FUSION, INTERPRETATION AND COMBINATION OF GEODATA FOR THE EXTRACTION OF TOPOGRAPHIC OBJECTS

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ABSTRACT

The extraction of objects from images and laser scans has been a topic of research for years. Nowadays, with new services expected, especially in the area of navigation systems, location based services, and augmented reality, the need for automated, efficient extraction systems becomes more urgent than ever. This paper reviews some of the existing approaches and outlines the goals of a new research group established at the University of Hannover, Germany. This group works on methods for the fusion, interpretation and consistent combination of geodata with respect to the extraction of large scale topographic objects. First results of the group with respect to the design and implementation of a common platform for the representation of features, images and tasks are presented.

1 INTRODUCTION

Nowadays, topics like “location based services”, “augmented reality”, and “personal navigation” are not only actively discussed in the scientific community but are also areas where applications are expected to enter the market soon. Even though technical aspects like device or network characteristics often dominate the discussion in the public, it has in the meantime become clear that the quality and usefulness of services is the major key to success. For services tied closely to spatial information, the accuracy, detail, up-to-dateness and coverage of the underlying databases is of major relevance.

To give an example, one of the very few cases where area covering, highly up-to-date digital geo-databases are in today’s use by end consumers are digital, navigable street maps for car navigation systems. On the one hand, one could see those databases as being relatively simple: They are acquired with respect to a defined, limited purpose (navigable street maps), they provide information only in two dimensions, and the change rate of the street network is relatively low and in most countries under strict governmental control. Also, since it is still possible for single companies to acquire entire countries, data consistency can be enforced by appropriate acquisition guidelines. Even then, however, it is evident that the effort for acquisition and update is very high. As of today, the two major street map suppliers – Tele Atlas and NavTech – together employ almost 3000 people. In particular, the effort for keeping street maps up-to-date had been underestimated in the beginning.

With expectations from users rising, the situation becomes worse. It seems that today’s plans to extend existing street map databases into the third dimension or to integrate additional three-dimensional information such as city models cannot be realized economically. The reason for this is that three-dimensional information is not only more difficult (i.e. expensive) to acquire, but also the change rate of additional information is often higher than the change rate for street maps.

One can identify major shortcomings in today’s data acquisition practice:

The *degree of automation* in today’s acquisition systems is too low and certainly lower than it could be if results from research had been incorporated more consequently into production systems.

For example, Germany’s street network alone consists of some six to seven million edges, most of them having in turn several shape points. All of those edges and points were digitized manually – from maps, aerial images, or by ground survey.

As another example, one major supplier of city models in Germany has acquired – according to his own estimates – approximately 30.000 square kilometers of German cities. All this has been done by digitizing each point manually – several points per building – using stereo photogrammetry. This is not only a huge acquisition effort in the first place, it is also estimated by the supplier that an update of the database will require about 70 percent of the initial acquisition cost.

There is a lack of automated systems which *combine* geoinformation from different sources.

Coming back to the street map example, the production of consistent datasets has so far been relatively easy since every aspect is under control of the corresponding map producer. This will, however, be not possible anymore in the future when expectations towards navigation systems rise and several data sources have to be combined in order to obtain the final map product. Three-dimensional navigation systems will make it necessary to *combine current two-dimensional street networks with digital terrain models and three-dimensional city models*. It is unlikely that single map producers are able to acquire and update all these data sets. Therefore, highly automated procedures will be necessary to solve the problem efficiently.

Thus, it becomes clear that automation for initial acquisition, automation for update, and combination of different data sets and data sources are actual problems which are closely tied together. Progress on these topics will be crucial for extending and maintaining detailed and area covering databases in the future.

2 CURRENT RESEARCH STATE

2.1 Extraction of Man-Made Objects

Efficient extraction of man-made structures has been a topic of intense research for the past years (Grün et al., 1995, Grün et al., 1997, Baltsavias et al., 2001). The great interest of the scientific community was driven by the obvious need to automate or to facilitate manual processes for capturing data efficiently. The extraction of man-made objects is an *object recognition problem.* As such, it is part of an extremely wide research field (e.g. (Grimson, 1990, Jain and Flynn, 1993, Faugeras, 1994)) – an extensive discussion of which would be much beyond the scope of this paper. However, one can identify some basic principles which are present in most object extraction systems:

