ON THE AUTOMATIC RETRIEVAL OF UPDATES IN GEOGRAPHIC DATABASES BASED ON GEOGRAPHIC DATA MATCHING TOOLS

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Abstract

The integration in geographic databases of the updates delivered by a producer of reference data sets is still problematic. One of the main reasons is that the detection of updates in the new version of the database may be impossible to process. The purpose of this paper is to provide a generic tool for the automatic retrieval of the updates in geographic databases in order to make their integration easier. This mechanism is based on geographic data matching tools. Thus the implementation of systems of identifiers or time management is not necessary in the databases. The use of this process in the definition of new delivery modes of updates for geographic databases is also discussed.

1. INTRODUCTION

Nowadays, Geographic Information Systems (GIS) are considered to be truly analysis and decision-making tools. For that reason, a growing number of organizations invest in such systems and add specific information necessary to the tasks that they have the responsibility for. However, the implementation of such systems is difficult and relatively expensive. That is why these institutions purchase reference data sets from geographic information producers. From these they are able to develop their own information systems. Thus, these organizations are considered, by the producer, as users of reference geographic data sets.

To carry out their assignments, these institutions clearly need updates from the producer, in order to have the most faithful and realistic image of the geographic space reality. However, at the present time, the integration of these updates is still problematic. Indeed, few different delivery modes of the updates are available for geographic databases. Thus the whole up-to-date database is often delivered even if only 10% of the objects stored in the database have changed (this is a common estimation of the rate of evolution per year for geographic databases [Raynal, 1996]). This implies that users have to integrate the whole new version of the database in their information systems, which may induce significant risks of information loss or leave the database in an inconsistent state. Otherwise, they have to retrieve the updates by themselves. This task may fail if a reliable and stable system of identifiers is not implemented in the reference database.

The purpose of this paper is to provide a generic tool for the automatic retrieval of the updates in geographic databases in order to make their integration easier. This mechanism is based on geographic data matching tools implemented at the COGIT laboratory of IGN (the French national mapping agency). They allow the detection of the geographical entities that represent the same phenomenon in two representations of the real world. This process of detection of the updates is also a component of a wider investigation, which aims at developing a generic updating tool for multi-scale databases. Thus, the details of this mechanism are presented and illustrated by the results of a first experimentation made with the road network of the BDCARTO® (a 1:100 000 geographic database produced by the IGN which covers the French territory). The use of this process in the definition of a new delivery mode of the updates for the geographic databases is also discussed.

2. THE GEOGRAPHIC DATA MATCHING

Geographic data matching is akin to the notion of conflation defined [Saalfeld, 1988; Laurini and Thompson, 1992]. It consists in the computation of correspondence relationships between sets of geographical entities that represent the same phenomenon in two representations of the real world [Lupien and Moreland, 1987; Lemarié and Raynal, 1996; Lemarié and Bucaille, 1998]. The two representations may have very different scales, levels of abstraction and/or representations. Such a mechanism has been developed at the COGIT laboratory of IGN (the French national mapping agency) for several years. It relies on the implementation of numerous algorithms involving all geographical information levels (i.e. semantic, geometrical and topologic). It can be detailed as below (see Figure 1).

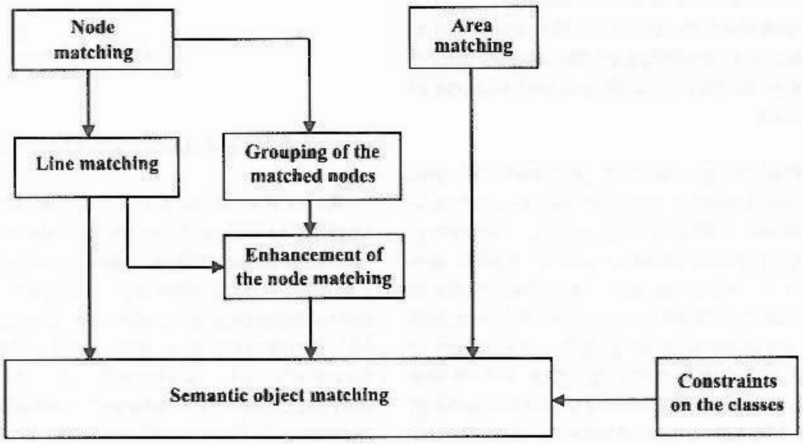


Figure 1. General structure of the geographic data matching mechanism

So, the data matching mechanism adopts a bottom-up behaviour. Data matching is first performed on the geometrical primitives. Correspondence relationships between simple objects are then deduced. Complex objects (i.e. composed of simple objects and/or of complex objects) are finally reconstructed, because they depend on the matching of the simple objects. The geometry of complex objects is indeed the union of the features describing the simple objects.

