Web cartography with open standards – A solution to cartographic challenges of environmental management

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**Abstract**

The visualization of spatial information in the form of maps is a critical task to facilitate decision making in environmental management. Web Map Services (WMS), Styled Layer Descriptor (SLD) and Symbology Encoding (SE) already created an open framework for Web mapping services. However, from the cartographic point of view, the OGC standards have several limitations for producing high quality cartographic representations.

Fortunately, these standards can be cartographically enriched to fulfil the complex visualization requirements coming from environmental management. A solution to creating cartographic visualizations based on open standards was developed in the frame of two major European projects, namely ORCHESTRA (Open Architecture and Spatial Data Infrastructure for Risk Management) and SANY (Sensors Anywhere). For example, the IST – 6th Framework Integrated Project SANY, focuses on interoperability of in situ sensors and sensor networks. In this context, sensors serve as an extreme illustration for the dynamic nature of spatial information that must be represented in the form of maps.

The cartographic extensions for the Symbology Encoding (SE) standards allow expressing cartographic rules with spatial operators and advanced feature filtering for layer masking, flexible point symbolization, and patterns and gradients for all spatial features. Furthermore the critical point of creating thematic maps is also solved with extensions for intuitive choropleth and various diagram types generation.

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1. Introduction

1.1. Motivation

The increased data acquisition capabilities such as sensors led to an exponential rise and availability of environmental data. Moreover simulation of environmental processes, e.g. modelling and simulation of air pollution inside city environments often produces spatiotemporal, high-dimensional and large georeferenced datasets. However, the information analysis and interpretation efficiency is not advancing to the same extent as data acquisition thus creating a “data crisis” (Van Dam et al., 2000) – a bottleneck in understanding the data and gaining insights.

In this context, visualization is a very powerful tool among other knowledge discovery techniques, because it uses the highly developed human pattern recognition skills. To gain better insights and detect patterns, e.g. pollution distribution and impact on population, graphical representation of the numerical data is often more adequate than looking at raw or tabular data. It is widely accepted that graphical representation of numerical data is a key element for understanding complex environmental processes (Van Dam et al., 2000).

Moreover the major challenge for the next generation of Environmental Systems is that they have to be based on open standards that enable interoperability (EC, 2007). This challenge has been undertaken by two major European projects, namely ORCHESTRA (Open Architecture and Spatial Data Infrastructure for Risk Management) and SANY (Sensors Anywhere). Both of these projects, in which the Institute of Cartography at ETH Zurich was responsible for the means of visualization of spatial and thematic data, have been proposed for the environmental management domain, a domain with highly dynamic and sometimes volatile data sources. The ORCHESTRA Integrated Project solved the lack of interoperability for risk and environmental information and provided an open service-oriented architecture (SOA) which is enabling risk information management across Europe (Klopfer and Kannellopoulos, 2008). The IST – 6th Framework Integrated Project SANY advances the results of ORCHESTRA with a focus on...
interoperability of in situ sensors and sensor networks. SANY aims to create an effective and cost-efficient service-oriented architecture for data exchange from currently incompatible sensor and data sources. In addition, one of the major objectives of the project is to develop advanced data fusion and decision support, making use of the new architecture for providing added value to end users.

By solving the problem of coupling different systems so they can interoperate, ORCHESTRA and SANY expects the emergence of networks of risk management systems. Managing risks (including supporting decisions) is a complicated problem as usually many interested parties have a stake in the process. Depending on the problem, sometime decisions must be taken rapidly based on cartographic visualizations for the careful examination of risks.

Therefore an important design requirement for the service architecture was to endorse high quality, standards-based cartographic output as part of more complex Decision Support Systems (DSS). Such map-centric DSS can be efficiently deployed in the various phases of the risk management cycle. In case of a disaster, where life and property are in stake, cartographic visualizations must occur automatically based on predefined rules, without sacrificing visual differentiation of features or the legibility of the map.

1.2. Open standards for web cartography

Standards-based interoperability is a must when up-to-date data from various systems has to be collated to provide the latest view of the problem. From this point of view, the Web Map Services (WMS) is currently the only widely accepted open standard for map visualization as demonstrated by the fact that the majority of GIS software solutions have implemented the OGC WMS standard.

In an attempt to disseminate elements of desktop GIS to a larger audience over the Web, major GIS vendors created their own Web mapping systems. Unfortunately most of these interactive mapping systems were developed as a set of proprietary implementations with no published interfaces. To address this problem, the Open Geospatial Consortium, Inc. (OGC) developed a non-proprietary Web mapping approach based on open interfaces, encodings and schemas – Web Map Services (WMS) and Styled Layer Descriptor (SLD) Specifications (ISO, 2005; OGC, 2002). These standards solve the above problem by defining a way to enable the visual overlay of complex and distributed geographic information maps simultaneously, over the Internet.