- The presence of *object models* which can be *generic* or *specific*. In the context of man-made object reconstruction, the use of specific models is usually not possible due to the great variety of objects in the real world. Simple generic objects are *parametric* descriptions where the general form is fixed but geometric parameters such as position, height, width, depth, and angle can be adjusted. On the other end of the spectrum, models based on the *Gestalttheorie* can be considered as complex generic models where properties like neighborhood, closedness, continuity and symmetry are used to recognize structures in scenes (Lowe, 1985). Such general models have also been used in the context of building extraction from images (Lin et al., 1995, Collins et al., 1995). One approach used by many researchers is that object models are build from object primitives by a given set of aggregation rules.
- The *detection* and *recognition* of one or more objects present in a scene. This is the core step of object recognition, which of course assumes the availability of appropriate object models. Different control paradigms can be identified, such as bottom-up (data-driven), top-down (model-driven) and mixed approaches such as hypothesize-and-test. A key aspect is also how the search is organized, in particular how the usually huge search space is reduced by techniques such as (discrete) relaxation or constrained tree search (Grimson, 1990).
- Measurement of *geometric information* about the position, orientation and size of the recognized objects. This step is not generally required in object recognition, however it is naturally present in object extraction for geoinformation systems. The geometry of objects can be described e.g. by a boundary representation, constructive solid geometry (CSG) or spatial enumeration (i.e., voxels).

There have been quite a number of research systems which were proposed for the extraction of man-made objects. They can be classified according to the data sources they use, the underlying object model, and the kind of intended operation: semiautomatic or fully automatic.

2.2 Registration and Segmentation of Range and Image Data

Registration is the process of aligning multiple, independently acquired datasets into a single, common co-ordinate system. Often, exterior orientations cannot be measured to sufficient accuracy and a classical photogrammetric registration involving the measurement of targets in images cannot be used. Especially for range images, registration techniques have been developed which use the measured data itself to perform the alignment, for example the iterative closest point (ICP) method proposed by Besl and McKay (Besl and McKay, 1992). One of the drawbacks of this method is that a quite accurate initial alignment is required, which can be improved to a certain extend by the integration of additional information such as intensity (Godin et al., 1994) or curvature (Godin and Boulanger, 1995) data.

However, non-iterative robust registration techniques can only be obtained when *range image interpretation* is used to resolve initial correspondences and appropriate error models are taken into account (Pennec and Thirion, 1997, Williams and Bennamoun, 1999). Many open questions remain to be addressed, including how well the methods – which were mostly developed in the context of close range applications – can be applied to situations where terrestrial and aerial scan data and images are combined.

Another aspect is the combination of data sets from different sources, i.e. different sensor input. An interesting approach is presented by (Schenk and Csathó, 2002) which describes the combination of LIDAR data and aerial images. Here, sensor-invariant features are detected and used for referencing between input data. Thus, a surface description combining the advantages of laser scanning and aerial imagery is obtained.

The *segmentation* process extracts meaningful primitives such as points, lines or regions from images or range data. In aerial photogrammetry, it has become clear by now that simple segmentation schemes are not appropriate. The reason is that on the one hand existing object structures might not be visible due to noise, too low brightness or radiometric similarity, while on the other hand a multitude of features is present in the images – e.g. generated by differences in material, color or shadows – which cannot be traced back to geometric object properties.

There have been a number of approaches to tackle this problem, for example using a polymorphic segmentation (Lang and Förstner, 1996, Fuchs, 1998), attributes based on color images (Henricsson, 1996, Mason and Baltsavias, 1997) or the early transition and reasoning in the third dimension during the segmentation process (Haala, 1996, Fischer et al., 1998). Especially the integration of DSM's has proven to be helpful for the reconstruction of buildings (Haala, 1994, Baltsavias et al., 1995, Ameri, 2000) or the classification-based segmentation (Walter, 1999).

A stronger role of DSM's in the segmentation process can be obtained by using *range image segmentation* techniques, which where mostly developed for close range applications. Fundamental results date back to the work of Besl (Besl, 1988) who introduced the curvature based "HK sign map" and a segmentation scheme based on variable order surface fitting (Besl and Jain, 1988). The curvature based method was later extended by Thirion to the so-called extremal mesh (Thirion, 1996). Segmentation techniques often differ with respect to their control strategy, for example region growing (Yang and Kak, 1986), split and merge (Parvin and Medioni, 1986, Taylor et al., 1989), or clustering (Jolion et al., 1991).

