiation(f) | \; hasParentTS(f,p) \; \wedge \; hasChildTS(f,c) \; \wedge \; isMaxHas\rho(f, True) \\ \wedge \; isMaxHas\chi(f, True) \rightarrow (p.o = c.o) \wedge hasSameIdentity(p,c) \tag{19}$$

More complex rules can be easily defined, for instance by assigning minimum thresholds for *hasχ* or *hasρ*. For instance:

$$\forall Filiation(f) | \ hasParentTS(f,p) \ \wedge \ hasChildTS(f,c) \ \wedge \ isMaxHas\rho(f,True) \wedge \ isMaxHas\chi(f,True) \wedge has\rho(f, \geq 0.9) \wedge has\chi(f, \geq 0.9) \rightarrow \ (p.o = c.o) \wedge hasSameIdentity(p,c) \tag{20}$$

4.4 Land Cover taxonomy and identity inheritance

The identity inheritance process can be defined by more complex rules based on other timeslice characteristics. There exist classifications for land cover that can be used to qualify a land cover change. For instance CORINE classification offers a hierarchical classification. Figure 4 depicts part of the CORINE land cover taxonomy.

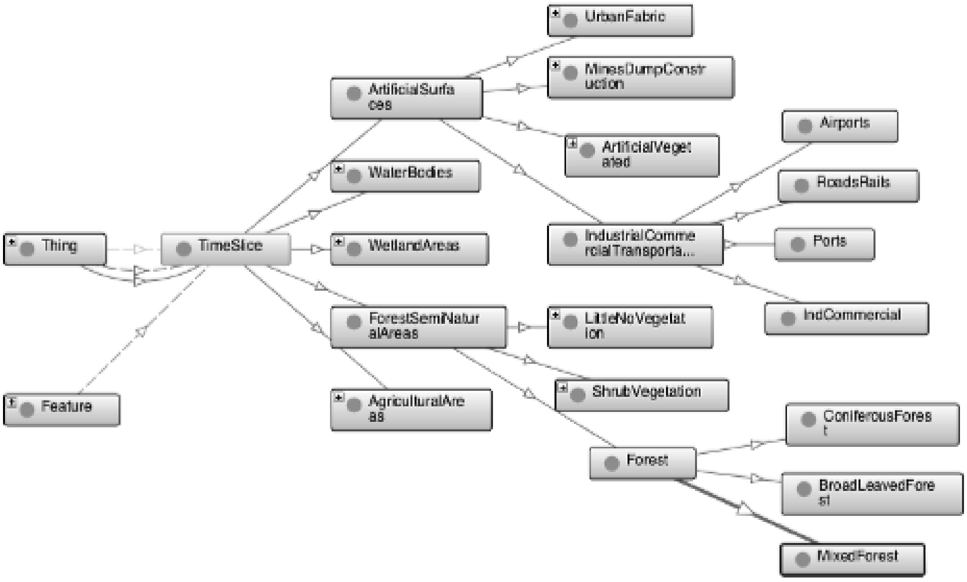

Figure 4: Partial view of the Corine Land Cover taxonomy.

$$\begin{gathered} AgriculturalAreas \sqsubseteq TS \\ ArtificialSurfaces \sqsubseteq TS \\ ForestSemiNaturalAreas \sqsubseteq TS \\ WaterBodies \sqsubseteq TS \\ WetlandAreas \sqsubseteq TS \end{gathered} \tag{21}$$

$$\begin{gathered} ArableLand \sqsubseteq AgriculturalAreas \\ HeterogeneousAgric \sqsubseteq AgriculturalAreas \\ Pastures \sqsubseteq AgriculturalAreas \\ PermanentCrops \sqsubseteq AgriculturalAreas \end{gathered} \tag{22}$$

$$
\begin{gathered}
ArtificialVegetated \sqsubseteq ArtificialSurfaces \\
IndustrialCommercialTransportation \sqsubseteq ArtificialSurfaces \\
MinesDumpConstruction \sqsubseteq ArtificialSurfaces \\
UrbanFabric \sqsubseteq ArtificialSurfaces
\end{gathered} \tag{23}
$$

Using the taxonomy, we can create more complex identity inheritance rules that take into consideration the nature of parent and child timeslices. For instance a change of landcover between a parent and a child would be less severe between *ArableLand* to *Pastures* compared to from *ArableLand* to *UrbanFabric*.

Using the model, we can define rules such as:

$$
\begin{aligned}
\forall Filiation(f) |\ & hasParentTS(f,p) \ \wedge \ hasChildTS(f,c) \ \wedge \ isMaxHas\rho(f,True) \\
& \wedge \ isMaxHas\chi(f,True) \wedge ArtificialSurfaces(p) \\
& \wedge ArtificialSurfaces(c) \rightarrow
\end{aligned} \tag{24}
$$

$$
(p.o = c.o) \wedge hasSameIdentity(p,c)
$$

In this case, we restrict the identity inheritance only to cases in which both parent and child are members of the class *ArtificialSurfaces*. The rule can also be modified to trigger an alert when there is some identity inheritance process that deserves further attention. For instance in a deforestation scenario: when the parent is of type *MixedForest*, while the child is of type *IndustrialCommercial*.

