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MODELLING HETEROGENEOUS AND DISTRIBUTED SPATIAL DATASETS TO SUPPORT UPDATES MANAGEMENT

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ABSTRACT

The update of distributed geographic data still poses many problems due essentially to the data's specific characteristics (spatial constituent, topology, for example). We propose a metadata model to aid in the management of different actors located at several sites handling heterogeneous data that are regularly updated. This model is based on the ISO 19115 standard, which is the metadata standard for geographic information.

KEYWORDS: heterogeneous spatial datasets, metadata, updates, distributed systems, ISO 19115

1. INTRODUCTION

The decreasing cost for producing geographic data and the evolution of the computer technology such as network systems have considerably facilitated the collection and the distribution of geographic data necessary for users requirements. Nevertheless, the maintenance and the update of these data still remain a major problem.

Our work is interested in a general way in managing the updates of distributed geographic data. A specific domain very representative of our context is the change management during military missions. In this context, the actors are distributed across various sites and every unit collects, updates, enriches, transforms and distributes its own data according to its requirements and to its information system. In such a distributed environment, databases evolve simultaneously. To make good decisions and carry out a mission, every unit should have the same view of the area of intervention and should possess all the available data. To reach this point, it is necessary to regularly synchronize the data of every actor, while minimizing the problems of consistency.

The main question is therefore "how to best maintain the consistency of a system constituted of multiple actors distributed across different sites, handling diverse geographic datasets, which can evolve simultaneously but in different manners?" To answer this question, we propose a metadata model based on the ISO 19115 standard [ISO 19115: 2003], which specifies metadata for the description of the geographic information. Our model intends to insure the traceability of the distributed data, and to aid the management of updates by various actors. This model defines the relations between the actors, the datasets and the evolutions. It enables to track the origin of the data and their updates and determine some criteria such as the reliability (notion of trust or confidence in the source) or the quality (notion of accuracy and exactness) to make as much as possible a stable integration.

In the next section we review the main problems related to the update of geographic data, and we present some proposed solutions. We review ISO 19115 standard in section 3. Then, we present in detail our model in the section 4, by distinguishing between the existing elements of ISO 19115 and the elements we have added. We conclude with the description of our future work.

2. GEOGRAPHIC DATA AND UPDATES

The update of geographic data is a major problem. Because of the specific character of geographic data, the delivery of an update often still requires the delivery of the whole updated base to the user system. Some research works were proposed to overcome this problem. We evoke them in the last part of this section.

2.1. Heterogeneity of the data

One of the specificities of the geographic information is the heterogeneity of the data.

The first level of heterogeneity concerns the modelling of the geometrical data in information system. There are two main modes of representation: vector databases and raster databases. In vector databases, objects are represented by points, lines or polygons, while in raster databases, the space is tessellated to elementary cells.

Another heterogeneity concerns the geometrical representation used to model the vectors data. An object that represents the same thing in the real world can be modelled geometrically in a different way in the database. For example, a river can be symbolised by a line or a polygon.

One other concerns the various levels of details that can be used to represent the same geographic reality. Indeed, it is often useful to have several views of the same space, each one having more or less detail according to the requirement. For example, to plan a long haul air flight, the user needs a world map and might need a detailed map of the area of landing

The issue of geographic tessellation of the space also introduces heterogeneity. Indeed, for the same area, several databases can coexist and to obtain the desired data it is necessary to stack these data. A retiming is then necessary to ensure the correspondence of the various data.

All these differences of representation of the real world contribute to the heterogeneity of the data handled in geographic information and thus raise numerous problems during the update if we want to keep all of the databases consistent.

2.2. Specific problems in the updating process

The update of geographic data has proved to be particularly difficult because of certain aspects which must be verified throughout the process.

Some constraints should be taken into account during the updating process, so that the spatial integrity of the data is not compromised. For example, a road cannot usually cross a river without a bridge.

The consistency between different themes is also another factor to consider. The data are often distributed in themes (For example hydrography and road). It is necessary, when an update must be integrated, to know the theme to which it applies but also to know about which other themes the update must be propagated. For example, creating a road can engender incoherence in the building theme if the road crosses a house. It is thus necessary to check and to correct the effect produced by the integration of an evolution on all the concerned themes.

The difference of the representation evoked in the previous paragraph can engender some difficulties in the process of update. Indeed, an update made on an image can be propagated to a vector database (for example, in case the user handles only this type of data). It is then necessary to interpret and to transform the evolution to be able to integrate it into the user base.