In the context of topographic object extraction from DSM's, planar segmentation algorithms play an important role. A fast algorithm has been proposed by Jiang & Bunke (Jiang and Bunke, 1994). An experimental comparison of algorithms has been presented by (Hoover et al., 1996). The application of DSM segmentation algorithms to the special case of building extraction has been described by (Weidner and Förstner, 1995, Brunn and Weidner, 1997, Brenner, 2000).

3 GOALS OF THE RESEARCH PROJECT

In the fall of 2002, a junior research group on "Automatic Methods for the Fusion, Reduction and Consistent Combination of Complex Heterogeneous Geoinformation" was established at the University of Hannover, Germany. It is funded for the duration of five years by the Volkswagen-Stiftung, Germany. Funding includes personnel costs for three research assistants, student assistants, as well as software and hardware, including a terrestrial laser scanner.

The general aim of this project is to investigate how data from different origins can be brought together in order to obtain highly automated processes for the extraction of geoinformation in the context of topographic objects. To obtain a self-contained research program of manageable size, the project *(i)* is focused on a subset of sensors: data from aerial laser scanners, aerial images, terrestrial laser-scanners and images, *(ii)* concentrates on large-scale topographic objects such as buildings and streets in urban environments, and *(iii)* is limited to a number of important problems regarding the fusion, reduction and consistent combination of geoinformation. The project is partitioned into the following three major work areas, each of which addresses an important aspect of the processing chain.

3.1 Fusion of Multiple Datasets

This includes the *management and registration* of the following four data sources: aerial laser scanning and imagery as well as terrestrial laser scanning and imagery. The idea is to build a database where all sources are available to subsequent extraction algorithms in a single coordinate system. Major aspects are the registration of datasets of different characteristics, the applicability of methods from close range applications, representation and link to databases, and the support of registration by segmentation and object models.

In detail, one aim of the project is to register single scans to each other. This must especially be done for the terrestrial scans, which are acquired from different viewpoints, where the exterior orientation is usually unknown. Manufacturers of terrestrial laser scanners provide software to do this registration, but the degree of automation is often poor, with interactive work being necessary. Elevation models acquired by aerial sensors are provided area-wide, the strips are adjusted by the laser-scanning companies themselves. Registering terrestrial and aerial laser scanner data is a topic in itself, combining largely different resolutions.

The fusion of image and range data is another aspect within this part of the project. The goal is to merge the different datasets automatically. It shall be investigated how methods which use range and intensity data simultaneously can be applied to improve the registration process.

3.2 Interpretation and Object Extraction

This addresses development of *integrated extraction algorithms* for topographic objects which are built upon the previously collected and registered laser scan and image data sets. The goal is to obtain methods which – by using a tight coupling of all data sources – achieve a high level of automation. The main topics here are integrated extraction methods, definition of higher level primitives, usage of highly redundant data sets, and geometric modelling and consistence.

Lower level primitives include points, lines and connected areas. Higher level primitives are obtained by combining lower level primitives. Correspondences have to be found between 2D and 3D data sets. Algorithms for edge detection and region extraction have to be investigated.

3.3 Combination of Geodata

This involves the investigation of selected problems regarding the automated, *consistent combination* of heterogeneous and homogeneous geodata. One aspect is the integration of different data sets such as city models and digital street maps, which is closely linked to cartographic operations like displacement and generalization. The combination of homogeneous data is targeted mainly at the analysis of multitemporal data for the purpose of change detection.

4 DEVELOPMENT OF A COMMON PLATFORM

As the members of the research group are expected to work closely together, we have put some effort into designing a common platform for processing modules and for the representation of scalar, vector and image data.

Regarding the implementation of algorithms, our approach is to subdivide processing steps into high-level modules called “tasks” which can be easily exchanged and which work on data in a standardized format according to the dataflow principle. That is, each task reads its input parameters, then runs, and finally writes the output parameters. The uniform interface all tasks comply with makes it possible to add a user interface which is based on the “visual programming” paradigm and allows to edit task parameters as well as to define the control and data flow between tasks. This approach is commonly found in image processing tools.

For the representation and transport of data, we differentiate between symbolic information and iconic data. Symbolic information describes the geometry and attributes of individual objects and is handled using the Feature Library. Iconic data so far consists of regular rasters and is represented using the Raster Library.

