CORRECTNES PRECONDITIONS FOR CHANGES ON GEOMETRY OF CADASTRAL PARCELS WITH ANALYSIS OF IMPLEMENTATION OPTIONS

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1 Introduction

Until recently, cadastral information system were implemented with loosely structured data models on top of which a user interface, allowing direct and often weakly controlled updates is built. This was especially the case for spatial component of the data. In such systems implementation of flow of different processes depended on operator following to the prescribed rules. The advantage of such an approach was a rather simple implementation and especially autonomy of business process flows from the implemented system meaning that the process could be changed or adjusted without any intervention to the system. On the other hand of course, the correct execution of processes and updates to the data depended on careful usage of the system by highly specialized operator. Lately it has been realized that cadastral systems without implemented limitations and controls to the scope and type of updates and not supported by a kind of a workflow subsystem are inefficient and often become valuated as unsuccessful (Asian Development Bank 2010). High importance of business processes and the very nature of cadastral data has also been emphasized in the study of cadastral projects financed by World Bank loans in the past 15 years in the area of Europe and Eastern Asia (Adlington 2009).

Different mechanisms for ensuring data consistency during updates in large scale transactional systems for management of alphanumerical data (i.e. bank systems) are available ever since such systems have been digitalized. For instance, it is a trivial task to implement a consistency control which will check the balance of the source bank account during the transfer of money from one account to another. Similar approach can also be applied to alphanumerical component of cadastral information systems.

In order to avoid implementation of a system which will depend on operator's good will and skills but which will ensure maintaining the data consistency under updates autonomously from the operator it is necessary to understand the processes and the types of changes that are to be executed in advance. Furthermore, if the preparation of updates is to be outsourced to private companies (or other parties outside of the system) the changes must be both formally and technically described to a level of detail which will ensure efficient process flow from the field surveying to the execution of the change. Understanding the two on the alphanumerical segment of the data can easily be achieved by a detailed analysis executed by an experienced expert. In order for the processes to be implementable in a unified manner also on the spatial component of cadastral data it is necessary to understand the nature of the spatial data and the types of changes (in both technical and legal aspect).

According to the definition from the international standard for land administration (ISO 2010), spatial representation of cadastral objects can be based on sketches, points, text, unstructured lines, polygons and full topological data structure. Proportionally with the usefulness of each option increases the complexity for executing changes and ensuring consistency for each of the options. So, the implementation with the full topological data structure would be the most advanced in the aspect of ensuring the data consistency and the overall usefulness of the system, however a very complex methodology for executing updates makes it less popular. Most of the modern information systems for maintaining geometric segment of cadastral data are based on polygonal geometry because of the best ratio between complexity, the overall functionality and the available standard components that can be used for the implementation.

Because of all of the above the rest of the paper defines a classification of changes on cadastral parcels spatially represented by ISO simple polygons. Changes are defined by the scope and the type. Furthermore, for each of the types of changes the correctness preconditions that must be fulfilled are described.

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2 Classification of changes

2.1 Other related work

Most of the attention in the area of research in the cadastral domain has lately been directed towards data models and trying to find the best data model for cadastral domain covering as much as possible cadastral concepts. This has yielded the new ISO standard (currently still in draft status), the ISO 19152 Geographic information — Land Administration Domain Model (ISO 2010). The document only very generally references the dynamic segment of the cadastral systems, saying that it can be modeled using either event based or state based approach. There are some researches engaging the dynamic segment of cadastre and trying to classify and describe the types of processes or changes occurring in cadastral systems. So, for instance Zevenbergen and Stubkjær (2005) point out that, besides most often and most obvious types of changes in cadastre, the selling and the dividing also the others like vesting of easements and land consolidation need to be researched. Zevenbergen (2004) emphasizes the importance of a special type of process, the adjudication during which an object of registration and a relation of a subject to that object get registered for the first time. This could also be called initial registration. Navratil and Frank (2004) in their study recognize three types of changes from the legal point of view, establishment, transfer and deletion of rights. Establishment of rights is not considered to be the initial registration because the object is already registered, but creation of a new right on that object. Claramunt and Thériault (1996) emphasize a very important fact that the process of land reallocation can not be modeled as two separate processes in which first all the parcels would be joined into one, and then this one would be subdivided into new parts because the underlying common cause would be lost caused by the separation.

There are also several papers dealing specifically with the changes on the spatial component of cadastral data. Spery et al (1999) analyze French cadastral system in which state owned land is not registered so besides the obvious types of changes being division, merge, rectification of common border and reallocation also detect the extraction and passage. The latter two occur when the land is moving from public ownership (which is not registered) in to private (registered)and vice versa respectively. Extraction can be considered to be the same concept that Zevenbergen uses with adjudication. Transaction correctness rules based on topological classification is described by (Gröger and Plümer 1997).