This process is mostly automatic: only the enhancement step for node matching involves an interaction with a user. This interaction is however assisted by the automated detection of conflicting correspondences. The different steps of the geographic data matching process are detailed in the next sections.

2.1. Data matching of the geometrical features

This part of the data matching process is generic and independent of the databases' schemas. It can be divided in three main steps depending on which kind of geometrical primitive is processed: points, lines or areas. Methods involved in this step are purely geometrical and topologic. Semantic information is never used. The data matching of areas is totally independent of the others. But there are interactions between the data matching steps for points and lines.

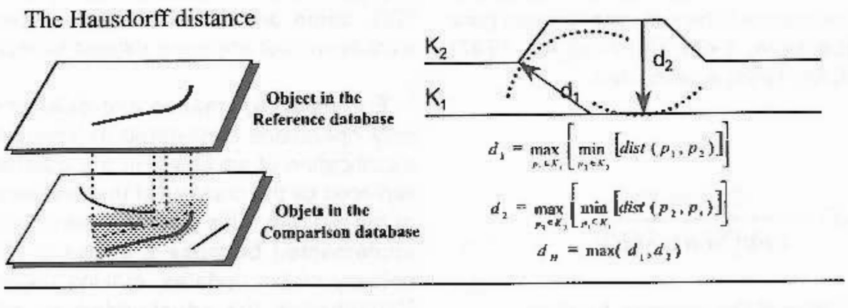
2.1.1. The node matching step

A reference database is first chosen (the other is named the comparison database) in order to define how the process will compute the correspondence relationships (i.e. from the reference database to the comparison one). A search area for each node of the reference database is then defined by means of a Euclidean distance threshold. The value of this threshold is generally based on the knowledge of the scales and of the root mean square error on the positions of the features stored in the databases. For each node of the reference database, all the nodes of the comparison database included in the tolerance area are searched.

In order to reduce the number of matching candidates, geometrical and topologic tests are processed. For instance, a test of geometrical equality is performed and the number of arcs connected to the nodes is checked. When node matching is finished, lines are processed. This step is detailed in the next section.

2.1.2. The line matching step

This step of the data matching process involves specific algorithms inspired from those described [Abbas, 1994] and especially based on the Hausdorff distance (see Figure 2). This is a distance which accounts for differences not only between the positions but also between the shapes of the geometrical features.



$$d_1 = \max_{p_1 \in K_1} \left[\min_{p_2 \in K_2} \left[dist(p_1, p_2) \right] \right]$$

$$d_2 = \max_{p_2 \in K_2} \left[\min_{p_1 \in K_1} \left[dist(p_2, p_1) \right] \right]$$

$$d_H = \max(d_1, d_2)$$

Figure 2. Definition of the Hausdorff distance

Since the reference database is already defined, only one component of the Hausdorff distance is computed. For each line of the reference database, all lines of the comparison database included in the tolerance area (see Figure 2) are considered as matching candidates. As before, the definition of a threshold is necessary. This threshold is here expressed in terms of Haussdorff distance and defined by the knowledge of the scales and of the root mean square error on the positions and shapes of the geometrical features.

As in the node matching, various geometrical and topologic tests are performed in order to retrieve consistent correspondences between objects. Notably, relationships previously processed between nodes are involved in this step. For instance, each matched node is scanned and angles between all the connected arcs are checked. Moreover, an algorithm of graph exploration is implemented in order to retrieve missing links. When line matching is completed, an enhancement and checking step is triggered on the correspondence relationships. Details are presented in the next section.

2.1.3. Enhancement and checking step of the correspondence relationships

To provide n-to-m relationships (i.e. n objects of the reference database are corresponding to m objects of the comparison database), 1-to-1, 1-to-n, and n-to-1 correspondences between nodes are first grouped. This grouping allows the detection of crossroads which have been simplified or detailed from database to the other.

As described [Gabay and Doytsher, 1994], the correspondence relationships established between lines are then scanned in order to enhance the node matching by grouping the intermediary vertices (points that are missed by the node matching process) with the sets of matched lines. This allows the detection of mismatched features which could have been produced during the node matching step. Simplified or detailed crossroads are finally processed by adding the linear primitives to the corresponding sets of nodes. At the end of this enhancement and checking step, node and line correspondences are consistent. Area matching can be now performed. This step of the data matching process is detailed in the next section.