4.5 Identification of process type

Using the instances of the *Filiation* class, it is possible to identify processes involving one to one, one to many and many to one timeslices. In this section, we rewrite equations 10, 11, 12, 13, 15 and 16, in order to be able to identify different spatial processes using the values stored in the related instances of *Filiation* , without using expensive geometric functions, thus reducing spatial processing.

4.5.1 Expansion

$$
\begin{gathered}
TS(p), TS(c) \\
\begin{aligned}
\forall Filiation(f) |\ & hasParentTS(f,p) \ \wedge \ hasChildTS(f,c) \\
& \wedge hasContinuation(p,c) \wedge \ has\chi(f,<1) \wedge has\rho(f,1) \\
& \rightarrow hasExpansion(p,c)
\end{aligned}
\end{gathered} \tag{25}
$$

By using this implementation, we avoid the use of the spatial operation *Within* (See Equation 10).

4.5.2 Contraction

$$\begin{gathered} TS(p), TS(c) \\ \forall Filiation(f) |\ hasParentTS(f,p)\ \wedge\ hasChildTS(f,c) \\ \wedge\ hasContinuation(p,c) \wedge\ has\chi(f,1) \wedge has\rho(f,<1) \\ \rightarrow hasContraction(p,c) \end{gathered} \tag{26}$$

In this case, we avoid the use of the operation *Contains* (See Equation 11).

4.5.3 Separation

$$\begin{gathered} TS(p), \forall c\ \in [c_0, c_1 \dots c_n], TS(c) \\ \forall [p,c] \exists Filiation(f) |\ hasParentTS(f,p)\ \wedge\ hasChildTS(f,c) \\ if\ (\forall\ has\chi(f,1)) \wedge (sum(has\rho(f) = 1) \wedge (\exists_{=1} hasContinuation(p,c)) \\ \rightarrow hasSeparation(p, [c_0, c_1 \dots c_n]) \end{gathered} \tag{27}$$

In this case, we identify all the instances of Filiation involved in the process. We assume that children timeslices do not overlap between them. By obtaining the summation of the values of the property *hasρ,* we can determine if the combined geometry of the children corresponds to the one of the parent.

4.5.4 Annexation

$$\begin{gathered} \forall p\ \in [p_0, p_1 \dots p_n], TS(p), TS(p) \\ \forall [p,c] \exists Filiation(f) |\ hasParentTS(f,p)\ \wedge\ hasChildTS(f,c) \\ if\ (\forall\ has\rho(f,1)) \wedge (sum(has\chi(f) = 1) \wedge (\exists_{=1} hasContinuation(p,c)) \\ \rightarrow hasAnnexation([p_0, p_1 \dots p_n], c) \end{gathered} \tag{28}$$

We assume that parent timeslices involved do not overlap between them. To analyze this process, first we identify all the instances of Filiation that link the parents and the child. Then, we calculate the addition of the values of the property *hasχ.* If the result of the addition is equal to one, we can affirm that the combined geometry of all the parents corresponds to the geometry of the child.

4.5.5 Splitting

$$\begin{gathered} TS(p), \forall c\ \in [c_0, c_1 \dots c_n], TS(c) \\ \forall [p,c] \exists Filiation(f) |\ hasParentTS(f,p)\ \wedge\ hasChildTS(f,c) \\ if\ (\forall\ has\chi(f,1)) \wedge (sum(has\rho(f) = 1) \wedge (\neg \exists hasContinuation(p,c)) \\ \rightarrow hasSplitting(p, [c_0, c_1 \dots c_n]) \end{gathered} \tag{29}$$

4.5.6 Merging

$$\begin{gathered}\forall p\ \in [p_0, p_1 \dots p_n], TS(p), TS(p) \\ \forall [p, c] \exists Filiation(f) |\ hasParentTS(f, p)\ \wedge\ hasChildTS(f, c) \\ if\ (\forall\ has\rho(f, 1)) \wedge (sum(has\chi(f) = 1) \wedge (\neg \exists hasContinuation(p, c)) \\ \rightarrow hasMerging([p_0, p_1 \dots p_n], c)\end{gathered} \tag{30}$$

By using the values stored in instances of *Filiation*, we reduce the processing load. Previous research such as Del Mondo et al. (2013), uses a construction similar in nature to the class *Filiation*, however, they use spatial operators such as *Union* or *Equals* to identify the evolution processes. In our approach we reuse the results of the filiation identification process to identify relevant types of evolution. In our approach, we use basic arithmetic operators reducing in this way the computing cost.