The coexistence of various levels of details can also be source of inconsistency during the update process. We regularly want to propagate updates made at a certain scale to another scale, but it is difficult to find the data representing the same phenomenon at different scales. The data may not exist from a scale to the other one (for example a little village will not appear on a national map but will appear on a local map), or might have been simplified so that the representation is different (for example, on a roadmap, a traffic circle can be seen as a simple point at a local scale, and as a complex crossroads at an urban scale).

The tessellation applied to the source dataset also raises some problems during the updating of the data. Let us take the example of an image divided into several fragments, representing a whole space. An update can take place on several fragments of this image, and it is thus necessary to be able to remerge the parts concerned seamlessly. The join is important for the visibility and the consistency of the final image.

The distribution of the data on several sites also raises the problem for the updating process. Indeed, the data may evolve at the same time according to the capabilities of each system and when an update must be integrated, problems of consistency (inter-theme and spatial integrity) arise between the systems. The solution commonly used to by-pass these difficulties is often that the system most up to date sends to the other systems all of its data. However, the changes made by the local user on his own system are then lost and have to be re-done manually.

2.3. Some works in management of geographical updates

Several works have proposed solutions to the updating problems according to various points of view.

Numerous works on versioning in the domain of geographic information were begun by Jomier and his team [Cellary and Jomier 90, Jomier et al. 01]. A thesis was also written on the subject by Peerbocus [Peerbocus 01] where the author uses multi-versioned databases to automatically detect the conflicts due to updates. He uses the formal model of multi-versioned database defined by Gañçarski [Gañçarski 94, Gañçarski et al. 94] which allows the management of the various versions of entities according to the context. An application of these techniques for geographic databases was also proposed by Ding who has defined a system of incremental update for the city of New York which rely on the object-oriented models and on the mechanisms of version of databases [Ding et al.04]

For the problem of propagation between themes or at different scales, Badard suggests establishing links between the various themes of the datasets and between the data with various scales to have pre-established correspondences, which can be used during the updating process [Badard 00]. These links allow the propagation of an evolution to all the data directly concerned. Using the work of Badard and Devogele [Devogele 97], the SGME project [Raynal et al. 01] suggested propagating an evolution between military datasets having different scales by using the links of correspondence and the inter-themes links.

Others authors propose the use of multi-representation databases. These databases allow representing several views of the same space, either in various scales, or according to different points of view [Vangenot et al. 2002]. The goal is to move from one representation to another one in the easiest possible manner. Kilpeläinen suggests establishing bi-directional links between the various objects represented in such databases. The idea is that by preserving all these links, it is easier to find an object corresponding to an evolution at any level of representation [Kilpeläinen 00].

Another solution to bypass the problem due to the distribution of the databases is the use of federated databases. A federated database is a common view of several databases, which allows cooperation between these bases. It is thus necessary to create a common schema to all the databases, and some rules allowing a specific schema to interact with the federated schema. Christensen suggests in particular creating a federative geographic database allowing grouping the common features of several objects resulting from various collections [Christensen 03].

In our case, the context includes data that are very diverse and independently managed. It seems difficult to use a federated database. Indeed, every system possesses its own schema according to its own requirements, and every base can evolve in parallel, it is thus impossible to have a common schema to all the bases. It is also impossible to use a single multi-representations database inside the global system, but on the other hand, every sub-system can possess its own multi-representations base. We thus are faced with the use of multi-bases: several heterogeneous databases (or not) that can communicate together without a common view. On the other hand, we can be inspired by the work of Badard [Badard 00] to establish links between the various datasets as well as those of Jomier [Cellary and Jomier 90, Jomier et al. 01] and Gañçarski [Gañçarski 94, Gañçarski et al. 94] for the mechanisms of version applied to the geographic databases.

3. GEOGRAPHIC DATA AND METADATA: THE ISO 19115 STANDARD

A solution to manage these multiple, diverse, and distributed databases is to use metadata which supplies precise information on the data and the actors handling them.

