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CHAPTER 26

Updating geospatial databases from images

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ABSTRACT: This chapter reviews the process of updating geo-spatial databases from images. After a general discussion of updating and its relation to data quality updating, we discuss the generic system architecture for updating geo-spatial databases. We then reflect upon the role of automation in our field, before giving examples of two state-of-the-art developments, one for automatic data verification and change capture from images and a second for automatic data validation. The chapter concludes with some observations for future developments.

Keywords: System architecture, updating, data quality, images

26.1 INTRODUCTION

Geo-spatial information, i.e. information about objects and facts with spatial reference, is an essential part of the national and international infrastructure for the information society. It is estimated that some 80% of our daily decisions rely on geo-spatial information. Geographic information systems (GIS), which allow for the acquisition, storage, manipulation, analysis, visualization and dissemination of geo-spatial information, are therefore of prime interest to society at large. Due to the demands of a number of modern applications—we mention only car navigation and disaster management as two very obvious examples—the updating cycles of the past, amounting to years, are no longer acceptable. Today's applications require much more current information. Thus the need arises for frequent updates of geo-spatial information.

The currency of a database counts among the most important key components of the quality description of the data set. Every application based on spatially referenced data or geo-data requires some knowledge about their quality or at least an idea of the consequence of possible errors and the risk associated with these errors.

Sonnen has highlighted the importance of data quality as spatial data moves into enterprise environments (or mapping moves to spatial information):

"Data quality is a problem we need to address if we in the geo-spatial industry expect to be a part of the enterprise IT picture. Our most pressing need is a simple, reliable way to answer: 'Are these data fit for this purpose?' each time spatial data are merged or shared in an enterprise system" (Sonnen 2007).

Sonnen has also highlighted the fact that data quality issues may be resolved or exacerbated within each data management function. Careful attention to quality issues in the design of data management workflows is required to minimize problems.

Data quality is usually described by a certain set of measures, which express comprehensive and useful criteria. These should enable the user to compare the quality of different data sets. Therefore, quality measures are part of standards or specifications from ISO (International Standards Organisation) and OGC (Open Geo-spatial Consortium). ISO 19113:2002 (ISO 2002) establishes the principles for describing the quality of geographic data and specifies components for reporting quality information. It also provides an approach to organizing information about data quality. Rather than going into detail about these specifications, we start with a subdivision of quality measures into two categories:

- consistency with respect to the data model, also called logical consistency
- consistency with respect to the real world, i.e. consistency of data and reality within the scope of the model.

We refer to the first category as logical consistency since it can be checked by logical reasoning without any comparison of the data to the real world. We can perform a complete and fully automatic data validation for logical consistency using solely the data set and the specifications of the data model. Format specifications, topological constraints, uniqueness of identifiers and domains of attribute values are typical relevant criteria.

For the second category, a comparison of data and reality is required. Basically the comparison can be performed by means of current sensor data or field work. A complete comparison of data and reality requires significant effort and cost, but in return it furnishes all the necessary update information.

Updating a database should obviously not lead to a loss of data quality. Therefore, any change made to the data in the database in order to maintain or restore the consistency with respect to the real world has also to be validated for logical consistency. Thus, both aspects must be considered when updating a geo-spatial database.

The chapter is organized as follows. After a description of the updating task, we discuss the generic system architecture for updating geo-spatial databases. We then reflect upon the role of automation in our field, before giving examples of two state-of-the-art developments, one for automatic data verification and change capture from images and a second for automatic data validation. The chapter concludes with some observations for future developments.

26.2 THE UPDATING TASK

26.1.1 *Verification and data capture*

Updating a database refers to the task of comparing two or more data sets (one representing the current state of a database, the others representing some more recently acquired data) with the aim of detecting and capturing changes, and to import these changes into the database, while keeping the new data logically consistent with the existing data. Note that in this text we use the term "updating" as a synonym for "revision". Updating tasks that need to be supported are the creation, deletion, splitting and merging of objects, and the modification of their geometric, topologic, thematic and temporal descriptions. Basically three tasks are being performed during updating: (a) in a verification step data existing in the database are checked against the new source data for correctness and geometric accuracy; (b) in the following data capture step, new or changed objects are added to the database; and (c) the new state of the database is checked for logical consistency, either stepwise or in a final process. By means of such updating, the database is constantly adapted to the changes of the landscape. Updating is thus closely related to temporal issues in GIS.