4.1 The Feature Library

The Feature Library represents geometric primitives and non-geometric entities. It also provides some algorithms that operate on these geometric primitives as well as I/O interfaces for different purposes. The LEDA library is used for underlying implementation of some entities (Mehlhorn and Näher, 2000). The FeatureLib is designed to support the development of high-level applications and allow efficient data exchange between tasks (see section 4.3). It is implemented in C++, platform-independent and can be easily ported. An open architecture allows for future extensions, there is no limit to the kind and number of features that can be added. Feature classes are arranged in hierarchical order and inherit properties from higher level feature classes as appropriate (see figure 2).

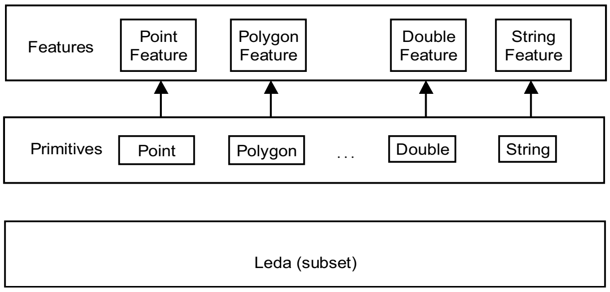

Figure 1: Feature Library Layers

The FeatureLib is organized in layers (see figure 1). The middle layer is the layer of primitives. These are representations of elementary low-level data types which are either implemented in the FeatureLib or are adapter classes to the corresponding objects of the LEDA library (the lowest layer). This way, it is possible to use the functionality provided by LEDA immediately, but still keep an option to replace the underlying implementation at a later point in time.

Among the geometric primitives represented so far are points, lines, segments, polygons and some of their most important special cases, like rectangles and triangles, and generalized polygons, which allow the modelling of polygons with holes. The latter are of major importance for building representation. Non-location primitives include integer, double and rational numbers and strings. The use of rational numbers and integers of arbitrary length, provides arbitrary precision when performing operations on primitives, whereas double approximations can be used when computational speed is an issue.

The top layer contains interface classes for the previously defined primitives. Here, functions for coding and decoding features (codecs) are implemented to provide easy and user-friendly access. It is possible to read and write features in binary (little and big endian) and XML format. There are also a graphical representation and an interface for editing primitives in their text representation. These two make use of Trolltech’s Qt toolkit and are implemented as widgets, which allows use in any Qt-based application. For each codec, a format has been designed. Every format is downward-compatible. This means that older versions of the FeatureLib are still able to read files that were created with a newer version and contain features not known to previous implementations. Further utilities allow the import of ESRI shape files and export into VRML.

Instances of features are mostly organized in tables. These tables are stored in memory. In the future, connection of the FeatureLib to databases like Oracle is planned so tables can also be stored in a database. A table consists of columns, each specified by a feature type and a given name, and an arbitrary number of rows (only limited by storage space) which contain feature entries. An entry can be null. Apart from that, a table can contain global information (meta information) which is in turn represented as features. For example, one could have a table containing a column “ground plan”, specified as a generalized polygon, a column “street name”, specified as a string, and a column “house number” which is an integer number. The table can then contain the ground plans for say, an entire city. Information about the city itself (name, administrative area, country, population size ...) can be represented as global properties of that table. A feature table is a feature itself: it can be contained in another table. A table row can contain multiple geometry features, so it is possible to store e.g. a ground plan, its minimum enclosing rectangle, and its center of gravity, all in a single row.

4.2 The Raster Library

The Raster Library, together with the Feature Library a central element of the common platform, is responsible for the administration of raster data sets. For standard image processing, several libraries of this kind already exist, but normally they are not suitable directly for storing range data or coordinates, the support of floating point values is often poor or does not exist.