Since 2003, ISO 19115 [ISO 19115: 2003] is the standard for metadata specific to geographic information which was established by the Technical Committee 211 of the International Organization for Standardization. This standard defines the items of metadata, supplies a schema and establishes the terminology, definitions and procedures common to all the metadata necessary for geographic information. It is divided into packages, all dependent on the mandatory package: "Metadata entity set information". The class MD_Metadata in the UML schema associated with the standard represents this package. This class describes the general metadata about the resources (e.g. area of application, date of initial creation, name and version of the standard of metadata used). All the mandatory or optional data which are present in this standard are related to this class (see figure 1). Some information that we can find is:

- Identification of the data (MD_Identification, mandatory). For example the description of the data, the spatial mode of representation used ...

- Quality of the data and the dataset (DQ_DataQuality, optional). This class is divided into two to supply on one hand, genealogy information about the producer and the process used to create the data (LI_Lineage specialized in LI_Source and LI_ProcessStep) and on the other hand, quantitative information on the quality such as the accuracy or the data consistency (DQ_Element).

- The scope and the frequency of updating (MD_MaintenanceInformation, optional). We find information on the frequency, the scope and the date of the next update there. This class also allows the user to know the period envisaged for the future updates.

- The distributor of the data and options for obtaining the resource (MD_Distribution, optional). This class describes the media of storage of the data, useful to determine if the resource is available on the network or not. It also informs about the distributor, the cost and the availability of a dataset.

- Information on the spatial, temporal and vertical extent of the dataset (EX_Extent) or the constraints associated to the data (MD_Constraint, optional) where we find the restriction on the access and the use of a resource or

a metadata (copyright, licence) as well as on the level of confidentiality of the data (confidential, top secret). But also, a description of the reference information (CI_Citation), such as the name, the reference date, the publishing date or the version of the resource.

- Finally, one package allows the extension of the standard according to the specific requirement of the user (MD_MetadataExtensionInformation, optional), in particular the name, the definition and the terms of service of the new items of metadata, is expected.

- Other information is also available but is not detailed here because they do not concern directly our problem. It is important to note that this standard allows the user to know the origin and the quality of the data according to the production process used for their initial creation. Information on the rhythm of the updates can be available, but they are essentially used to define the frequency to which the updates must be applied and not to manage evolutions that are delivered in continuous flows.

A special case of the ISO 19115 standard is the file format of metadata METAFOR. It is an implementation in XML of a profile of the standard ISO 19115:2003 and standards associated for metadata requirements of the French Defence. According to their requirements, the defined profile increases and restricts the ISO standard. It does not deal with vector data and no information about the evolutions is currently taken into account.