In general it will be necessary to use multiple data sources for updating a GIS database, and the second data set can take the form of imagery, results from a field survey, or data acquired from some other source. From a photogrammetric point of view, and for other reasons, updating from images is most attractive (Heipke 2004). The challenge here is to automate all three updating tasks.

26.1.2 *Periodic and continuous updating and the role of images*

While traditionally most topographic information was captured from aerial images, the much shorter updating cycles of today have resulted in major changes in the processing chain. Often field data are incorporated into the database as soon as they become available; thus we move from a periodic to a continuous updating process. Obviously, in many countries man-made changes have gone through a detailed planning process prior to being executed, and information about these changes can be provided by the planning authority, although it is useful only after translation into the schema of the topographic database and field verification. New information sources currently being brought into use range from using large groups of people commonly collecting information via the internet (such as ratings of all sorts) to using taxi driver tracks recorded by GPS as information for the road network, or having the postman deliver information about building changes.

While continuous updating is a very attractive alternative, there is a danger that the data quality slowly degrades over time. Therefore, we believe that continuous updating from data sources such as those mentioned above should be complemented with a periodic verification of the complete database. We also argue that for verification aerial and satellite images are prime sources of information. In addition, they can be used to identify areas that have changed, even though the actual capture of the changed data is then performed on the ground.

26.1.3 *Incremental updating and versioning*

Two important concepts for the update of geo-spatial information are incremental update and versioning. A methodology for updating geographic databases using map versions is given in Peerbocus et al. (2002). Users often link the core geo-spatial information to some application data of their own and thus create value-added information. In order not to lose the key links between the core data and the application data, once a new version of core data becomes available, it is mandatory to provide "change only" information. In this way, users are able to incrementally update their own data sets only in those areas where change has actually occurred. Also, updating is often done in parallel by different operators, possibly using mobile equipment or in distributed environments. In this case, versioning allows exclusive write access to parts of the database to be given to different users and to create various spatially non-overlapping versions. In a second step, these different versions have to be merged to generate a consistent new data set. Incremental updating and versioning can also be used to record time series of events.

26.1.4 *Updating and new generation data models*

Another fundamental factor influencing updating issues is the emergence of a new generation of data models, designed to be more capable and to serve multiple purposes; in short to realize the goal of 'store and update once, use many'. A recent EuroSDR Workshop (EuroSDR 2006) explored this trend, the reasons for it and the current state-of-the-art. It revealed an encouraging degree of convergence and consensus in the emerging pattern (reliance on standards, feature/object based models, use of persistent unique identifiers, use of UML (Unified Modelling Language) as a design tool, use of XML/GML (Extensible Markup Language/Geographic Markup Language) as delivery vehicle) and some research issues, particularly in dealing with formal semantics. These trends are not restricted to Europe and are evident globally.

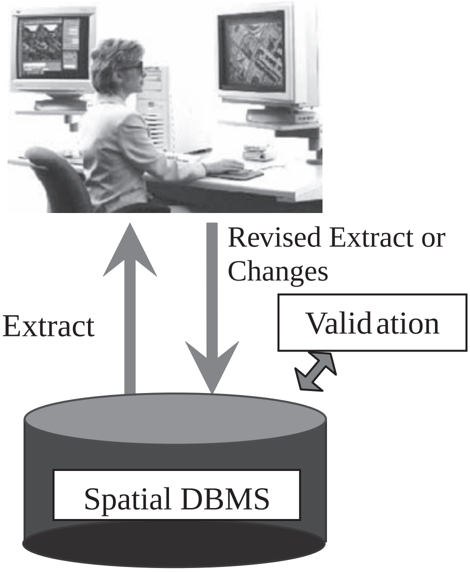

Figure 26.1. File-based data exchange: several cycles are needed, resulting in a very low efficiency. (see colour plate page 504)