5. Model Implementation

In order to test our model, we opted for using LULCC information from CORINE. The information was obtained as raster with a pixel resolution of 100 meters. The data corresponds to three time points being the years 1990, 2000 and 2006 (EEA 2014).

The CORINE dataset covers multiple countries. For the purposes of testing our model, we decided to use a portion of the whole dataset. In this research we use only the information contained within the boundaries of mainland Portugal.

In order to obtain objects we vectorized the original raster data using ArcGIS. The results, encoded as shapefiles were then translated into RDF triples using a custom made JAVA program using the library GeoTools (OSGF 2014). The information in triple format was then uploaded into a Stardog (Clark&Parsia 2014) triplestore.

At the moment Stardog does not offer support for GeoSPARQL (OGC 2011, ClarkParsia 2014), therefore spatial analysis has to be made with tools external to the triplestore. In our case, we have developed a tool based on JAVA/Geotools to perform all the required spatial analysis.

In our research polygons for each time point were identified and encoded as a timeslices. Then, our JAVA program, queries the triplestore and retrieves the timeslices using a spatial index. Next, it proceeds to identify the filiation relationships, taking into consideration the overlapping between timeslices of consecutive time periods. Our application also identifies the adjacency relations for timeslices that coexist in time. After the relations have been identified, they are translated into triples and uploaded into the triplestore.

After processing the datasets and uploading the information to the triplestore, we have a knowledge base of 3.9 million triples.

5.1 Derivation processes

In this section we will describe the implementation of *Derivation* processes, assuming that no identity inheritance rule has been defined in the model.

5.1.1 Splitting

In this case, we implement the Equation 29 with the following SPARQL query:

```
select * where
{
  {
  select ?p ?lc_Code ?geo (sum(?rho) as ?SumRho)
  (count(?c) as ?countC) (sum(?xhi) as ?sumXhi)
  where{
  ?f a checksem:Filiation.
  ?f checksem:hasParentTS ?p.
  ?f checksem:hasChildTS ?c.
  ?f checksem:hasRho ?rho.
  ?f checksem:hasXhi ?xhi.
  ?p checksem:hasGeometry ?geo.
  ?p checksem:hasTime checksem:Time_1990.
  ?p checksem:hasLandCoverCode ?lc_Code.
  FILTER(?xhi=1)
  }
  group by ?p ?lc_Code ?geo
  }
FILTER((?SumRho=1)&&(?countC>1))
}
```

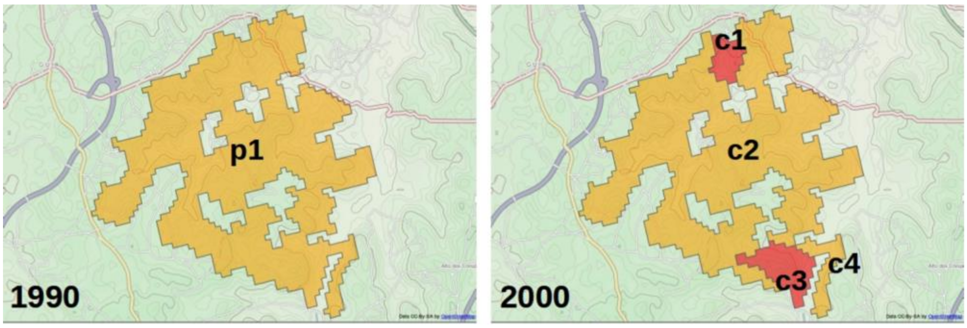

Figure 5: Example of a split process. Background map from OSM (2014).

Figure 5 depicts a split processes between the year 1990 and 2000. In this case the timeslice `ts_1990_25040` corresponding to the year 1990, splits into four timeslices: c1) `ts_2000_25938`, c2) `ts_2000_26295`, c3) `ts_2000_26324` and c4) `ts_2000_26359`, corresponding to the year 2000. In this example, the parent timeslice has land cover *Mixed Forest*, while two of her children keep the same land cover type, we can see that there are other two that change landcover to *Shrub Woodland* (See Table 1).

Table 1: Parent and Children timeslices in a Split Process

	Parent	**LandCover**
p1	ts_1990_25040	Mixed Forest
	Child	**LandCover**

	Parent	**LandCover**
c1	ts_2000_25938	Shrub Woodland
c2	ts_2000_26295	Mixed Forest
c3	ts_2000_26324	Shrub Woodland
c4	ts_2000_26359	Mixed Forest

5.1.2 Merging

A similar approach can be used to identify *Merging* processes. The following SPARQL implements the Equation 30, which detects *Merging* processes that surged in in the year 2000 (`checksem:Time_2000`).

```
select * where
{
  {
  select ?c ?lc_Code ?geo (sum(?xhi) as ?SumXhi)
  (count(?p) as ?countP) (sum(?rho) as ?sumRho)
  where{
  ?f a checksem:Filiation.
  ?f checksem:hasParentTS ?p.
  ?f checksem:hasChildTS ?c.
  ?f checksem:hasRho ?rho.
  ?f checksem:hasXhi ?xhi.
  ?c checksem:hasGeometry ?geo.
  ?c checksem:hasTime checksem:Time_2000.
  ?c checksem:hasLandCoverCode ?lc_Code.
  FILTER(?rho=1)
  }
  group by ?c ?lc_Code ?geo
  }
FILTER((?SumXhi=1)&&(?countP>1))
}
```