Zhou et al. (2004) find that there are four such types of changes during land subdivision, split, union, reallocation and modification of the common border, however in their approach the concepts of initial registration and removing from the register are not included. Following this paper other papers from same group of authors deal with very detailed formalization of changes on spatial representation of parcels based on topological relationships and rules. This is to detail described in Zhou et al (2008) however it's complexity makes it unsuitable for practical implementation.

2.2 Classification

The paper considers geometric aspects of correctness of spatial change on cadastral parcels. The other aspect of spatial change on cadastral parcels is the lineage or the semantic aspect. The semantic aspect defines the parent/child relations between objects before and objects after the change is executed. The semantic aspect of spatial change is elaborated in the paper by Spery et al (1999). It is also worth noting that geometric correctness can be achieved without also achieving semantic correctness. The semantic correctness can be checked by comparing the required lineage relations (which are defined in the metadata of the change) with the lineage relations which would result from the execution of the change. We first argue that controlled change can be adequately defined by two factors, the scope and the type of the change. The scope of the change is a set of objects (defined by a list of references or by the area they cover) which are allowed (or required) to be changed by that specific change. The type of the change is a set of allowed operations on the objects from the scope. The ultimate aim is to have a set of rules that can be used to test the correctness of the change defined by it's scope and it's type.

In order to define the domain of the second factor (the type) which is not known, we analyze the first of two basic factors which define the change, it's scope. This means that the coverage of the scope (subject area) by the parcels has been selected as the basic classification criteria for the types of changes.

The main factor defining the classification of changes are the status of being covered (yes or no) of the subject area both before and after the change. Note that the whole area of jurisdiction needs to be covered by parcels in order for the database to be in correct status. Combining the two possible statuses (covered / not covered) yields four possible combinations, three out of which represent meaningful change types (table 1).

Table 1: classification of changes based on coverage of subject area

Subject area covered before	***Subject area covered after***	***Type of change (geometric aspect)***	***Subtypes of change (semantic aspect)***
No	Yes	Initial registration	---
Yes	No	Removing from register	---
Yes	Yes	Re-registration	Division, merge, rectification, reallocation
No	No	---	---

Initial registration is defined as the process of registering a set of parcels given that on the subject area there were no parcels registered prior to the execution of change. As shown before, such changes occur in systems that do not register the whole area or when the system is put into operation before full coverage is achieved, meaning that additional registrations are done when needed. Analogue to that, the removing from the register will occur when the subject parcels no longer need to be registered. Finally, re-registration is the process during which both before and after the change subject area is covered by parcels (figure 1).

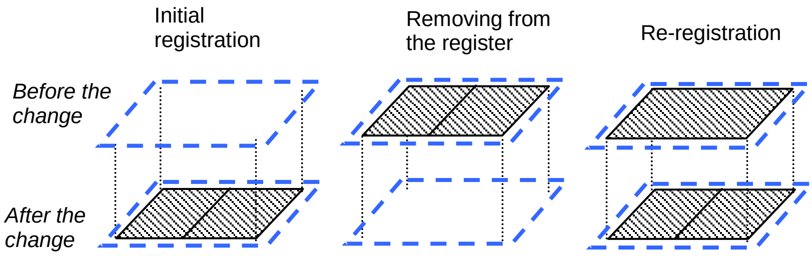

Figure 1: Types of changes

The question could be risen on how a complex types of changes will be tested if such a classification is accepted. For instance a composite change which includes all the basic types of changes is imaginable.

Such case would be handled by creating three different processes of three different types. Initial registration and removing from the register will be prerequisite processes for re-registration process. The two can either be executed prior to executing registration or a simple predecessor-successor relationship between processes can be established so the successor processes takes in account the status of the database as if the predecessor processes have been executed.

3 Correctness preconditions

For the purpose of this research the basic idea of the change as a process of replacing a subset of a geographic database with a new subset has been adopted from Spery et al (1999).

3.1 Primary precondition

First we define planar partition function for a set of parcels. A simple and easily understandable definition of planar partition is given in (CGAL 2003): A partition of a polygon P is a set of polygons such that the interiors of the polygons do not intersect and the union of the polygons is equal to the interior of the original polygon P (figure 2).