26.3 A GENERIC SYSTEM ARCHITECTURE FOR UPDATING GEO-SPATIAL DATABASES

The first and perhaps most important observation with respect to system architectures is a major trend to database-centric architectures. This centralizing tendency, together with the implications of more complex data models, has profound implications for update (Woodsford 2004). Update processes need to be 'data model-aware', and to be tightly coupled with validation services, to avoid costly and lengthy error detection-correction cycles. Whilst it is possible to replicate such validation services in each update client (field, photogrammetric systems, imagery change detection systems) as models become more complex, and business rules come to the fore, such an approach becomes more costly and difficult to sustain. Traditional approaches, with several lengthy iterations to detect and correct errors (see Fig. 26.1) become less and less viable. Note that while Figure 26.1 (and also Fig. 26.2) show a human operator who carries out data verification and change capture, these tasks can at least be partly automated (see also Section 26.4).

Good results have been achieved by close-coupling of a photogrammetric client with an object-oriented database (e.g. BAE Systems SOCETSET with Laser-Scan (now 1Spatial), Gothic (Edwards et al. 2000) or with a geo-spatial database (SOCET SET with ESRI ArcGIS), (BAE Systems 2007). This tightly-coupled approach removes the need for repeated re-validation of changes and lengthy delays.

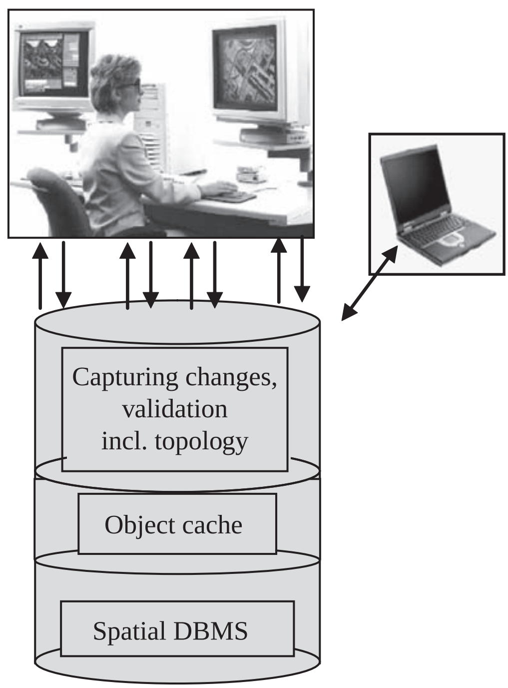

Figure 26.2. Direct link with multi-tier architecture. (see colour plate page 504)

Modern multi-tier architectures extract the changes and the validation procedures including, for example, topology checking, into a middle tier component, for ease of creation, maintenance and scalable access by all client processes (see Fig. 26.2). Service-oriented architectures take this one step further, to a distributed services architecture.

26.4 AUTOMATIC UPDATE OF GEO-SPATIAL DATABASES USING IMAGERY

26.1.5 *Automatic verification and capture of change*

One of the most time-consuming tasks in updating is the verification of the existing data and the detection and capture of change. In the following, we assume that we use up-to-date aerial or satellite imagery for this task. Then, both verification and change detection and capture are prime candidates for automation, and much effort has been spent towards this goal. Indeed, automatic and semi-automatic feature extraction has been a focus of international research in photogrammetry and computer vision for a few decades (e.g. Baltsavias et al. 2001, Heipke et al. 2004, Mayer 2004, Mayer et al. 2006). As a consequence, the results are now starting to enter the commercial market. Obviously, algorithms give particularly good results if applied to well-defined application areas. One of the reasons is that in principle an object extraction task needs additional knowledge in the form of appropriate models or data, which can more easily be formulated for restricted situations.

Historically, knowledge is often buried inside data or hidden in people's heads. This results in serious problems in keeping such knowledge up to date. Progress towards rigorous semantics contributes to removing ambiguities and to storing the knowledge and expertise of the organization where everyone can contribute to it and share it, as enterprise metadata that is portable and independent of specific datasets and systems. Today, techniques developed in artificial intelligence are usually employed for the representation of this additional knowledge in a computer readable form, e.g. semantic networks or production rules.

