Towards Standards-Based Processing of Digital Elevation Models for Grid Computing through Web Processing Service (WPS)

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Abstract. Digital Elevation Models (DEM) and 3D spatial data plays an important role in typical earth science applications. Numerous simulations, e.g. flood modeling, and spatial analysis, requires very exact terrain data. During the acquisition of these data, for an example by means of laserscanning, very large data sets results due to the high measuring point density (up to four points per square meter). Current classical Geo-Information-System (GIS) software cannot manage the demand of processing and analyzing these massive raw terrain data. A lack of computing power may appear. There is a need for sophisticated data processing techniques. For this purpose the use of Grid Computing is a good choice to accomplish high processing performance and storage capacity. To process these massive raw geodata we develop a range of terrain Web Processing Services (WPS) which are made available as Grid services.

Keywords: WPS, SDI, Grid Computing, OGC, Web services, GIS, processing, DEM.

1 Introduction

The need for computing power is steadily rising within Geosciences through the increasing volume of available geodata. Furthermore there is a range of applications requiring high performance computing, e.g. disaster management tasks. One example for the increasing demand is the processing of Digital Elevation Models (DEMs) and 3D spatial data which play an important role in typical earth science applications. Numerous simulations, e.g. flood modeling, are based on DEMs and 3D-models. For this purpose very computationally intensive preprocessing operations are necessary for the handling of massive amounts of raw geodata. This means that an efficient usage and optimization of current existing IT resources is necessary. Nowadays, these challenges are met by using Grid Computing technologies and development of so called Grid infrastructures for the combination of distributed computing power. Thus, the project Spatial Data Infrastructure-Grid (SDI-Grid) focuses on the efficient processing of spatial data by grid computing technologies and the integration of an SDI into a Grid environment.

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Currently, distributed spatial data is accessed by services based on the specifications of the Open Geospatial Consortium (OGC). Visualization, vector and raster data access, along with the ability to search for spatial data is covered by the established OGC standards Web Map Service (WMS), Web Feature Service (WFS), Web Coverage Service (WCS), and Catalog Service for the Web (CSW), whereas a recognized standard for distributed spatial data processing was missing for a long time. This issue was addressed by the development of a Web Processing Service (WPS), which has been approved as official standard by the OGC in December 2007 [**Error! Reference source not found.**].

For offering a variety of DEM processing functionalities based on OGC Web Services (OWS) standards, we define and implement a set of such WPS processes. The huge amount of terrain data (especially laserscanner data) for the generation of a DEMs as well as modeling spatial processes based on the DEMs require an enormous demand on IT resources. Particularly during the laserscanning supported capture of three-dimensional data for modeling DEMs, very large data sets results in consequence of the high measuring point density (up to four points per square meter). The potential of this spatial data is increased by the design of services for the preparation, fusion and processing, based on grid technologies. Currently we are developing a range of terrain Web Processing Services (WPS) for generalization, geotessellation, spatial partitioning, converting and semantic streaming (sorted by relevance) of DEM data within the project SDI-Grid (www.gdi-grid.de). These services will be implemented into the German-Grid (D-Grid) Infrastructure. This kind of implementation accounts for various challenges concerning the combination of OGC and Grid standards. Especially the integration of OGC Web Services (OWS) into an Open Grid Services Architecture (OGSA) involves some obstacles which will be brought up later in this contribution.

The remainder of this contribution is structured as follows: Section 2 introduces basic concepts of both Grid Computing and SDIs and discusses how these can work together. Also a short overview of the project SDI-Grid is given. Section 3 gives an introduction of the OGC WPS specification, in particular aspects of processing DEMs and 3D-data with WPS. Section 4 demonstrates proposals for realizing DEM functions as WPS and section 5 illustrates a flood modelling simulation as an example scenario. The last section describes the broader context of related research activities.