The Web Map Server (WMS) Specification standardizes the way in which Web clients request maps. Clients request maps from a WMS by naming map layers and providing parameters such as the size of the returned map and the spatial reference system to be used in drawing the map. The WMS (which recently became also an ISO standard for Web map services) defines three operations: GetCapabilities (returns service metadata), GetMap (returns a map as digital file) and GetFeatureInfo (optional operation that returns feature information at a specified location). The Styled Layer Descriptor Implementation Specification standardizes how the Web Map Server specification can be extended to allow user-defined symbolization of feature and coverage data, this being the most important standard for cartography. SLD is an XML-based (Extensible Markup Language) description language for extending Web Services such as Web Map Services (WMS), Web Feature Services (WFS) and Web Coverage Services (WCS). Main advantages of SLD are the structuring of the style attributes and understandability for computers as well as for users. Since OGC Web Services are based on layers, each layer can be symbolized with user-defined styles. For fine-grained selection and symbolization of individual geometric features, SLD makes heavy use of another OGC standard, namely the Filter Encoding Standard (FES). It defines an XML encoding for filter expressions that logically combines constraints on the properties of a feature in order to identify a particular subset of features to be operated upon. For example based on constraints specified on values of spatial, temporal and scalar properties it is possible to identify a subset of features and render them in a particular color.

Another OGC standard – Symbology Encoding (SE) – together with the Styled Layer Descriptor Profile for the Web Map Service Implementation Specification (OGC, 2005a,b) are the direct follow-up of the Styled Layer Descriptor Implementation. SE is the most recent OGC standard for portrayal of geographic information. The SLD specification document was split up into two documents to allow the parts that are not specific to WMS to be reused by other service specifications. For the scope of this paper, in order to prevent confusion, the notion of SLD includes also to the latest Symbology Encoding Implementation Specification as applicable for the Web Map Service Specifications.

1.3. Shortcomings of existing standards for web cartography

The combination of Web Map Services (WMS), Styled Layer Descriptor (SLD) and Symbology Encoding (SE), already provides a viable basis framework for basic topographic representations. However advanced cartographic features like user-defined point symbols, multi-layered symbols, transparencies, textures, marking, patterns and diagrams are the means that enable the cartographer to achieve map quality required by environmental management applications: a good differentiation of features and map legibility. In this direction OGC WMS and SLD standards are generally considered as too restrictive. Absence of custom vector-based point symbols, patterns for spatial features and layer transparencies severe limit the use of WMS from a cartographic perspective. Moreover, its inappropriateness to create thematic maps is the main reasons why WMS is used for presenting topographic maps, and not for thematic representations.

Fortunately, these standards are very flexible and can be cartographically enriched to fulfill the complex visualization requirements coming from environmental management. This paper presents the researched performed for advancing open standards from the cartographic perspective and describes extensions to standards as a solution for cartographic challenges of environmental management.

2. Web cartography for environmental and risk management

2.1. Distributed and dynamic data sources – a new challenge for web cartography

SOA and Web services allow seamless information integration by abstracting the complexity of the heterogeneous nature of the data sources. And this change from static to dynamic and distributed data sources requires new ways of creating cartographic visualizations (Hurni et al., 2006). In this context, sensor data, as handled within the SANY Project, serve as an extreme illustration for the dynamic nature of spatial information that must be represented in the form of maps. Modern Web cartographic applications are required to immediately reflect the updates in the data without sacrificing the cartographic quality.

This novel situation has a considerable influence on the established cartographic workflow. In order to produce the map, cartographers do not have the possibility anymore to prepare and symbolize directly the data. They might even know that certain parts of the data are being changed or updated on a continuous basis (as in the case of sensor data). Therefore data symbolization has to be thoroughly controlled in an open and distributed manner by...
Cartographic Web Services. Such services must contain two major components: an open cartographic interface and cartographic rules. The open cartographic interface is required for the communication with other services and clients within a SOA. Abstract cartographic rules are required to produce cartographically correct representations of the current state of the data, so that a defined visualization workflow holds through the progression of time.

2.2. Cartographic interfaces

Cartographic interfaces refer to a software interface defining the desired map symbolization adapted to the area of distributed mapping. It has been recently recognized that cartographic web applications evolved from closed monolithic applications to open distributed systems in which real-time map rendering components and services play an important role (Sykora et al., 2007). Conceptually, SOA represents an architectural style based on loosely coupled interacting software components that provide services. A service can be defined as a piece of functionality made available by a service provider in order to deliver end results – a map in the case of Cartographic Web Services – for a service consumer. Everything is built upon the basic concept underlying the Web, the concept of request–response. A service consumer sends a service request to a service provider. The service provider returns a response to the service consumer containing the expected results. In SOA, services are the crucial element to develop applications, by organizing them into a set of interacting services (Alonso et al., 2004; Erl, 2008).