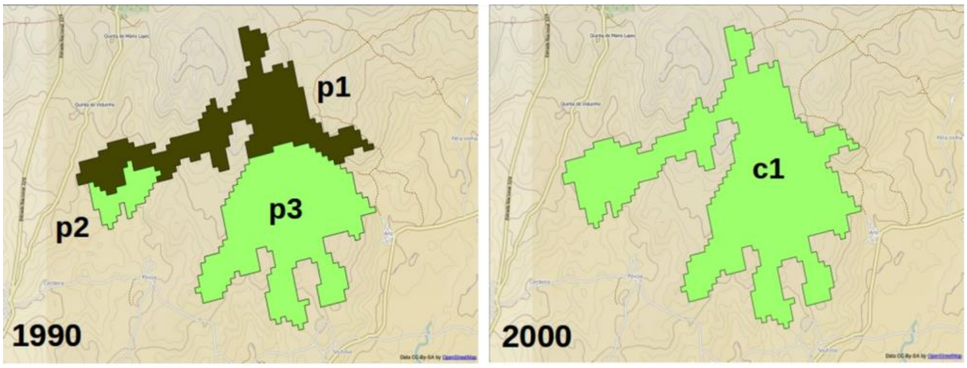

Figure 6: Example of a merge proces. Background map from OSM (2014).

Figure 6 depicts one of the identified merging processes. In this case, the timeslice `ts_2000_16622` is the result of the merge of three parent timeslices: p1) `ts_1990_15486`, p2) `ts_1990_15497`, and p3) `ts_1990_15777`. In this example, the geometry of three timeslices merge into a new one. In the example, the parent timeslices have two types of land cover type, *Burned Areas* and *Moorland*, while the child timeslice has landcover type Moorland, indicating a land cover change in the areas previously burned (See table 2).

Table 2: Parent and Child timeslices in a Merge process.

	Parent	**LandCover**
p1	ts_1990_15486	Burned Areas
p2	ts_1990_15497	Moorland
p3	ts_1990_15777	Moorland
	Child	**LandCover**
c1	ts_2000_16622	Moorland

5.2 Identity Inheritance

In our research, we do not have any *a priori* information regarding the identity inheritance. However, for the sake of the argument and in order to show the effectiveness of our approach we opted for implement some of the rules previously presented in the form of equations. The following SPARQL code implements Equation 19, which assigns the identity of a certain timeslice to a given object based on the maximum values of the properties *has*χ and *has*ρ.

```
insert
{
  ?tsC checksem:isTimeSliceOf ?o.
}
where
{
  ?o a checksem:Feature.
  ?tsP a checksem:TimeSlice.
  ?tsC a checksem:TimeSlice.
  ?tsP checksem:isTimeSliceOf ?o.
  ?f1 a checksem:Filiation.
  ?f1 checksem:hasParentTS ?tsP.
  ?f1 checksem:hasChildTS ?tsC.
  ?f1 checksem:isMaxHasChi "true"^^xsd:boolean.
  ?f1 checksem:isMaxHasRho "true"^^xsd:boolean.
}
```

5.3 Continuation processes

This kind of processes involves the preservation of the identity from a parent to a child.

5.3.1 Separation

This process is similar in nature to Splitting. However in this case one of the resulting children has the same identity as the parent.

Let us assume that we implement the rule specified in Equation 19 and in Section 4.2. Using the same example introduced in Section 4.1.1, we have a parent timeslice `ts_1990_25040` which is a temporal representation of an object identified as: `feature_1990_16174`.

After 1990, the parent timeslice is divided into four children, although only one of them keeps the identity of the parent, representing the same object. The following SPARQL code queries the knowledge base for the children of timeslice `ts_1990_25040`.The results obtained from this query can be seen in Table 3.

```
select ?f ?c ?xhi ?rho ?o
where
{
  ?f a checksem:Filiation.
  ?f checksem:hasParentTS checksem:ts_1990_25040.
  ?f checksem:hasChildTS ?c.
  ?f checksem:hasXhi ?xhi.
  ?f checksem:hasRho ?rho.
  ?c checksem:isTimeSliceOf ?o
}
```

In Table 3, the first column indicates the url of the filiation that links parent and child, the second column contains the url of the children, the third and fourth column contain the values of the properties *hasχ* and *hasρ*, finally the fifth column contains the identity of the object that the children timeslices represent. By examining the values we can see that the timeslice `ts_2000_26295` has the same identity as the parent timeslice (`feature_1990_16174`), implementing the rule specified in Equation 19.