2.1.4. The area matching step

This step of the data matching process is totally independent. It includes algorithms based on the computation of surface intersections to account for the full "surfaceness" of the geographical entities. Methods based on boundaries only have indeed the drawback to be much too sensitive to shape differences, which entails that numerous valid correspondence relationships are not established. In order to filter the data sets and find all the polygons which can be matched, the inclusion function (see Figure 3) defined [Lemarié, 1996; Bel Hadj Ali, 1997; Vauglin and Bel Hadj Ali, 1998] is computed.

$$I(A,B) = \frac{S(A \cap B)}{\min[S(A), S(B)]}$$

Figure 3. Definition of the inclusion function

To complement the inclusion function, a surface distance is also calculated. This distance presented [Lemarié, 1996; Bel Hadj Ali, 1997; Vauglin and Bel Hadj Ali, 1998] is defined below (see Figure 4):

$$d(A,B) = 1 - \frac{S(A \cap B)}{S(A \cup B)}$$

Figure 4. Definition of the surface distance

As in the node and line matching steps, this process implies to define tolerance thresholds in respect with the scales and the different quality indicators of both data sets. Finally, in order to retrieve the actual n-to-m correspondences between areas, all correspondence relationships are grouped. Data matching of the geometrical features is now achieved. The correspondences between semantic objects have to be processed. Details of this step are presented in the next section.

2.2. Data matching of the simple and complex objects

This step is relatively simple. If the geometrical primitives of two simple objects have been matched, objects are matched. To avoid inconsistent object matching, constraints on schemas' classes are necessary. For instance, without such a system of class constraints, close roads and rivers could be matched. This mechanism allows also the management of the differences in databases' schemas, which may occur if data sets present different content specifications or levels of abstraction. As before, correspondences between complex objects are deduced from simple objects. If the components of two complex objects have been matched, complex objects are matched. This ends the data matching process, retrieval of updates can now be triggered.

3. TOWARDS THE EXTRACTION OF UPDATES

Classifying updates implies to first define the semantics of the spatio-temporal evolutions undergone by the geographical entities. This is the subject of the present section.

3.1. About semantics and logic of the spatio-temporal evolutions

Several typologies of the spatio-temporal evolutions have already been established in the literature. Some approaches are closest to the implementation of time in GIS, some are closest to the modelling of real world evolutions, but are more difficult to implement.

For instance, creation and deletion of entities are the only operations considered in [Poupart-Lavoie, 1997]. A modification of an object in the database can always be replaced by the creation of the new entity and the deletion of the old one. This voluntary minimal typology has been implemented because it allows a simple and efficient delivery of the updates, making their integration easier. Nevertheless, the actual underlying nature of the spatio-temporal evolutions is lost.

Another interesting approach is described in [Cheylan et al., 1994]. Four main types of spatial entities are defined: fixed spatial entity with time-varying attribute, modifiable spatial entity (i.e. an entity with a fixed boundary but composed of a set of entities with time-varying shape and attribute), distorted spatial entity (i.e. an entity composed of a set of entities with time-varying attribute, shape and area) and transformed spatial entity (i.e. the position and the shape of such an entity are varying with time). This typology aims at identifying the spatial evolutions and attributes' modifications undergone by a set of geographical entities. Close to real world evolutions, the implementation of this typology in a process of update extraction seems to be difficult.

A rich and easier to be implemented typology has been proposed in [Claramunt et al., 1994]. It is composed of sets of basic processes, transformation processes and movements. Basic processes are apparition, disappearance and stability. Transformation processes are expansion, contraction, distortion. Movements are displacement and rotation. This typology provides a relevant description of the evolutions undergone by a single geographical entity. Nevertheless, this typology is too restricted to represent some modifications of particular geographical objects or groups of objects, taken as a whole. For instance, only the succession of an apparition and a disappearance could allow the description of the modification of a crossroads in a roundabout. Besides, how to represent merging, splitting or aggregation of geographical entities with it ? Moreover, attribute modifications are not taken into account.