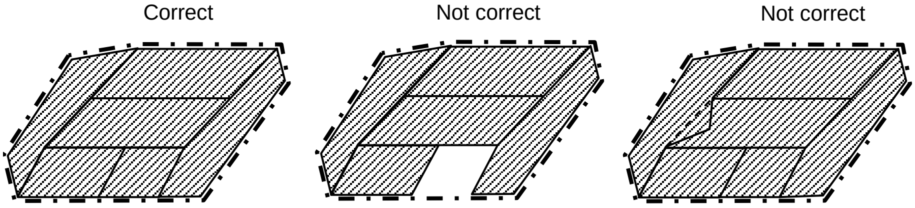

Figure 2: correct and not correct configurations of polygons with regard to planar partition

However, unlike the function which partitions the universal polygon into a set of polygons forming a planar partition, what is needed here is a mechanism that checks whether a set of polygons with unknown origin form a planar partition of the selected universal polygon. The implementation options for such a functionality are discussed in the section 4 of the paper. We now proceed with a simple definition for correctness rules. Parcel is spatially defined as an ISO simple polygon (ISO 2004). The database is defined as a set of n parcels:

(1) $DB=\{p_1, p_2, \ldots, p_n\}$

The area of jurisdiction AJ is defined as a simple polygon covering the entire area for which the database is established. The area of jurisdiction is in fact the universal polygon for the DB when planar partition is to be tested. In the remainder of the text the planar partition testing functions is denoted with *q()*. We also define a geometric union *u()* function which, given a set of arbitrary arranged simple polygons, returns a simple polygon created by executing geometric union operation on consecutive members of the set. A very important relationship between the union of a set of polygons and the correctness of planar partition of the set to the universal polygon, saying that when in correct status, the union of all the polygons is equal to universal polygon, follows from the very definition of the planar partition. We use this relationship later. Now, given that it is required that the database is initially in correct status we know that:

(2) $q(DB)=AJ$

Next we define two time instants. The Tb (before) is an instant before the change is executed and Ta (after) is instant after the change is executed and Tc is the instant in which the change is executed. The temporal distance of Tb and Ta from Tc is irrelevant since the requirement is that no other changes have occurred in the mean time. Therefore we will consider only two separate instants Tb and Ta to be infinitely close to each other.

The scope of the change is a subset of DB over which the change will (or is allowed to) be executed. The scope of change is:

(3) $S=\{p_1, p_2, \ldots, p_m\}$ where $m \leq n$

Here we call upon the requirement that the DB is in a correct state, meaning that there are no overlaps and gaps between polygons. This means that the affected area of the change is a geometric union of all the parcels contained within the scope. This need not be checked as it follows from the correctness prerequisite.

(4) $AA=u(S)$

The reminder of the DB is a set of parcels which are not involved in the change (or are outside of the scope):

(5) $R=\{p_1, p_2, \ldots, p_o\}$ where $o=n-m$

Now at Tb the DB can be represented as:

(6) $DB=R+S$

Now we give the definition of the change, as replacing the parcels within the scope of the change with new set of parcels. The new subset is defined as:

(7) $S'=\{p'_1, p'_2, \ldots, p'_v\}$

After replacing the S with S' at Ta, we get the new version of DB which we name DB'.

(8) $DB'=R+S'$

Now, the rules which need to be imposed on the change as a process of transforming from DB to DB' need to be defined. Since the main requirement for the DB is defined as q(DB)=AJ it is obvious that the requirement that after the change is executed, we have q(DB')=AJ or q(DB)=q(DB') is compulsory. Since it would be impractical to execute geometric test on the entire database we rearrange the equation. From (6) and (8) it is obvious that:

(9) $q(R+S)=q(R+S')$

and since obviously R=R then the requirement is to have S=S' to comply to the requirement of retaining the planar partition correctness for the AJ after the change. In other words the new subset S' of DB' must comply to the following:

$$(10)\ q(S')=AA \text{ or}$$

$$(11)\ q(S')=u(S)$$

Which in fact represents the primary correctness precondition.

3.2 Extended precondition

In the above elaboration two important presumptions were used. Firstly it is presumed that the DB was in the correct state before the change has occurred (given by q(DB)=AJ), and secondly it was presumed that the change will always take place having a constant and unchangeable AJ. However, as has been shown in the part where the classification was devised, the latter is in cadastre not always the case. Initial registration is a type of change where the area of jurisdiction is extended. This in turn renders the previously defined correctness prerequisite (equation 11) unusable since S is not available.