Table 3: Identity inheritance in a Separation process.

Filiation	**Child**	***hasχ***	***hasρ***	**Identity**
`ts_1990_25040_ts_2000_25938`	`ts_2000_25938`	1.00	0.031	`feature_2000_2619`
`ts_1990_25040_ts_2000_26295`	`ts_2000_26295`	1.00	0.870	`feature_1990_16174`
`ts_1990_25040_ts_2000_26324`	`ts_2000_26324`	1.00	0.062	`feature_2000_2726`
`ts_1990_25040_ts_2000_26359`	`ts_2000_26359`	1.00	0.037	`feature_2000_2734`

5.3.2 Annexation

This process is similar in nature to Merging. However, in this case the identity of one of the parents involved is preserved in the resulting child.

Like in the previous section, we implement the rule specified in Equation 19 and in Section

4.2. When, identity inheritance rules are applied to the example provided in Section 4.1.2, we can identify one parent timeslice that shares the same identity as the child. The following SPARQL code, gives us information related to the parents of timeslice `ts_2000_16622`.

```
select ?f ?p ?xhi ?rho ?o
where
{
 ?f a checksem:Filiation.
 ?f checksem:hasChildTS checksem:ts_2000_16622.
 ?f checksem:hasParentTS ?p.
 ?f checksem:hasXhi ?xhi.
 ?f checksem:hasRho ?rho.
 ?p checksem:isTimeSliceOf ?o
}
```

Table 4, depicts the results from the previous query. In this table we can see in the first column the url of the filiation. The second column depicts the url of the parents.The third and fourth column contain the values for the properties *hasχ* and *hasρ* respectively. Finally the fifth column contains the url of the object that the parent timeslice represent. By examining the values we can see that the filiation relationship with the highest values for *hasχ* and *hasρ* is `ts_1990_15777_ts_2000_16622`, then we know that both timeslices `ts_1990_15777` and `ts_2000_16622` are temporal representations, at different points of time, of the object `feature_1990_6420`.

Table 4: Identity inheritance in an Annexation process.

Filiation	**Parent**	***hasχ***	***hasρ***	**Identity**
`ts_1990_15486_ts_2000_16622`	`ts_1990_15486`	0.393	1.00	`feature_1990_6097`
`ts_1990_15497_ts_2000_16622`	`ts_1990_15497`	0.065	1.00	`feature_1990_6109`
`ts_1990_15777_ts_2000_16622`	`ts_1990_15777`	0.542	1.00	`feature_1990_6420`

5.4 Land Cover change and identity, case example: Increase of Wild Fire risk areas

Portugal has a high incidence of forest fires compared to other European countries. In 2010, half of the fires in southern Europe were located in Portugal (Paton and Fantina 2013). Combined, forested areas and shrub land represent more than 50% of the surface of the country (Varela 2006).

Forest fires are catastrophic events not only in economic terms, but also have dire consequences for the flora and fauna of the affected areas. In the aftermath of a fire, the soil surface is prone to erosion due to the lack of vegetable coverage.

Research conducted by Paton and Fantina (2013) indicates that in the past farming areas behaved as a buffer between forests and urban areas, protecting in this form towns and cities from forest fires. However, nowadays this buffer is disappearing due to rural depopulation, population ageing and loss of economic value for agricultural activities. Currently, it is possible to see abandoned farms that turn into unmanaged shrub land or forests increasing fire risks and increasing the risk for adjacent urban areas.

A basic three level classification of fire susceptibility is proposed by Baptista and Carvalho (2002): a) Null - Agriculture riparian vegetation, land burned in the last two years, urban and irrigated agricultural areas. b) Medium - Brush land and rock outcrop. c) High - Forest land and brush with high density and fuel loads.

Using the model, we can define objects that become fire risk, as objects that in one point have a land cover that represents low or null fire risk, and in a later point evolve, having a land cover that makes them more prone to fires. We can define a SPARQL query, that identifies objects with this kind of evolution:

```
select *
where
{
  ?o a checksem:Feature.
  ?ts1990 checksem:isTimeSliceOf ?o.
  ?ts2000 checksem:isTimeSliceOf ?o.
  ?ts1990 a checksem:AgriculturalAreas.
  ?ts2000 a checksem:ForestSemiNaturalAreas.
  ?ts1990 checksem:hasTime checksem:Time_1990.
  ?ts2000 checksem:hasTime checksem:Time_2000.
}
```