We propose thus to extend the typology presented in [Claramunt et al., 1994], in order to better take into account all the missing modifications. The formulation of the different types of evolution is voluntarily closer to the changes encountered in geographic databases. It aims at providing users with a detailed information on the nature of the changes in order to make their integration in geographic information systems easier. This new typology can be decomposed in eight main types:

- Creation (identical to apparition).
- Deletion (identical to disappearance).
- Splitting.
- Merging.
- Aggregation.
- Geometrical modification (it includes distortion and displacement).
- Semantic modification.
- Stability.

This typology allows thus the description of the evolutions undergone by one or a set of spatial entities. Besides, attribute modifications and all kinds of geographical objects are taken into account. The implementation of this typology in a process of update extraction between two versions of a same geographic database is detailed in the next section.

3.2. The process of update extraction

In order to extract updates and to classify all modifications in the different types previously defined, it is necessary to analyse the correspondence relationships computed during the data matching step. This analysis deals with the cardinalities of the relationships established between reference and comparison databases. In the following part of this section, we assume that the reference dataset is the up-to-date version of the database and the comparison one is the old version. The purely geometrical modifications are first processed and the semantic differences are then detected in order to extract all objects that have semantically and/or geometrically changed. This analysis which is at the core of the mechanism of update extraction proceeds as detailed below:

- Unmatched objects of the reference dataset are considered as the newly created geographical entities.
- Unmatched objects of the comparison database are considered as the deleted objects.
- Objects referenced in a 1-to-n relationship (with n>1) denote a merging operation.
- Objects referenced in a n-to-1 relationship (with n>1) are involved in a splitting operation.
- Objects involved in a n-to-m relationship (with n>1 and m>1) have undergone an aggregation operation.
- Objects involved in a 1-to-1 relationship are more precisely analysed. A test of geometrical equality is first performed. If the objects have a different geometry, a geometrical modification is detected. If they have undergone a geometrical modification or not, their attributes are then checked in order to find semantic differences. If at least one of their attributes differs (different value for a common attribute, different attributes found, ...), a semantic modification is detected. So, it is only in this step that the semantic level of the geographic information stored in the databases is used.
- All remaining objects are considered as unchanged (i.e. stable).

So, this process of update extraction allows not only the retrieval of simple modifications (as creation or deletion) but also the detection of complex updates (as both semantic and geometrical changes). Objects involved in a merging, splitting or aggregation operation are not semantically analysed (i.e. their attributes are not checked). It is not necessary because such modifications are generally due to changes in the capture and/or content specifications of the database. The update is nevertheless detected and the new values of the attributes are delivered with the up-to-date version of the database.

Due to the different thresholds used during the data matching process, the actual nature of an update may not be detected. For instance, an object may be left unmatched because the threshold value was too tight. This results in the detection of a creation or a deletion, even though it is a geometrical modification that should be retrieved. A similar problem may occur with the merging, splitting or aggregation operations on the elements of a network (road, rivers, ...). For instance, due to the tolerance allowed in terms of position and shape by the Hausdorff distance (see Figure 2), two different objects may be considered as merged with another one even if they do not share the same supporting primitives. So, the choice of the different thresholds involved during the data matching process is important and has to be made judiciously if the actual nature of the updates wants to be retrieve. Several experiments carried out at the COGIT laboratory of the IGN seems to prove that the different thresholds have to be set close to the value of the root mean square error on the positions and shapes of the objects stored in the databases. The automatic valuation of these different thresholds is presently a part of a PhD research engaged in this laboratory in order to make the data matching process fully adaptive.

Nevertheless, this process of update extraction based on topologic and geometrical data matching tools is complete: all the changes are detected, only the nature of the extracted updates may not be right. It is fully automatic and dispenses with the implementation of a reliable and stable system of identifiers or time management in the databases. Contrary to [Uitermark et al., 1998] in which only the changes on the buildings may be detected, all kinds of geographical entities stored in the databases may be processed. This mechanism can thus be considered as generic.

Moreover, the updating information provided by this process is detailed and close to the modifications performed in the geographic databases. It allows users to automatically retrieve all the updates in the whole up-to-date version of a database delivered by a producer. The integration of theses updates in their information systems is then easier: they are able to choose the relevant updates and to control their effects especially on their own added information. Users are thus not compelled to integrate the whole new version of the database in their information systems, which may induce significant risks of information loss or leave the database in an inconsistent state.

This last point addresses the problem of the delivery of updating information for geographic databases. Indeed, few different delivery modes are now available. Only the whole up-to-date database is mainly delivered to users. The definition of a new mode dedicated to the delivery of updates is presented in the next section.