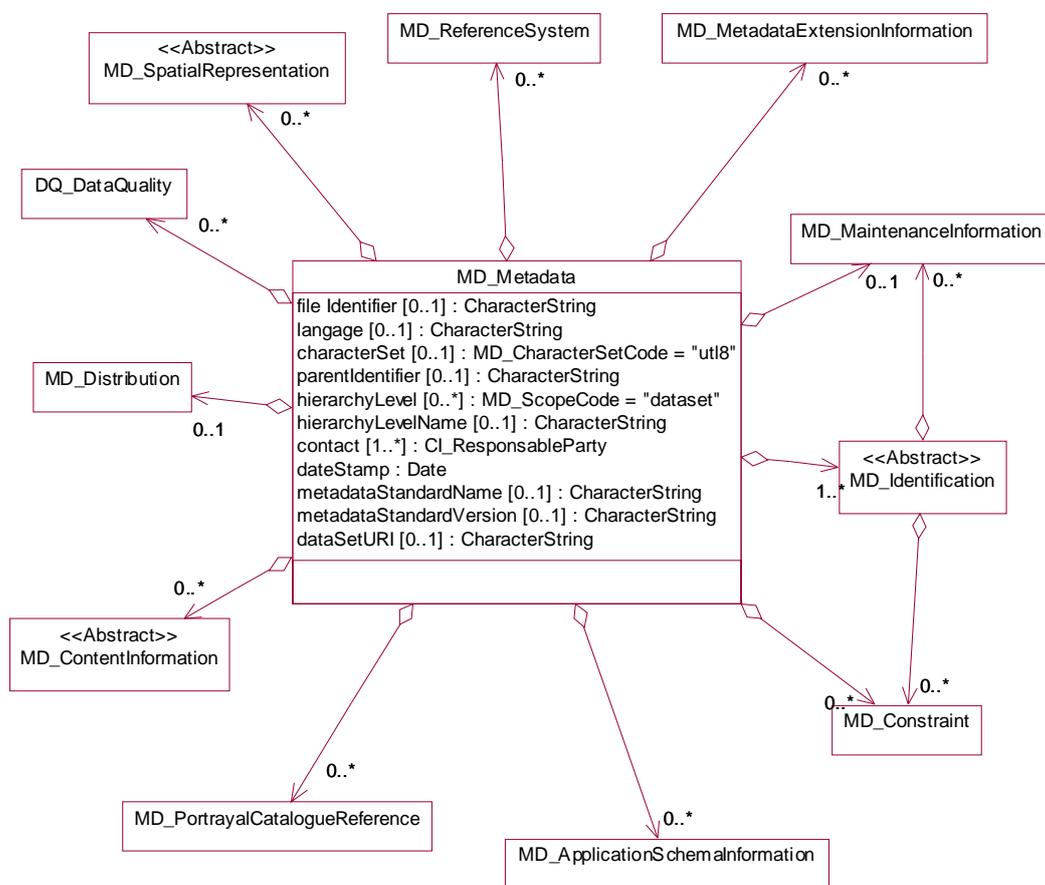


Figure 1: Main aspects of metadata in ISO 19115

4. A MODEL « DATA, ACTORS, EVOLUTIONS »

Several actors handle datasets of various types, with various dates, of various qualities, having various logic models, various specifications, various levels of details, various storage formats, and various storage sites... These actors have to cooperate with others. In particular, they have to exchange and synchronize their data, without putting their own system or the global system in danger (loss of information, incoherence)

The data can be collected, updated, enriched, transformed and redistributed according to user requirements. Every actor possesses his own datasets (that can be possibly modified compared to the other datasets), which evolve at the same

time than the others datasets, and to obtain a coherent and machine-processable result, it is often necessary to validate interactively the update.

To best maintain the consistency of a system containing diverse and distributed data which evolve in parallel, we have to find easily certain information concerning the datasets and others concerning their evolutions. It is necessary to know for example the source of the datasets and the updates (who sends them), their quality (how they were acquired or seized), to which area they apply (where), what they represent (what), the date in which they were created or modified (when)...

We thus suggest defining a model of metadata to manage not only the datasets, but also the updates and the actors. This model has to allow storing a maximum of information to guide the integration of the evolutions. It also has to answer certain questions concerning the datasets (version, date, area of coverage, size), the actors (means of collect, the role), the evolutions (storage format, quality, date of collect) and finally on the relations between the datasets, the updates and the actors (as the author of the dataset, the type of update applied to a specific dataset)

This model being a model of metadata, we propose that it rely on the ISO 19115 standard. Some information in the ISO model are used in our model, but others (notably with respect to evolution) have been added to answer the questions put by the problem. We present the model in four parts: an overview of the relations between the actors, the datasets and the evolutions, then the detail of each of these three entities. In the schemas shown in the figures, we distinguish the existing metadata from what we added with a different texture. A background of marbles for the classes that did not change with regard to the ISO standard, the white background for those that were added or modified.

4.1 General structure

The datasets, actors and evolutions have strictly defined relationships (see image 2). A dataset belongs at least to an actor and can derive from another dataset (boundary of area, schema's change, change of scale). An actor possesses at least a dataset that can be acquired in various ways (outer suppliers, direct digitalisation or specific processing on existing datasets at the other actors). He can also produce or receive evolutions. By "to produce" we mean the fact that it is the actor himself who creates the evolutions, by "to receive", the fact that the evolutions result from another actor (collection of new data for example). The actors can thus exchange the information each other, according to certain criteria, which we will define more exactly in the modelling of the actors. In this general model, we consider the evolutions as a whole containing several elementary evolutions that are collected for a specific dataset. The evolutions thus apply at least to a dataset. The evolutions belong at least to one actor, the actor who produced them.

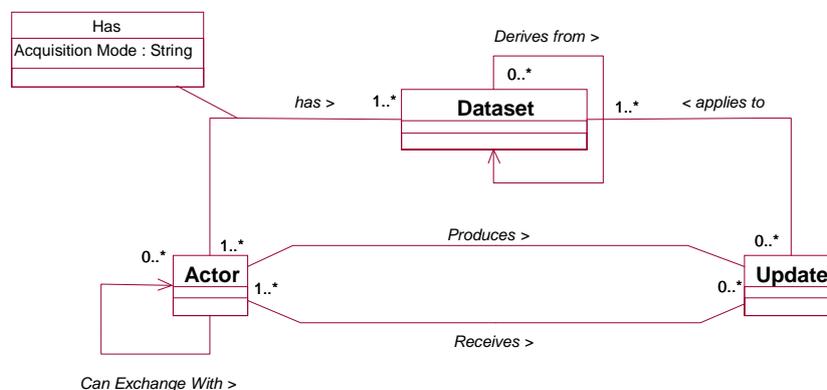


Figure 2: Model of the interactions between the actors, the datasets and the evolutions.