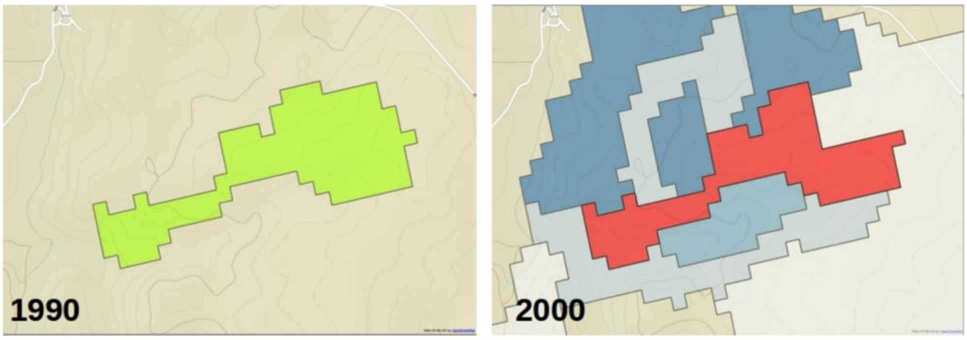

Figure 7: Example of an increase of fire risk process. Background map from OSM (2014).

Figure 7 depicts an object that evolves, increasing its fire risk. In 1990 object `feature_1990_9064` is represented by the timeslice `ts_1990_18156` with land cover *Arable land, non irrigated*. However, by the year 2000, the same object is represented by timeslice `ts_2000_19078` with land cover *Natural Grass Lands*.

In this case, to answer the query, the ontology navigates through the class taxonomy and infer new statements. Because *ArableNonIrrigated* is a subclass of *ArableLand* which itself is a subclass of *AgriculturalAreas*, then timeslice `ts_1990_18156` is also a member of class

AgriculturalAreas. For the second part of the query, we have timeslice `ts_2000_19078`, which is a member of class *NaturalGrassLands*, which is a subclass of *ShrubVegetation*, which itself is a subclass of *ForestSemiNaturalAreas*, then we can infer that timeslice `ts_2000_19078` is also a member of class *ForestSemiNaturalAreas* (See Equation 31).

$$\begin{gathered} ArableNonIrrigated \sqsubseteq ArableLand \sqsubseteq AgriculturalAreas \\ AND \\ NaturalGrassLands \sqsubseteq ShrubVegetation \sqsubseteq ForestSemiNaturalAreas \end{gathered} \tag{31}$$

The fire risk of an object might increase due to changes on their environment. For instance, if the neighbour parcels suffer some land cover change that dramatically increases their own fire risk. Our model is capable of answering queries of this type by using the adjacency information. For instance, the following query, would retrieve the objects that are located next to objects that have increased their fire risk by the year 2000.

```
select ?oNeighbour ?tsNeighbour2000
where
{
  ?o a checksem:Feature.
  ?ts1990 checksem:isTimeSliceOf ?o.
  ?ts2000 checksem:isTimeSliceOf ?o.
  ?ts1990 a checksem:AgriculturalAreas.
  ?ts2000 a checksem:ForestSemiNaturalAreas.
  ?ts1990 checksem:hasTime checksem:Time_1990.
  ?ts2000 checksem:hasTime checksem:Time_2000.
  ?oNeighbour a checksem:Feature.
  ?tsNeighbour2000 checksem:isAdjacentTo ?ts2000.
}
```

Figure 7 depicts the results of this query.

6. Discussion

The starting point of our analysis is data in raster format. We vectorize the information and create objects based on pixel similarity. This step could be improved by using ancillary information in the form of land ownership information. The addition of this layer of information would help us to distinguish between objects with similar land cover but with different management. The addition of ancillary information is no challenge from a technical point of view, however, this type of information is more difficult to obtain.

We use information from the CORINE program. Therefore we can assume that the class definitions have been homogenized across the study area. However, researchers should be aware that this might not be the case when integrating data from different sources. For instance, categories such as deciduous or coniferous or commercial forest can have different meanings in different countries.

In our research, after evaluating the LULCC, we decided to loose restrictions suggested in other studies such as Del Mondo et al. (2010). For instance, in our model we allow a child to have multiple parents. However, a child can only have one continuation relationship, while the other relations must be of type derivation.

Previous research in Del Mondo et al. (2013) suggest the use of topological operators for the identification of spatial processes (splitting, separation, anexation, merging). However, these type of operators are computationally expensive. We provide an alternative that uses low cost operators, capable to work within the operational limits of a triplestore, even without the use of GeoSPARQL. In our implementation we do not need to convert from a DB schema into a graph, because the system works natively as a graph.

7. Conclusions

The temporal dimension is not commonly used in GIS. Blaschke et al. (2014) indicates that in the field of GEOBIA, it adds a layer of complexity that is often avoided. However, using the temporal dimension in the analysis allows the identification of the evolution of entities along time. In our research we define a flexible methodology that can be used to study spatial objects evolving in time and space. We use our approach to study land cover objects. However, this approach can be used for other applications due to its flexibility.

By aggregating pixels into areas (polygons) and performing our analysis at this level, we are able to perform contextual analysis. For each entity of interest we are capable to identify its neighborhood in space and time, allowing us to better study the evolution of entities.

Our results are promising, in future work we will include additional layers on information such as land use ownership, DEMs, among others, to improve the sophistication of the analysis.