2 Grid-Computing and SDI

The project SDI-Grid started in summer 2007 and is funded by the German Ministry for Education and Research (BMBF). The project focuses on solutions for efficient integration and processing of spatial data based on GIS and SDI technologies in a working SDI-Grid infrastructure. This connection of SDI and Grid standards is causing a couple of problems, which are for instance differences in service communication, the implementation of security mechanisms, and definition of service interfaces.

Concerning the service communication, there are differences in the service discovery, description, and messaging. The Grid community follows the IT mainstream. Grid Services are described by the Web Service Description Language (WSDL) and communicate by means of Simple Object Access Protocol (SOAP), both standards of the W3C. On the other side, SDI Web services are based on standards of the OGC. All OGC Web Services (OWS) implement the mandatory operation GetCapabilities for receiving a service description and communicate via the Hypertext Transfer Protocol (HTTP) methods GET and POST. This fundamental difference in the description and messaging methods leads to interoperability problems between OWS and "normal" Web Services. The OGC is aware of this drawback and recently started working on solutions. Lately approaches are developed to describe OGC Web Services with WSDL and messaging with SOAP.

Table 1. W3C and OGC Web Services

Web Service	W3C	OGC
Service description	WSDL	GetCapabilities
Messaging	SOAP/XML	HTTP GET/POST, KVP, GML

Furthermore there are two substantial differences between OGC Web Services and Grid Services. OWS are persistent and stateless, Grid services are transient and condition afflicted. To implement stateful Web Services, the Web Service Resource Framework (WSRF), a collection of specifications under the support of the Organization for the Advancement of Structured Information Standards (OASIS), is used.

For standardization of grid-based applications, the Global Grid Forum (GGF) [3] developed the Open Grid Service Architecture (OGSA). OGSA is a concept for the development of an open Grid infrastructure based on the principles of Service Oriented Architecture (SOA), taking the specifications of the WSRF into account. As a basic implementation of these concepts the software Globus Toolkit 4 (GT4) is used within the SDI-Grid project. The GT4 is an implementation of the Open Grid Service Infrastructure (OGSI), which is the first formal and technical specification of OGSA. It is a collection of software components which provide many of the building blocks that are necessary to create a Grid-based application. For developing Grid applications the GT4 primarily includes a number of high-level Grid infrastructure services that implement interfaces for managing processing power, storage, and other resources [19].

The first task is to achieve that OGC Web Services and the GT4-based Grid-infrastructure can work together. Thereby the SDI-Grid components are adapted to the D-Grid infrastructure. In the following we focus on the OGC Web Processing Service (WPS), since it represents the central component in SDIs for processing data and performing nearly arbitrary calculations. Therefore this Service is the first and major service, which will be connected to the Grid middleware, thus bridging the gap between the GRID world and the OGC world.

3 OGC Web Processing Service (WPS)

The OGC WPS standard was developed for offering any kind of GIS processing functionality by a standardized interface. A WPS may provide simple calculations (e.g. the calculation of a buffer) as well as complex computations (e.g. the simulation of a climate model), whereby a WPS is able to handle more than a single process. That means a WPS instance may provide a set of different processes. According to the specification, there are three mandatory operations performed by a WPS, namely GetCapabilities, DescribeProcess and Execute [14]:

- GetCapabilities returns a brief service metadata document describing the resources of the specific server implementation, and gives a short description of each process offered by the WPS instance.
- DescribeProcess returns a detailed description of a process including its required input- (including the allowed formats) and output-parameter.
- Execute finally run the offered process.

These operations can be requested by a client and performed by a WPS server implementation. Many of the metadata structures are based on the ISO 19115 international standard for geographic information metadata.

In general a client communicates with an OWS via the Hypertext Transfer Protocol (HTTP) by sending a request which is answered with a response by the OWS server. Requests can be executed by the two methods GET and POST. The GET request is simply transported via the Uniform Resource Locator (URL) where the URL has the following form:

http://<server_address>/<server_path>?<parameter_list>.