The demand for the development of a raster library was to provide efficient routines for reading and writing raster data. Furthermore, the data should be organized in tiles, a multilayer concept should be integrated to allow storage of several images in one file (as required e.g. for image pyramids), and the image data should be readable by other applications. Taking these premises into account, it becomes

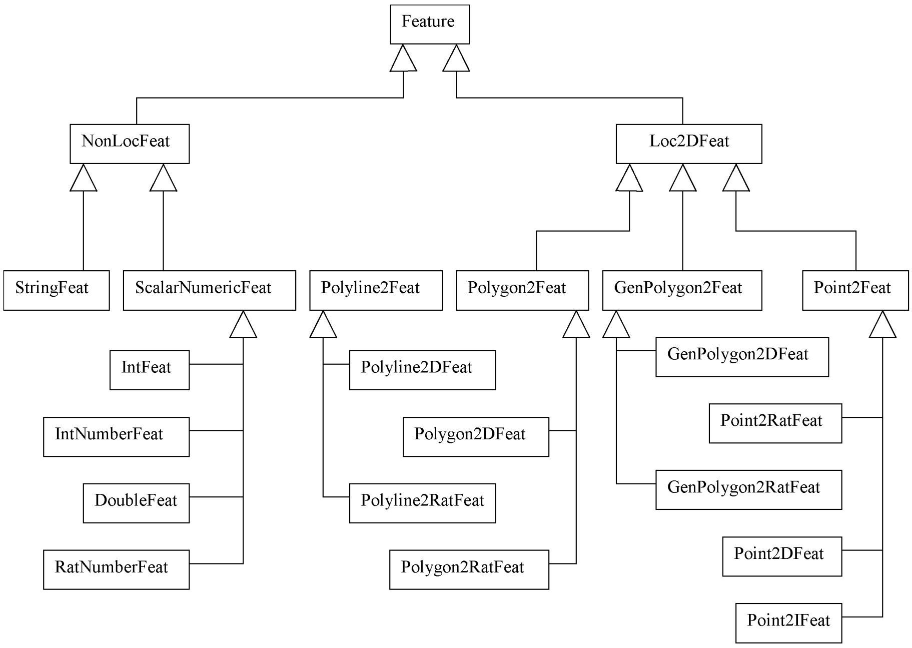

Figure 2: Part of Feature Library Hierarchy

clear that the usage of the well known "Tagged Image File Format" (TIFF) is predestined. TIFF allows a flexible composition of an image, additional information can be stored in private tags, but the image data remains still readable for other applications due the compliance with the TIFF standard (Adobe, 1992).

All these features have been implemented in the Raster Library. Routines are provided for read and write access to the data, new layers can be added to existing files. The image data may contain values of different data types, from 8 to 64 Bit. With the multilayer concept, it is possible to store an image, the coordinates acquired by a terrestrial laser scanner as well as the range and intensity images in one file. The library is designed to handle large datasets efficiently. For this, the organization of image data in tiles is essential. It is possible to load an image partially, only required data is accessed on disk. The library uses a cache mechanism to minimize the read and write access to disk. This architecture of the library enables an efficient data handling. Data can be accessed by pixel-, area- or tile-based read/write functions.

As with the Feature Library, the Raster Library is implemented platform independent in C++. The library will be a basic component for further development of this research project.

4.3 The Task Concept

The basic idea behind the task concept is to break down complex problems into high level task components. According to our experience, this facilitates greatly exchange and reuse of functionality, enlarges life time and leads to a higher productivity as compared to simple code fragments. The system probably coming closest to our concept is AAI's KBVision environment, popular on UNIX workstations in the late 90's (Amerinex, 1996).

A task itself performs a certain elementary processing step, such as an affine transformation, finding a planar segmentation, labelling blobs, etc. The important aspect is that the basic functionality is "wrapped" inside a box always providing the same interface. Input, output and in/out parameters are represented in a standard way, in our case quite naturally by features from the FeatureLib hierarchy. Thus, a task can exchange not only scalar parameters, such as integers, doubles, strings, but also geometric entities like points, polylines and polygons. Entire feature tables as well as mass data in the form of rasters can be exchanged by specifying their file names. The proper wrapping is of course ensured by inheritance from a general task class.

Because the wrapped tasks all exhibit the same interface, they can be treated uniformly. Thus, a visual programming tool can be used to select, place and connect tasks on a graphical user interface to build a more advanced functionality. The execution of the tasks is then controlled according to the "data flow" paradigm, where a task starts execution as soon as all its predecessors are terminated.

Using the task concept, functionality can be developed separately. Moreover, the possibility to run steps of an algorithm individually – with each step reading and writing parameters in a well defined format – offers a high level of introspection. This is often a great advantage when complex algorithms consisting of many processing steps, each possibly with its own parameters, have to be developed.

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