References

Al Debei, Mutaz M. 2012. “Conceptual Modelling and the Quality of Ontologies : Endurantism Vs Perdurantism.” *International Journal of Database Management Systems* 4 (3) (June): 1–19.

Armstrong, Marc P. 1988. “Temporality in Spatial Databases.” In *Proceedings GIS/LIS 88,* 880–889. San Francisco California, USA.

Artale, Alessandro, and Enrico Franconi. 1998. “A Temporal Description Logic for Reasoning About Actions and Plans.” *Journal of Artificial Intelligence Research* 9: 463–506.

Arvor, Damien, Laurent Durieux, Samuel Andrés, and Marie-Angélique Laporte. 2013. “Advances in Geographic Object-Based Image analysis with Ontologies: A Review of Main Contributions and Limitations from a Remote Sensing Perspective.” *ISPRS Journal of Photogrammetry and Remote Sensing* 82 (August): 125–137.

Aryal, Jagannath, Ahsan Morshed, and Ritaban Dutta. 2014. “Land Cover Class Extraction in GEOBIA Using Environmental Spatial Temporal Ontology.” *South Eastern European Journal of Earth Observation and Geomatics* 3 (2S): 429–434.

Baptista, Manuela, and Josefa Carvalho. 2002. “Fire Situation in Portugal.” International Forest Fire News.

Batsakis, Sotiris, and Euripides G M Petrakis. 2011. “SOWL : A Framework for Handling Spatio-Temporal Information in OWL 2 . 0.” *Lecture Notes in Computer Science6826*: 242–249.

Bittner, Thomas, Maureen Donnelly, and Barry Smith. 2009. “A Spatio-Temporal Ontology for Geographic Information Integration.” *International Journal of Geographical Information Science* (23): 765–798.

Blaschke, Thomas. 2010. “Object Based Image analysis for Remote Sensing.” *ISPRS Journal of Photogrammetry and Remote Sensing* 65 (1) (January): 2–16.

Blaschke, Thomas, Geoffrey J Hay, Maggi Kelly, Stefan Lang, Peter Hofmann, Elisabeth Addink, Raul Queiroz Feitosa, et al. 2014. “Geographic Object-Based Image analysis - Towards a New Paradigm.” *ISPRS Journal of Photogrammetry and Remote Sensing : Official Publication of the International Society for Photogrammetry and Remote Sensing (ISPRS)* 87 (100) (January): 180–191.

Chen, Jun, Hao Wu, Songnian Li, Anping Liao, Chaoying He, and Shu Peng. 2013. “Temporal Logic and Operation Relations Based Knowledge Representation for Land Cover Change Web Services.” *ISPRS Journal of Photogrammetry and Remote Sensing* 83 (September): 140–150.

Claramunt, Christophe, Marius Theriault, and Christine Parent. 1997. “A Qualitative Representation of Evolving Spatial Entities in Two-Dimensional Topological Spaces.” In *Innovations in GIS V*, 119–129.

Clark&Parsia. 2014. “Stardog Website.” www.stardog.com (accessed August 15, 2014).

Del Mondo, Geraldine, M.a. Rodríguez, Christophe Claramunt, L. Bravo, and Remy Thibaud. 2013. “Modeling Consistency of Spatio-Temporal Graphs.” *Data & Knowledge Engineering* 84 (March): 59–80.

Del Mondo, Geraldine, John G. Stell, Christophe Claramunt, and Remy Thibaud. 2010. “A Graph Model for Spatio Temporal Evolution.” *Journal of Universal Computer Science* 16 (11): 1452–1477.

EEA. 2014. “CORINE Land Cover.” *European Environment Agency Institutional Website*. http://www.eea.europa.eu/publications/COR0-landcover (accessed August 15, 2014).

Egenhofer, Max J, and Khaled K Al-taha. 1992. “Reasoning About Gradual Changes of Topological Relationships.” *Lecture Notes in Computer Science* 639: 196–219.

Gruber, Thomas R. 1995. “Toward Principles for the Design of Ontologies Used for Knowledge Sharing?” *International JOurnal of Human-Computer Studies* 43 (5-6): 907–928.

Gutierrez, Claudio, Carlos Hurtado, and Alejandro Vaisman. 2007. “Introducing Time into RDF.” *IEEE Transactions on Knowledge and Data Engineering* 19 (2) (February): 207–218.

Harbelot, Benjamin, Helbert Arenas, and Christophe Cruz. 2013a. “A Semantic Model to Query Spatial-Temporal Data.” *Lecture Notes in Geoinformation and Cartography, Information Fusion and Geographic Information Systems*: 75–89.

Harbelot, Benjamin, Helbert Arenas, and Christophe Cruz. 2013b. “Continuum : A Spatiotemporal Data Model to Represent and Qualify Filiation Relationships.” In *4th. ACM SIGSPATIAL International Workshop on GeoStreaming (IWGS)*. Orlando-USA.