4.2 Modelling of actors

The actors are not modelled in the ISO 19115 standard. We thus propose a model that allows the management on one hand of the exchanges occurring in a distributed context and on the other hand the possible interactions between the various actors.

As it is defined in [Delavar, Rajabifard and Rezayan 2003], “an infrastructure is a kind of organisation, which is the main basis for other organizing activity developments”. In [GSDI cookbook, 2004] “the word infrastructure is used to promote the concept of a reliable, supporting environment, analogous to a road or telecommunications network, that, in this case, facilitates the access to geographically-related information using a minimum set of standard practices, protocols, and specifications”.

In this model, we consider a global infrastructure as an organisation which manage and update geographical data. This global infrastructure is divided into local infrastructures, which are distributed between different sites. We also

introduce two types of actors: the internal actors which belongs to the local infrastructure and the external ones. The reason why we differentiate the actors being a part of the infrastructure from those external is that the latter ones cannot receive data but only give some. For example, in the military context, we could consider that an organisation set up to execute a particular mission is a global infrastructure. The headquarters units in France and those deployed on the battlefield are the local infrastructures. The staffs using the data corresponds to the internal actors and the external actors are the allied country already in place and possessing data which they agree to supply to the French army.

According to their role, the internal actors can exchange the data and the updates more or less easily. The mode of transmission must be also provided so that the actors can know how to acquire the data. These indications allow us to know who can send their updates or data and how they can receive them. For example, an actor being a simple user can only receive data and updates and will have no right to deliver some to the other actors. If this actor has a low volume data link, he would also be informed of the expected long time for downloading any voluminous file.

So that efficient data exchanges take place, we model certain information, notably the confidence which we can grant to an actor who provides data or updates. Indeed, the reliability is an important criterion that allows the user to define the interest to acquire or not the data and the available evolutions. But the confidence can also serve to forecast the way in which the integration of the data or the evolutions will be made according to the degree of confidence granted to the supplier.

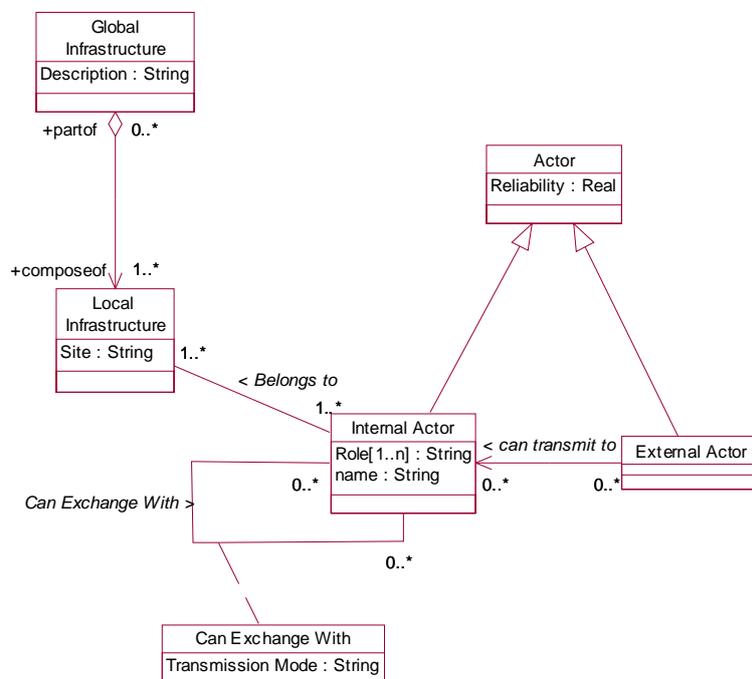


Figure 3: Modelling of actors

4.3 Modelling of datasets

The datasets are defined in the ISO 19115 standard and in METAFOR through the notion of “DS_Dataset”. Nevertheless, in our specific context, certain necessary information are not foreseen, and so we introduce them.