A critical component in this development is a language to enable logical constraints to be specified. Such a language needs to be unambiguous, logical and portable, compact, intuitive, quantitative, web compatible, declarative and refinable. For a full discussion of these requirements and potential choices of these languages, see e.g. Watson (2007). There are currently several candidates to consider as a knowledge representation language (RDF - Resource Description Framework, OWL—Web Ontology Language, XML Rules/SWRL—Semantic Web Rule Language). None as yet covers all the functionality needed in the geo-spatial domain. This area has received much attention of late through initiatives such as the Semantic Web community (W3C—World Wide Web Consortium 2004a, b) and rapid progress can be anticipated. Also for image interpretation tasks, such knowledge-based systems have proven to be a suitable framework for representing knowledge about objects and exploiting it during the recognition process.

Since any automatic feature extraction algorithm will show a certain error rate, it should be integrated in an interactive workflow leaving final decisions to a human operator. For achieving an efficient workflow, the algorithms have to be equipped with appropriate and reliable self-diagnostics allowing the operator to concentrate on situations where the automatic procedure fails. Walter (2004), for instance, developed a system that supports the operator in quality control of ATKIS (**A**mtlich **t**opographisch-**k**artographisches **I**nformations **s**ystem (Authoritative Topographic Cartographic Information System)) region and line objects by automatically extracting land cover classes from satellite imagery by multi-spectral classification, and comparing them to the corresponding ATKIS objects. He used prior information derived from the existing ATKIS dataset to define training sets for a supervised classification. ATKIS objects showing a high probability of differences to the extracted object classes are indicated as presumed changes. They are visualized to support the human operator's final interactive analysis.

Another example for GIS update from images is the ATOMI (Automated reconstruction of Topographic Objects from aerial images using vectorized Map Information) project of ETH Zürich and the Swiss Federal Office of Topography (Zhang 2004), in which road data were extracted from high resolution colour stereo images and were compared to cartographically generalized vector data in order to update the latter. Champion (2007) and Gladstone et al. (2007) are concerned with updating building information, whereas Ruiz et al. (2007) search for regular patterns as indicators for certain object classes before comparing the results to existing map data, primarily in agricultural areas. A very good overview of existing approaches is given by Steinocher & Kressler (2006).

26.1.6 *Automatic data validation*

Given the database schema and the logical constraints expressed in a rules language, logical consistency can be validated automatically by rules-based processing following the FACT-PATTERN-ACTION dynamic: Given some facts, if they meet any of the patterns/rules, they perform the defined action(s). FACTs are a known data source. PATTERNs are the business rules

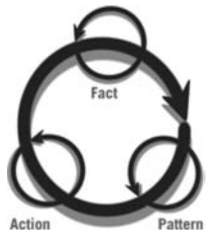

Figure 26.3. The Fact-Pattern-Action dynamic.

that the data source obeys or should obey. ACTIONs happen as a result of PATTERNs being applied to FACTs (see Fig. 26.3). Typically, ACTIONS in the validation context are automatic 'fix-ups' or reports on the basis of which targeted user action can be taken to correct errors.

26.5 WIPKA-QS: A SYSTEM FOR AUTOMATIC VERIFICATION AND CHANGE CAPTURE

In this section, we briefly describe our developments towards a specific system for data verification and capture of change. The development is embedded in a broader concept of the knowledge-based workstation WiPKA developed for the Federal Office of Cartography and Geodesy in Germany (BKG), which provides functionality from photogrammetry, GIS and cartography for the acquisition and maintenance of ATKIS. While other such systems exist (see above), the description is intended to show what can be achieved with today's technology (for more details, see Busch et al. 2004, 2006).