4. TOWARDS A NEW DELIVERY MODE OF UPDATING INFORMATION FOR GEOGRAPHIC DATABASES

If few different delivery modes are now available and used, it is mainly due to the specificity of geographic information. Indeed, if for "classical" databases, it is relatively easy to represent the changes in the value of an attribute, it is more difficult to describe the evolutions of the geometrical information stored in the geographic databases. Nevertheless, the notions of state versioning and logs could be easily adapted to the geographic information domain in order to define a new delivery mode of updates.

In state versioning, changes are delivered as couples of objects (new/old) or simply as couples of new objects/ references on old objects, if such a reliable system of identifiers is implemented. With logs, no objects are delivered but only the description of the evolutions that objects referenced by their identifiers (which assumes the existence of such a stable and reliable system) have undergone.

The information structuring provided by the previously presented process of update retrieval seems to be close to the one involved with state versioning and logs. As updates are extracted from the correspondence relationships, updated objects or groups of objects are known and the "temporal succession" relationships are established between the different versions. Moreover, the type of the update is known. A detailed and minimal delivery mode of the updating information could thus be to deliver the geometry of the new and old versions of the updated objects and to specify the nature of the evolutions in a log. This is what we have named "updating deltas".

In order to illustrate this delivery mode, results provided by the process of update extraction on the road network of the BDCARTO® (a 1:100 000 geographic database produced by the IGN which covers the French territory) are now presented.

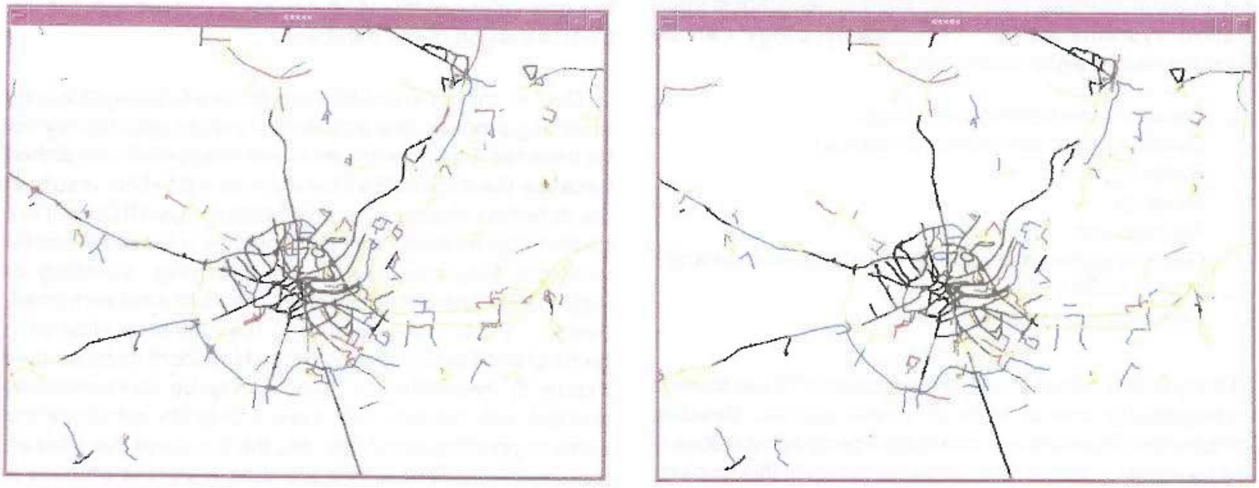


Figure 5. Sample of the "updating deltas" processed with the road network of the BDCARTO® (City of Caen, Calvados)

The first figure (see Figure 5, left) is a geometrical representation of the up-to-date objects (i.e. included in the up-to-date version of the BDCARTO®). We have named it "delta +1". The different colours on the figure indicate the nature of the evolutions. Objects stemming from a creation, merging, splitting, aggregation, semantic and/or geometrical modification operations are thus represented.

The second figure (see Figure 5, right) is a geometrical representation of the objects that have undergone an evolution (i.e. objects which have been updated and are included in the old version of the BDCARTO®). We have named it "delta -1". As before, the different colours deal with the nature of the evolutions. Objects that have been deleted, merged, split, aggregated, semantically and/or geometrically modified are represented.