The <parameter_list> is a sequence of elements in the form <parameter_name>=<value>&. The combination of <parameter_name> and <value> is denoted as a Key Value Pair (KVP) encoding because the name of a parameter always links a pair with its value. The length of an URL is limited and therefore the GET method is only qualified for a handful of parameters. In order to send more complex requests, the POST method is used which allows the embedding of XML encoded documents inside the body of an HTTP message. The request encodings of the three WPS operations are listed in Table 2.

Table 2. Operation request encoding [14]

Operation name	Request encoding
GetCapabilities (mandatory)	KVP
DescribeProcess (mandatory)	KVP and optional XML
Execute (mandatory)	XML and optional KVP

As mentioned above, service communication in line with OWS differs from general computer industry standards. The OGC is aware of this fact and is working on solutions. So, e.g. the WPS is compatible with the Web Service Description Language (WSDL) and the Simple Object Access Protocol (SOAP), and definitions for how to use WPS with these standards have been defined in the specification.

A specific characteristic of the WPS is the passing of input parameters within the Execute request. The specification provides the possibility to hand over required parameters directly within the request or to pass a reference. This means a process requiring a specific dataset (e.g. GML encoded) as input should be able to retrieve this data from a web-accessible resource by using the reference sent within the Execute request. Especially regarding the used Grid Computing environment, this possibility of passing data references instead of raw data within a WPS request offers a huge advantage: required data can be directly stored within the Grid and retrieved by the WPS. So there is no need to send huge amounts of data around.

Due to the generic interface of the WPS, various GIS tasks of arbitrary complexity can be carried out. In our work package in the project SDI-Grid different tasks for processing large DEMs are implemented and integrated into the WPS. These are very calculation and memory intensive DEM-processing operations. Therefore the processing power of a Grid is necessary in order to perform these calculations more efficiently. Generally Grid Computing and OWS act on different interfaces, which prevent communication. This incompatibility problem needs to be solved. To link the two worlds Grid Computing and SDI, the coupling of WPS and Grid takes place via the transport of the processing services into the Grid. This "gridification" of the WPS infrastructure is realized within a special work package within the project. A first version of a generic WPS infrastructure has been developed within the deegree framework, a Java framework offering the main building blocks for SDI based on standards of the OGC and ISO/TC 211 (ISO Technical Committee 211 – Geographic Information/Geomatics) [6].

Within our work package we developed a set of processes for very computationally intensive geometrical preprocessing operations of massive geodata. As there are no OGC standardization proposals for DEM processing functionalities, we developed our own interfaces. These are then linked to the WPS interface and may serve as input for later standardization efforts concerning terrain data handling, especially they may be used for the development of so called WPS profiles which are standardized WPS processes. The developed interfaces and the implemented functionalities are described in detail in the following section.

4 Proposals for Realizing Preprocessing DEM Functions as WPS

In this section we present the terrain preprocessing services. In particular we are developing a range of services for geo-tessellation (WPS Generic Geotessellation Service Framework), spatial partitioning (WPS Spatial Partitioning Service), generalization (WPS Terrain Generalization Service), and streaming (WPS Relevance Sorting Service) of DEM data within the SDI-Grid project. Furthermore there are several services planned along with the Institute of Cartography of the University Hannover in our work package namely the WPS 3D Converter Service and the WPS 3D Generalization Service. Within this paper we will only focus on the first mentioned.

At first we extend the functionally of our existing terrain library. In the second step we make the developed operations available as WPS processes and third we integrate these WPS processes into the Grid infrastructure by using the GT4 as middleware. Finally these WPS terrain operations are integrated within selected use case scenarios by mapping them together with other services in a service chain workflow. After the grid-enablement of the individual components it is possible to send a request from a client to a WPS. The WPS instance will accomplish an authorization and execute the request by accessing the Grid infrastructure.