Herold, H, G Meinel, R Hecht, and E Csaplovics. 2012. “A GEOBIA Approach to Map Interpretation Multitemporal Building Footprint Building Retrieval for High Resolution Monitoring of Spatial Urban Dynamics.” In *Proceedings of the 4th. GEOBIA*, 252–256. Rio de Janeiro - Brazil.

Hornsby, Kathleen, and Max J Egenhofer. 2000. “Identity-Based Change : A Foundation for Spatio-Temporal Knowledge Representation Identity-Based Change : A Foundation for Spatio-Temporal Knowledge Representation.” *International Journal of Geographical Information* 14 (1): 207–224.

Jiang, Jixiang, and Michael Worboys. 2009. “Event-Based Topology for Dynamic Planar Areal Objects.” *International Journal of Geographical Information Science* 23 (1) (January): 33–60.

Klein, Michel, and Dieter Fensel. 2001. “Ontology Versioning on the Semantic Web.” In *Proceedings of the First International Semantic Web Working Symposium SWWS’01*, 75–91.

Lambin, Eric F, B L Turner, Helmut J Geist, Samuel B Agbola, Arild Angelsen, John W Bruce, Oliver T Coomes, et al. 2001. “The Causes of Land-Use and Land-Cover Change: Moving Beyond the Myths.” *Global Environmental Change* 11 (4) (December): 261–269.

Langran, Gail, and Nicholas R Chrisman. 1988. “A Framework For Temporal Geographic Information.” *Cartographica: The International Journal for Geographic Information and Geovisualization* 25 (3) (October): 1–14.

Mahmood, Rezaul, Arturo I. Quintanar, Glen Conner, Ronnie Leeper, Scott Dobler, Roger a. Pielke, Adriana Beltran-Przekurat, et al. 2010. “Impacts of Land Use/Land Cover Change on Climate and Future Research Priorities.” *Bulletin of the American Meteorological Society* 91 (1) (January): 37–46.

Meskovic, Emir, Galic Zdravko, and Mirta Baranovic. 2011. “Managing Moving Object in Spatio-Temporal Data Streams.” In *Proceedings of the 2011 IEEE 12th. International Conference on Mobile Data Management*, 15–18. Washington, DC, USA.

Morshed, Ahsan, Jagannath Aryal, and Ritaban Dutta. 2013. “Environmental Spatio-Temporal Ontology for the Linked Open Data Cloud.” In *12th IEEE International Conference on Trust, Security and Privacy in Computing and Communications*, 1907–1912. Ieee.

Muller, Philippe. 2002. “Topological Spatio-Temporal Reasoning and Representation.”

Computational Intelligence 18 (3) (August): 420–450.

O’Connor, Martin J., and Amar K. Das. 2011. “A Method for Representing and Querying Temporal Information in OWL.” *Biomedical Engineering Systems and Technologies* 127: 97–110.

OGC. 2011. “GeoSPARQL A Geographic Query Language for RDF Data.” http://www.opengeospatial.org/standards/geosparql (accessed August 15, 2014).

OSGF. 2014. “GeoTools.” *Open Source Geospatial Foundation*. http://geotools.org (accessed August 15, 2014).

OSM. 2014. “OpenStreetMap” OpenStreetMap contributors. http://www.openstreetmap.org.

Paton, D. and T. Fantina 2013. Enhancing Forest Fires Preparedness in Portugal: Integrating Community Engagement and Risk Management. Planet@Risk 1 (1), 44–52.

Peuquet, Donna J, and Niu Duan. 1995. “An Event-Based Spatiotemporal Data Model (ESTDM) for Temporal analysis of Geographical Data.” *International Journal of Geographical Information Systems* 9 (1) (January): 7–24.

Sheeren, D, S. Ladet, O. Ribiere, B. Raynaud, M. Paegelow, and T. Houet. 2012. “Assessing Land Cover Changes in the French Pyrenees Since the 1940s : a Semi - Automatic GEOBIA Approach Using Aerial Photographs.” In *Proceedings of the AGILE 2012 International Conference on Geographic Information Science*, 1940–1942. Avignon,France.

Stell, J, Geraldine Del Mondo, Remy Thibaud, and Christophe Claramunt. 2011. “Spatio-Temporal Evolution as Bigraph Dynamics.” *Lecture Notes in Computer Science* 6899: 148–167.

Strobl, Christian. 2008. “Dimensionally Extended Nine Intersection Model (DE-9IM).” In *Encyclopedia of GIS,* edited by Shekhar Shashi and Hui Xiong, 240–245. Springer.

Varela, Maria Carolina. 2006. “The Deep Roots of the 2003 Forest Fires in Portugal.” 34. Vol. 34. International Forest Fire News.

Worboys, Michael. 1994. “A Unified Model for Spatial and Temporal Information.” *The Computer Journal* 37 (1): 26–34.