The basic concept relies on GeoAIDA, a knowledge-based system for image interpretation based on semantic networks developed at the Institut für Informationsverarbeitung (TNT), Leibniz Universität Hannover (Bückner et al. 2002). In our approach, the comparison of the ATKIS DLMBasis and up-to-date aerial and satellite images comprises two steps, namely verification and the capture of change. Verification is characterized by the following features:

- The image analysis algorithm makes use of the information stored in the GIS to detect the image object.
- If there is a certain degree of consistency of image features and information from the GIS, the object is accepted.
- Otherwise the object is labelled as rejected.

For the subsequent step of change capture, information of new objects not yet stored in the dataset or information about changes of old objects have to be

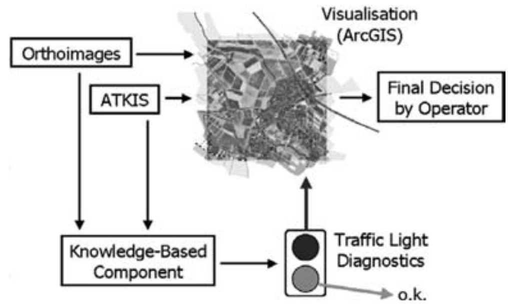

Figure 26.4. Workflow of quality control. (see colour plate page 504)

extracted from the image. Thus, it seems reasonable to start with the verification step.

The whole process is integrated in an interactive workflow in which the human operator can focus on those objects where the algorithms detect ambiguous situations and takes the final decisions (see Fig. 26.4). The results of the automatic procedure are passed to the human operator in the form of a so-called traffic light diagnostics, i.e. the results are displayed by means of red and green colour for each GIS object, where green means the object could be verified and red means the object could not be verified. Since the human operator decides on acceptance or rejection in the case of the red objects only, the decision of the automatic procedure has to be reliable, in particular for objects labelled green.

We are currently able to extract and verify road data (Gerke 2006, Ziems et al. 2007), to distinguish between built-up areas, forest and agricultural areas (Müller 2007) and to distinguish between cropland and grassland (Helmholz et al. 2007). Input in all cases are black-and-white orthophotos of approximately 0.4 m ground resolution; we can also process colour and high resolution satellite images. Although the system has been developed with German landscapes in mind, we have demonstrated that it can also handle scenes from other geographic areas.

Extensive testing has shown that we have obtained a gain in productivity of approximately a factor of 3. This means that while we paid special attention to obtain a very small amount of false positives (objects which we classified as correct, but which were indeed wrong), we are able to roughly process two thirds of the objects automatically and correctly.

26.6 THE RADIUS STUDIO EXAMPLE

In this section, a commercial system for checking the logical consistency of a given GIS data set is briefly described in order to demonstrate the state-of-the-art in data validation. We use the example of Radius Studio from 1Spatial as we are most familiar with this system.

Radius Studio is an implementation of a rules-based processing environment. It can be deployed as an instance of a generic multi-tier architecture as shown in Figure. 26.5, or as a Web Service.

The rules-base is a set of conditions that objects from the data store should satisfy. A rule in Radius Studio is a tree of predicates against which objects can be tested. Rules are expressed in a form independent of the schema of any particular data store.

This means they can easily be re-used with different data sources. Before formally defining the rules for use within Radius Studio, they must be articulated and understood. A wide range of circumstances are encountered. The rules may be defined in text form, perhaps in conjunction with a logical data model or feature catalogue. They may be formally expressed in an ontology language such as OWL, in which case they can be used directly (by interfacing with the open source Jena ontology library (Jena 2007)). More often the rules are not explicit or formalized, but exist in the form of knowledge held by domain experts.

Radius Studio provides an intuitive web-based interface for defining rules and building up a rules-base in a tree structured form. For more details, see Woodsford (2007) and 1Spatial (2007).

An action is a procedure (or set of procedures) to be applied to one or more objects, usually when they are found to violate a particular rule. Actions are expressed in a form independent of the schema of any particular data store, so that they can easily be re-used with different sources of data. Actions are defined using a similar graphical user interface as for defining rules, but can also include operations such as assignment, conditionals and sequencing, object creation and deletion, and report generation. Actions can be applied to all the objects from a data store, or in a more targeted manner by use of action maps.