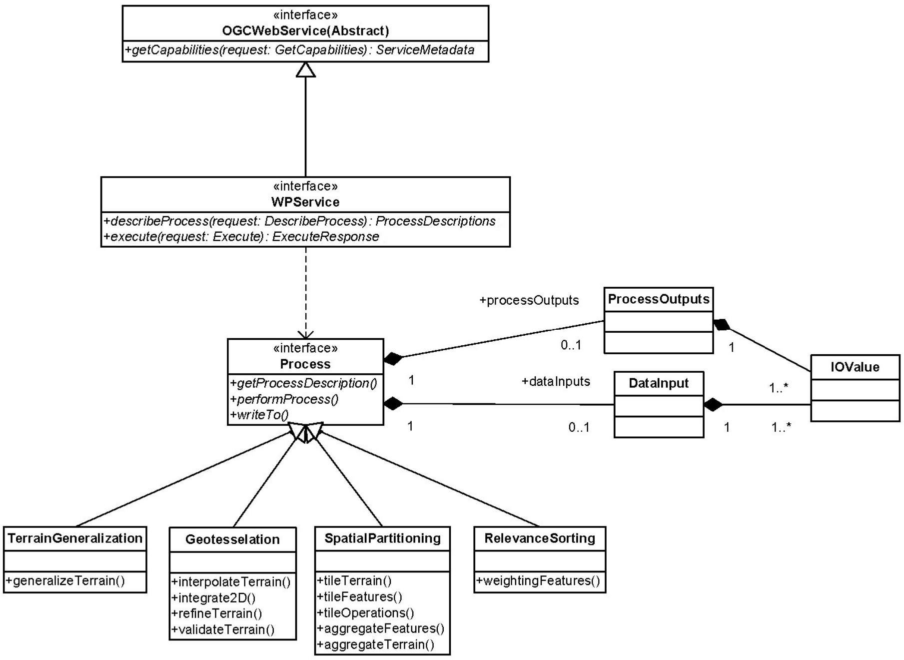

Fig. 1. WPS interface UML diagram with preprocessing services [14]

4.1 WPS Generic Geotessellation Service Framework

The developed Geotessellation Service generates DEMs from massive raw data, e.g. laserscanning data. The resulting surface geometry is stored as Triangulated Irregular Network (TIN). The default tessellation implementation is based on the Delaunay algorithm. This kind of tessellation divides the 2D space into triangles with specific properties, so that the resulting TIN is as regular as possible. Usually the height information is not taken into account during the computation, but attached as an attribute. Although this approach can be very fast, it sometimes yields imprecise results. Surface reconstruction techniques used in CAD software are far more efficient, but optimized for smaller, solid objects.

For geophysical computations like flooding or other hydrological simulations it is very important to reconstruct surface features like dikes and ditches very accurately. The apex line of dikes and banks and the bottom line of ditches must be appropriately represented by the triangulation. Another criterion is the volume of specific surface features, e.g. a river bed. Therefore we implemented a modified Delaunay algorithm, which incorporates the measurement of the surface curvature. In addition to the Delaunay criterion, that no other point may lie within the circum circle of a triangle, we also take the local curvature as an additional factor. The curvature is measured by multiplying the angle between the adjacent triangles at an edge with the edge length. When minimizing this curvature value, the TIN surface becomes smoother, and represents the original surface much better with the same amount of input points.