Again like before, the definition of the database (DB) is identical and the correctness requirement (q(DB)=AJ) is considered to be initially fulfilled. After the change we have:

$$(12)\ DB'=DB+S'$$

If following the logic from above it would be required that:

$$(13)\ q(DB')=AJ$$

However since the database has been extended this can not be achieved. Since the extension of the area of jurisdiction is defined by the union of newly added parcels (S'), equation 12 can be rewritten as:

$$(14)\ q(DB')=u(AJ, u(S'))$$

The above equation is correct and presents a sufficient prerequisite for enforcing correctness, however it requires that the entire database be checked for planar partition correctness. Again for practical reasons it would be useful to minimize the subset of the database over which expensive geometric tests need to be executed. Therefore we now define affected area as geometric union of all the new parcels:

$$(15)\ AA=u(S')$$

Now we can use the modified equation 11 to test the internal correctness of S'.

$$(16)\ q(S')=u(S')$$

Geometric union of all the members of the new set will produce the polygon which represents the extent of the change (the affected area) and the planar partition test will report if inconsistencies are present within the set. However, this will not eliminate the possibility for the new set to be incorrectly positioned related to the existing parcels. The additional requirement which can be used for testing that requirement is that AJ and AA form a correct planar partition:

$$(17)\ q(AJ,AA)=u(AJ, AA)$$

If both polygons, the area of jurisdiction and the affected area of the change which needs to extend the area of jurisdiction, intersect the planar partition test on the geometric union thereof will report an error. Finally, the correctness precondition for initial registration type of changes is made out of equations 16 (internal - to the new set) and 17 (external - to the rest of the existing set).

For the removing from register type of changes we start with a usual definition of the database as union of a set within the scope of change and the rest of the database:

$$(18)\ DB=R+S$$

Since in this type of change no new members are added to the database, the situation after the change is:

$$(18)\ DB'=R$$

If following the logic from primary precondition it would be required that:

$$(19)\ q(DB')=AJ$$

However since the database has been reduced this can not be achieved. Since the reduction of the area of jurisdiction is spatially defined by the union of parcels from the scope (S), equation 19 can be rewritten as:

$$(20)\ q(DB')=difference(AJ, u(S))$$

Finally, since the database was in correct status before the change, by removing some of the parcels no new inconsistencies can be introduced to the planar partition configuration. The only inconsistency would be generated if the AJ was not adjusted to the new set of parcels. This in turn means that no testing is required with removing from register type of change.

4 Implementation options

The most important facility needed for implementation of such a testing system into a cadastral information system is planar partition testing mechanism. There are different technological options available for implementation of planar partition testing functionality. The implementation can be either server based or client based and each of the approaches has both drawbacks and benefits. Client based approaches are usually richer with functionalities and are appropriate when heavy load on data processing is expected. However, client based processing is regularly more expensive and harder to maintain. Server based approach tend to be less expensive and easier to maintain but with less functionalities.

Following we give a brief description on two server based approaches to implementation of testing of planar partition correctness and direct the reader to other more detailed explanations thereof. Although the results and performance of both approaches are rather similar the implementation complexity and the level of detail of executing tests are different.

First we present a simple approach based on using *exclusive or* (symmetric difference or xor) geometric function. The xor function executes first union of two polygons from which the intersection thereof is subtracted. The idea for testing the correctness is based on the fact that each polygon the function processes will remove a part of the universal polygon until nothing is left. If however there is a part of the universal polygon that none of the input polygons has covered then this part will remain after the process is finished. Also, if there is a part that two polygons have tried to remove it will remain. The obvious drawback of such an implementation is the fact that only odd number of overlappings will be detected. This means that if there are two identical incorrect polygons the error would not be detected.

Although very efficient, such approach is not able to detect topological errors beyond the level of geometric precision. This means that it will not detect that for instance there is an extra vertex on one of neighboring polygons if the vertex is located near enough (within the distance smaller then the chosen tolerance) to the other polygon's edge.

The other option is to extract topological from geometric information of the polygons and then do the topological testing. Traditional topological implementations usually use straightforward implementation with faces, edges and nodes (Oosterom 1997). When using the approach with separate geometric from topological information, the algorithm is stable, meaning that it will not produce ambiguous results when marginal conditions (result of a calculation is very near the tolerance) occur. A detailed description of slightly different approach for implementation of topological testing using half-edges instead of edges is described in (Matijević et al 2008) and in (Ledoux and Meijers 2010) using constrained triangulations.

5 Conclusions

The paper gives a complete and elaborated classification of spatial changes on cadastral parcels represented by ISO simple polygons. Furthermore, for each of the types of changes correctness preconditions are defined which, if complied to, will ensure no inconsistencies are introduced caused by the change. Also, two server based options for implementation of planar partition testing functionality are briefly described. Although simple polygons were considered within the research, all the rules should also be applicable to polygon collections (in case disconnected polygon configurations need to be supported). Further research could focus on devising detailed rules for testing of semantic correctness of changes.

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