The datasets handled in geographic information are from two types: vectors and rasters. They are represented by the classes MD_GridSpatialRepresentation and MD_VectorSpatialRepresentation in the ISO 19115 standard and are thus present in our model (see figure 3).

The quality of the datasets is important information; it is strictly connected to the acquisition period of the data (period of crisis, reconnaissance mission), as well as in the acquisition mode (take directly on the terrain or by satellite images). These data are available by means of the existing class DQ_DataQuality in the ISO 19115.

Genealogy information is also essential to know the source of the datasets and their history since their initial creation. Let us suppose that we possess an evolution resulting from a dataset that is older than the one into which we want to integrate it. It is then necessary to find the version corresponding to the evolution as well as the modifications made on

the dataset since this version to integrate correctly this evolution. Such metadata exists in ISO 19115 and are available in LI_Lineage, who is a class aggregated into the class DQ_DataQuality.

One of the missing elements of the standard when we want to handle datasets updated regularly by different actors and distributed on the network is the notion of version. There is nevertheless an attribute in the class CI_Citation allowing informing about the version of a resource, but no link is established between the various versions of the datasets. We thus have to define a version mechanism to connect the datasets all together.

The attribute "Current Date" serves for knowing if our dataset is up to date or not. By comparing this attribute in several dataset, it is possible to know if one is more up to date than the others and also if more recent updates are available from one other actor's. Two attributes "date" exist in the class CI_Citation of the ISO 19115: the first one gives the date of reference of the resource and the second the date of publication (a date of the version).

The attribute "State" allows knowing quickly if a dataset was transformed since its acquisition. This attribute does not exist and must be added to the standard.

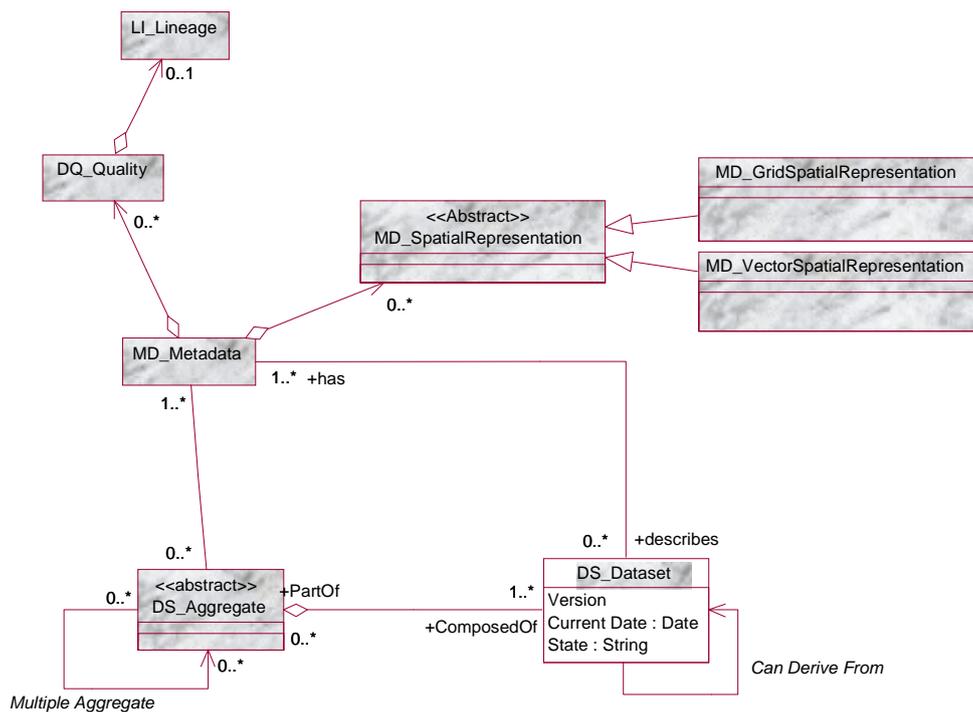


Figure 4: Modelling of datasets

4.4 Modelling of evolutions

The evolutions are not modelled as such in the ISO 19115. We thus define a model to manage, use and distribute the updates (see figure 5).

A set of evolutions is defined by a geographical zone, an interchange unit and by a list of elementary updates done on a particular dataset. To facilitate the integration of the evolutions, we must add some information about the set of evolution but also about each evolution. It is done thanks to metadata. This proposed model uses certain existing classes in the ISO 19115, notably to define the quality of the data.