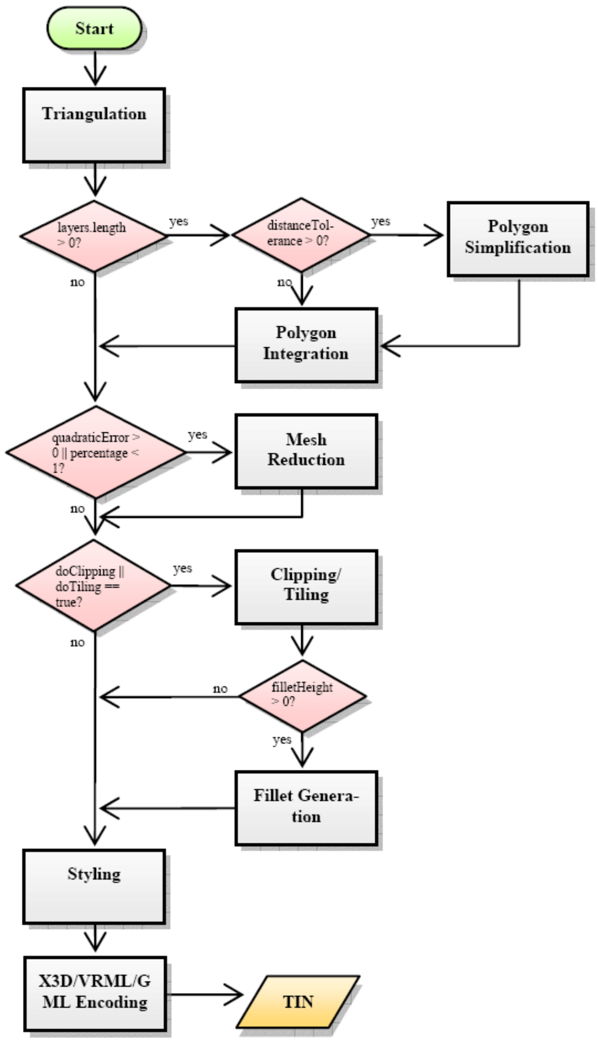

Fig. 2. Process chain of the Geotessellation Framework

The internal process chain of the tessellation functionality is shown in Fig. 2. The subsequent process is the integration of 2D polygon data; in our case areas of different soils, substrate, or land cover [17]. This data can be taken from the GIS of public authorities. The resulting TIN is divided into several segments containing possible additional information on the surface or substrate properties that is necessary for geo-simulations. Currently this segmentation is used for visualization purposes. Areas for vegetation, streets, water, and residential areas are cut into the terrain and different generic textures are applied to these segments.

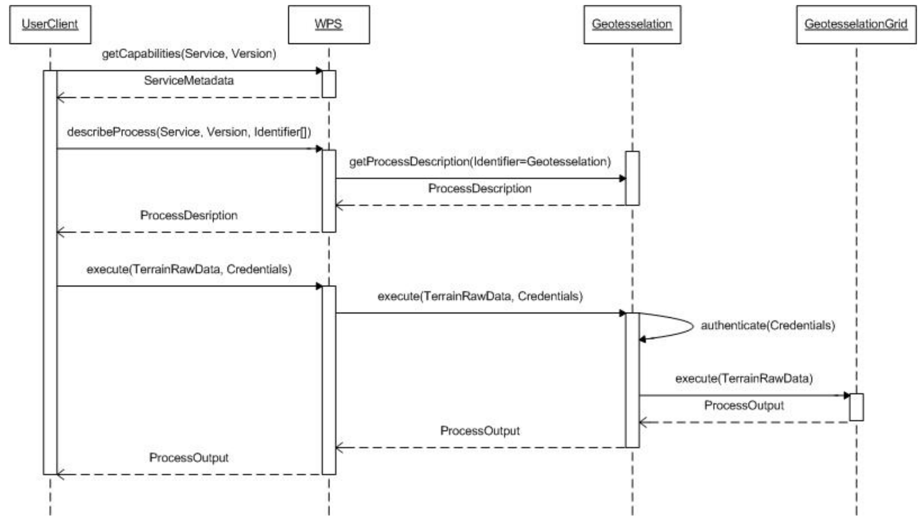

Fig. 3. Grid-enabled WPS Geotessellation workflow UML diagram

Other functions, which can be optionally part of this process chain, include a mesh reduction in order to reduce the geometrical complexity, tiling for cutting off not relevant areas at the borders, and fillet generation that is vertical faces at the borders.

A service client uses the conventional WPS interface. With the service request also credentials for the identification and authorizing to the Geotessellation Service will be submitted. If the authentication is successful the OGC WPS Geotessellation delegates the execution to an appropriate grid-enabled Geotessellation Service, which accomplishes the actual computation within the Grid (Fig. 3)

The parallelization of the whole geo-tessellation process is achieved by partitioning the input data spatially. Therefore the WPS Spatial Partitioning Service, which could be invoked by the WPS Geotessellation Service, is developed. Then it is possible to run many WPS processes in parallel within the Grid infrastructure. The resulting smaller fragments of the TIN afterwards are seamed together in order to reconstruct the final surface. These can then be forwarded to further services.