An action map is an ordered list of (rule, action) pairs. When an action map is invoked, objects are checked against the rules. If the object does not conform to that rule, then the associated action is invoked. Action maps are often used to associate fixes to problems with non-conforming objects.

Radius Studio can be used to measure the quality of data in the sense of measuring the degree of conformance of the data to a rules-base. A document or data store can be processed and a report generated with results of the conformance test at both a summary and individual feature level. The final results of the conformance tests are obtained in the form of metadata, which is compliant with the conceptual model of ISO 19115 Metadata (ISO 19115:2003) and encoded in the form recommended in ISO 19139.

Radius Studio can also be deployed using SOAP (Simple Object Access Protocol) Web Service interfaces for the purposes of validating features remotely. In outline, the web services are used to first define a sequence of data processing tasks called a session. The session is then run and rules are asserted against the data. Progress is monitored and finally the results of the conformance test at both a summary and individual feature level are obtained (Watson 2007). Increasingly, Radius Studio is being deployed in rich and potentially dynamic workflow environments such as are enabled by enterprise workflow technologies like BPEL (Business Process Execution Language, see Fig. 26.6) (OASIS 2007). The main drivers for the adoption of such Service Oriented Architectures (SOAs) are that they link computational resources and

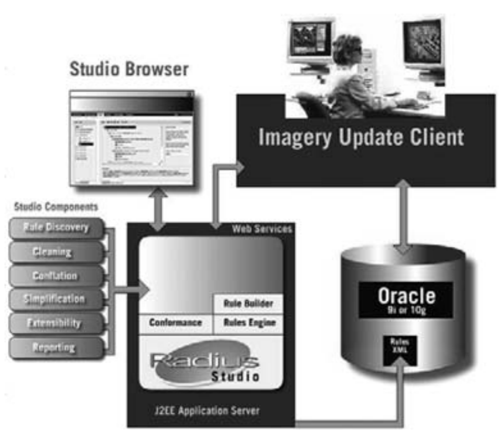

Figure 26.5. Radius Studio as a multi-tier architecture.

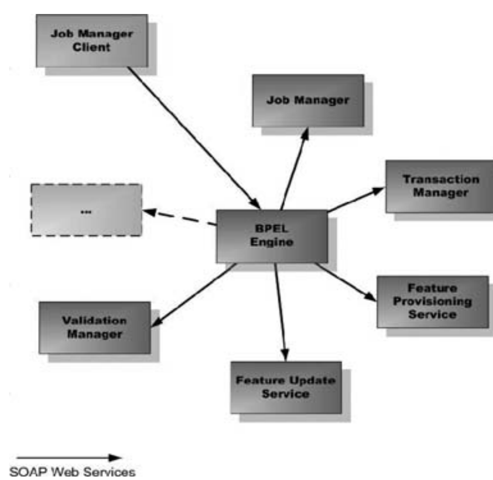

Figure 26.6. A BPEL workflow for update.

promote their reuse so as to help businesses respond more quickly and cost-effectively to changing market conditions.

26.7 SUMMARY AND CONCLUSIONS

In this chapter, we described the updating of geo-spatial databases using aerial and satellite images. The focus was on the updating process as such, rather than individual steps or algorithms. We conclude by emphasizing that images play an essential role in updating geo-spatial databases, because only from images can one obtain an overview of the whole area and is thus able to consistently capture and import into the database all relevant changes. While it can be difficult to obtain imagery at frequent intervals, e.g. due to clouds, terrestrial approaches are much more flexible with respect to suitable conditions for data capture. However, they can only capture individual changes and thus risk violating neighbourhood and/or overall consistency. Thus, the two approaches should be used as complementary methods rather than in competition with each other.

We showed with the help of two examples that while updating is a very time-consuming process, approaches exist and are used in practice that allow significant time and cost savings due to a refined integration of the work carried out by human operators and automatic algorithms based on image analysis and rules-processing. We believe that it is along this way that further progress will be made, if the general trends in computer science, knowledge representation and geo-spatial standards are appropriately taken into account.

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