T.Badard and D.Richard [Badard 00, Badard and Richard 01] defined the differential sets and the sets of evolutions to model all the evolutions:

- The differential sets supply the update by identifying the objects which evolved thanks to an identification number. It manages only old and new objects and an update is made only by a succession of initial creation and destruction. If the evolutions are modelled in differential sets, an attribute "DataSource" must be then filled in for every elementary evolution, allowing knowing the object in its ancient state and the object in its new state. The type of the elementary evolution will be in that case only creation or destruction.

- In the sets of evolution, objects are a direct interpretation of the updates. It means that it depends on the way the updates were made and on the nature of the evolution: it can be a creation, a destruction, a geometrical modification

or a semantic modification in the case of the vectors data or the substitution of a part of an image by another one more recent in the case of the raster data.

These two modes of representation allow the definition of delivery formats adapted to the transfer of the evolutions. The interchange units of these modes of delivery are strictly connected to the handled data; it can be in XML or GML (Geographic Markup Language) [OpenGIS Consortium 99] for the vector data or another special format for the raster data (JPEG2000 or GeoTiff).

The evolutions can be transformed to be integrated into a dataset having different features that served as support for the collection of the update (various schema, various scale). To insure a follow-up of the updates, we suggest using the version mechanism as it was already proposed for the datasets. This addition allows us to know exactly the history of the updates, their initial creation until their integration in the various systems (with or without transformation). We thus have a record of the changes that the evolutions underwent since their initial creation.

The quality must be supplied for a specific evolution but also on all the evolutions, notably to know in which conditions the updates took place. This quality must be able to give information about the acquisition type of the evolutions (for example, an acquisition or a delivery).

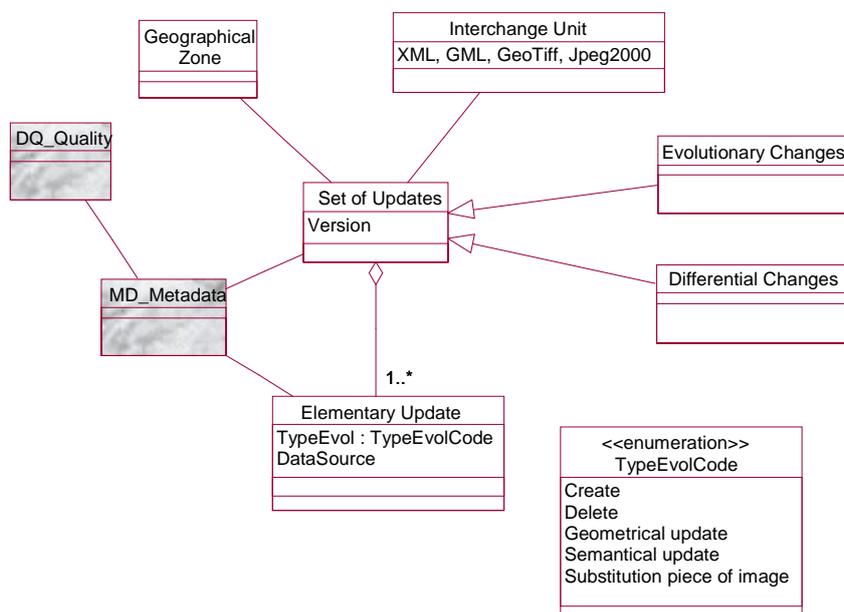


Figure 5: Modelling of evolutions

5. CONCLUSIONS AND FUTURE WORK

We presented a model of metadata allowing the management of datasets and their evolutions, handled by several actors distributed between different sites. This model is based on the standard ISO 19115, which currently guarantees a certain level of interoperability, thus facilitating the model's implementation in other contexts. It allows the actors to easily access to the origin and the quality of the datasets and the evolutions. This knowledge is essential to integrate effectively the data into a geographic information system. It also allows the connection of the datasets with the updates and vice versa to have an overview of the evolutions in the global infrastructure.

Our future work will concern the refinement of this model by using research in cooperative engineering to best model the interactions between all the actors and on the work in spatial data infrastructure to best manage the geographic data transfers and their evolutions. We shall also look at the research on the cooperation and the synchronization between agents [Reed 98] [Seguran 04].

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