In order to guarantee the consistency in a parallel tessellation, the Geotessellation WPS parses all input parameters and is responsible for the interpolation of all input raw data and all subsequent steps. The WPS acts thus as central, coordinating component.

4.2 WPS Spatial Partitioning Service

In order to be able to accomplish a distributed processing in a Grid environment, the processes and the data management of the Web services must be parallelized. Depending upon functionality or structure of the data there are several partitioning versions, e.g. tiling datasets, parallelization by features or by operations.

In a preparing step of the parallelization for example, the Spatial Partitioning Service spatially partitions the dataset into smaller chunks or tiles and conducts other servers to execute the described job on the subset in parallel. Thus a parallel treatment, distributed on several Grid-nodes is possible. The spatial segmenting is carried

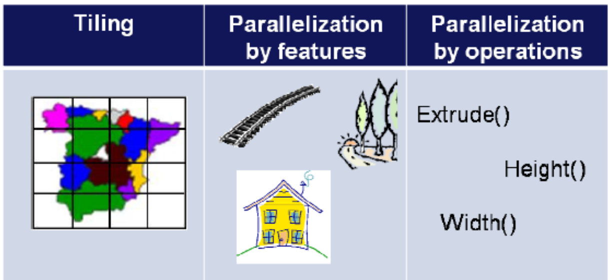

Fig. 4. Spatial Partitioning methods

out depending on the use case and according to different criteria, namely either simply via a raster or on the basis from geomorphologic, administrative or other criteria. The intermediate results are merged after the analysis of the individual tiles into a model.

For example a service call of the Partitioning WPS is made by the Geotessellation Service. The selected terrain area data that needs to be computed is partitioned and tessellated in parallel on the individual Grid nodes. The WPS Spatial Partitioning Service keeps the necessary parameters for partitioning from the inquiring Geotessellation Service as service request. The Partitioning Service makes the partitioning according to the request parameters of the Geotessellation Service and sends the result as service response back to the WPS Geotessellation Service. The service acts as so-called composed service which accomplishes the tessellation on different Grid nodes and administers it in an internal state.

4.3 WPS Relevance Sorting Service

Use-oriented boundary conditions, e.g. the constraint range at the streaming or the limitation of performance from the view of the client, can make it necessary that certain geodata objects or areas are processed with higher priority. Therefore a semantic weighting is to be computed in a preprocessing step dependent on application. This is used as basis for the treatment and the distribution of the geodata or the detail degree of the object with visualization.

Service requests must be treated with different priorities, so that the processes, with which e.g. a client waits for the answer preferentially is treated. In a preprocessing step a weighting of relevant geoobjects in dependence of the use case occurs. A goal is to produce a context sensitive prioritization for the processing of geodata. For the weighting of the geoobjects a standardized relevance function is defined. A classification that takes place which categories geoobjects into important and less important features by mapping corresponding relevance values. For the determination of the relevance values criteria for quantitative design must be specified. This takes place by a classification of the geoobjects depending on geometrical, semantic, visual and structural aspects. The sum of all classification factors results then in the relevance value of the geoobject.

The calculation of the semantic relevance of a geoobject and the assortment derived from it take over its own component, which is likewise put to the Grid over the

OGC WPS as service at the disposal. The relevance calculation takes place in the context of a generic framework.

4.4 WPS Terrain Generalization Service

Multi-scale 3D-models with different Levels of Detail (LOD) play an important role in terrain and landscape models. The goal of this WPS is to offer a service which automatically generates arbitrary generalization grades. Thus the 3D Generalization Service simplifies complex terrain models.

We distinguish components for the generalization of city models and of DEM. Within this paper we only consider the generalization of the terrain.

Based on the criteria given by the user, resolutions are assigned to parts of the described region. Furthermore the intersection of the generalized features with the terrain provided as constraints. For this purpose the Terrain Generalization Service supplies a terrain model according to these specifications.