The nature of the evolutions and the detail of the semantic modifications are provided in a log (see Figure 6). This update log uses the system of identifiers implemented in the BDCARTO®. Nevertheless, when such a system is not implemented, it is easy to deduce another structure for the delivery of the same information. For instance, for each evolution, it would be possible to deliver the geometry of the new and old objects, the type of updates, and eventually a list of the modified attributes with their old and new values. A temporary system of references, which allows the identification of the objects within the data exchange only, could be another solution.

Update log: BDCARTO® v1 -> BDCARTO® v2

Creation:
NEUD_ROU -> BDC_ID: 991584043
TRON_ROU -> BDC_ID: 992300803
TRON_BAC -> BDC_ID: 269
LIAISON -> BDC_ID: 153
CARR_CX -> BDC_ID: 1375
ROUTE -> BDC_ID: 39095
...
Deletion:
NEUD_ROU -> BDC_ID: 140005977
TRON_ROU -> BDC_ID: 991363378
ROUTE -> BDC_ID: 24254
...
Merging:
TRON_ROU : 140004577 TRON_ROU : 140004577 -> TRON_ROU : 140004577
TRON_ROU : 990157858 TRON_ROU : 140006846 -> TRON_ROU : 992260352
...
Splitting:
TRON_ROU : 140004259 -> TRON_ROU : 992260418 TRON_ROU : 992260417
TRON_ROU : 140002569 -> TRON_ROU : 992301214 TRON_ROU : 992300918
TRON_ROU : 991744402 -> TRON_ROU : 992300352 TRON_ROU : 992300349 TRON_ROU : 992300351
...
Aggregation:
TRON_ROU : 140003594 TRON_ROU : 990746918 -> TRON_ROU : 992300653 TRON_ROU : 992301195
TRON_ROU : 991520666 TRON_ROU : 991520657 -> TRON_ROU : 992301382 TRON_ROU : 992301381
TRON_ROU : 992301376
...
Semantic modifications:
NEUD_ROU : 990039893 -> NEUD_ROU : 990039893 , TYPE: 4 -> 5 COTE: 0 -> 9999
TRON_ROU : 140004360 -> TRON_ROU : 140004360 , NBV_TOT: 1 -> 3
...
Geometrical modifications:
NEUD_ROU : 140000215 -> NEUD_ROU : 991597654
TRON_ROU : 990747229 -> TRON_ROU : 992301035
...

Figure 6. Sample of the evolution log processed with the road network of the BDCARTO® (Department of Calvados)

This delivery mode of updating information provides users with a minimal (in terms of number of objects) but detailed description of the evolutions undergone by the reference data sets provided by a producer. The integration of these updates in their information systems is made easier: they are able to choose the relevant updates and to control their effects especially on their own added information. A whole old or up-to-date version of the database could be delivered with the "updating deltas" in order to allow users to build the contextual information or to retrieve some unfortunately deleted objects. This notion of contextual information is important because it addresses the underlying problem of data exchange format. Indeed, not all the data exchange formats dedicated to the geographic information allow an easy delivery of the "updating deltas". For instance, with EDIGéO [AFNOR, 1992], it is possible only if a non topologic mode is used and if a fictitious geometry for previous objects is provided. It may be a great danger for an unaware user. Reflections about structure and data exchange formats are presently in progress at the IGN for the delivery of the updates for the BDCARTO®.

5. CONCLUSION AND OUTLOOKS

This process of update retrieval based on topologic and geometrical data matching tools allows the automatic extraction of the evolutions between two versions of a same geographic database. The implementation in the databases of a reliable and stable system of identifiers or time management is not necessary. All kinds of geographical entities stored in the databases may be processed with it. So, it can be considered as generic.

Moreover, the updating information provided by this process is detailed and close to the modifications performed in the geographic databases. It allows users to automatically retrieve all the updates in the whole up-to-date version of a database delivered by a producer. The integration of these updates in their information systems is made easier: they are able to choose the relevant updates and to control their effects especially on their own added information. Users are thus not compelled to integrate the whole new version of the database in their information systems, which may induce significant risks of information loss or leave the database in an inconsistent state.

The use of this process in the definition of a new delivery mode of the updates for geographic databases has also been presented and detailed. The notion of "updating deltas" has thus been defined and illustrated by the results of a first experimentation. They are first tools which contribute to an easier integration of the updates delivered by a producer into the users' databases.

The definition of this process is in fact part of a wider investigation engaged at the COGIT laboratory of the IGN, which aims at developing an automatic updating tool for the multi-representation geographic databases. The structure of this more general mechanism is particularly presented in [Badard, 1998].

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