In form of a database terrain models with low and higher resolution are administrated. The generalization of the based terrain model takes place in dependence of the application scenario as well as the topography. For example a relatively low resolution of the DEM is sufficient with smaller relief dynamics, without changing typical characteristics of the relief. The DEM should adopt to the relief by reducing the geometrical complexity by means of LOD handling. LOD generation is based on a mesh simplification algorithm, which removes elements of the original TIN that have a low significance until a certain error value is reached. To reduce large 3D models captured by laser-scanning, an edge contraction algorithm is used. The result of this procedure is a collection of quadratic surface tiles of different accuracy and size that can be put together in order to build a complete DEM.

The multi-resolution model makes different LODs of terrain geometry available. The administration of the terrain LOD takes place independently of the 3D city models. By the decoupled produced generalization grades of city and terrain model, the resolution and accuracy of the two models are independent. This makes it possible to adapt the resolution of the DEM to the use case. The geometrical consistency between city and terrain model must be guaranteed. This could take place by the definition of a Terrain Intersection Curve (TIC).

The Terrain Generalization Service supports usual formats for terrain models. Independent of the data format, it is important that the terrain model is examined for its consistency. Inconsistencies like gaps or different resolutions can occur as a result of the distributed computation.

5 Use Case `Flood Modeling´

For geophysical computations like flooding or other hydrological simulations it is very important to reconstruct surface features like dikes and ditches exactly. The apex line of dikes and the bottom line of ditches must be appropriately calculated by the WPS Geotesselation Service. Within our work package along with the Institute of River and Costal Engineering of the Technical University Hamburg further services are developed.

The Geotessellation WPS accomplishes an adapted interpolation of the raw data for the flood modeling scenario according to the following criteria:

- recognition and derivation of breaking edges (Feature detection)
- inserting of additional breaking edges
- consideration of area borders

Apart from measuring points of the DEM thus additionally breaking edges, whose altitude also must be given, in a terrain data base are charged with. The triangulation takes place only on request via a Delaunay algorithm, which generates an even triangle meshing. Additionally if terrain edges are present, these must be taken into account during the triangulation of the TIN. The influence of these is visible as hard ridges and sharply bordered terraces. In particular sharp transitions between plain areas and steep hillsides or walls must be preserved. Also contour or height lines could be used as a constraint.

For flood modeling and simulation it is therefore necessary to extend the pure triangulation of sample points (e.g. Delaunay) by the integration of linear feature like breaking edges, which is referred to as Constrained Triangulation (CT).

Also important is the segmentation of the surface into areas with different substrate or vegetation parameters. Rock and soil properties can be used in order to derive hydrological parameters. Especially the infiltration capabilities play an important role in hydrological simulations. Regarding the geometrical solution, the approach of [**Error! Reference source not found.**] can be used. We partition the terrain surface based on 2D areas/polygons which may come from geological, environmental, geo ecological, soil, or other data sets. The result is a DEM consisting of many smaller surface parts within the same TIN representing areas of different attributes, which can then be used as input for further flooding simulations.

To process the high-resolution terrain data, a parallelization takes place by the use of the WPS Partitioning Service. By means of tiling the massive raw data and tesselation at several grid nodes, an area in the context of the discretization process is divided into approximately equal large tiles and processes into dependence of available computing resources.

6 Conclusion and Future Work

The presented components and interfaces are currently being implemented within the German project SDI-Grid. With the now officially released WPS interface, the spectrum of SDI services has been extended, so that the task of SDIs is no longer to only share geo data but also to offer services and computation resources. We showed that the geo community shares some interests with the Grid computing community when it comes to the processing of large terrain data sets and that linking both can be beneficial. Since their development has been carried out in parallel in the past, different technologies have been adopted; however the ideas are very similar. Exploiting Grid computing for SDI geo processing requires a middleware that contains translations between protocols, e.g. HTTP POST to SOAP and additional services for the partitioning and parallelization, which is unfortunately domain specific.

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