SOA enforces the concepts of interfaces and messages. Interfaces are defined for all participating services and they should be universally available for all providers and consumers. Messages are described and constrained by an extensible scheme and delivered through the interfaces. With these two concepts one can precisely describe the functionalities that a service provides, and they will be used extensively to present the developed cartographic Web service, namely the Map and Diagram Service.

Cartographic Web Services must offer a cartographic interface that combines advanced cartographic output with the generality and standardization of OGC specifications. Specifically, in the frame of the ORCHESTRA and SANY projects, the Map and Diagram Service was designed to pursue the vision for Cartographic Web Services.

The Map and Diagram Service can be defined as a service that visualizes, symbolizes and enables the geographic clients to interactively visualize topographic and thematic data. Its main task is to transform geographic data (vector or raster) and/or thematic data (e.g. census data, results of risk susceptibility analysis) into a graphical representation using cartographic rules.

The main design consideration is not to replace existing standards, but to extend them for cartographic usage. To support interoperability and use of open standards, the Map and Diagram Service is based on and enhances the OGC standards. The Map and Diagram Service Specifications introduces several operations based on the WMS and SLD standards as shown in Fig. 1.

Specifically the Map and Diagram Interface follows and complies with the WMS 1.3 specifications and the SLD profile for the WMS. The design of this cartographic Web service was modelled in UML according to the design standards of the ORCHESTRA Project. The well-known WMS requests can be recognized in the presentation of the Map and Diagram Interface Fig. 2.

The usage of the above operations for Web mapping applications is straightforward. A short illustration into the applicability of the Map and Diagram Service is provided on the example of the SANY Decision Support System developed by Spacebel, Belgium. As shown in Fig. 3, the SANY DSS integrates a web mapping component for displaying in near-real time sensor fusion results (e.g. a spatial or spatiotemporal interpolation) in the map viewer. In this manner the map viewer is the front-end (client) to a cartographic web service instance.

The GetMap is the main operation allowing the visualization of the fusion results. The graphical user interface allows the human user to create an appropriate style (e.g. choropleth and contours),

![Fig. 1. The interface of the Map and Diagram Service.](image)

<table>
<thead>
<tr>
<th>Operation Name</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>getMap</td>
<td>Returns a map of spatially referenced geographic and thematic information as an image document.</td>
</tr>
<tr>
<td>getDiagram</td>
<td>Returns a diagram representation of tabular data as an image document.</td>
</tr>
<tr>
<td>getFeatureInfo</td>
<td>Returns information about the features rendered in a certain point of a map or diagram layer.</td>
</tr>
<tr>
<td>getLegendGraphic</td>
<td>Returns a legend symbol corresponding to a layer as an image document.</td>
</tr>
<tr>
<td>getLayerDescription</td>
<td>Returns a layer description document containing schema information for a layer.</td>
</tr>
<tr>
<td>getStyle</td>
<td>Returns the cartographic rules (style) associated with a layer.</td>
</tr>
</tbody>
</table>

![Fig. 2. The operations of the Map and Diagram Service Interface.](image)
constructs the parameters of the GetMap operation (which includes the user style) and finally the map viewer performs the request in order to obtain the desired visualization in real-time. In addition spatial navigation (zoom, pan, recenter) and layer management is always controlled by the parameters of the GetMap request message, so that the user always receives the appropriate visualization within the interactive map.

The Map and Diagram Service enables clients to send data (along with the style) to be rendered as part of the request message for creating more complex client-side functionalities, i.e. real-time user editing or display of processed data. This is also the case of the SANY DSS, where it is possible to either reference the fusion results (available on FTP server or another Web service like a Sensor Observation Service) or to directly embed the computed data inside the request. The current Map and Diagram Service Implementations allows and encourages the clients to send their data using other open OGC standards, such as GML (Geographic Markup Language), or Sensor Web Observation and Measurements. Another useful highlight of extending the GetMap request for the environmental management is the introduction of a DPI parameter which allows creating maps with different resolutions, including for printing purposes.

Although the other operations of the Map and Diagram Interface are not as prominent as the GetMap operation, they have nonetheless their importance for Web mapping applications. The GetFeatureInfo and GetDiagram are useful for reporting information about the features present at/near a specified point in the map. GetLayerDescription operation offers extended information about the data layer (including the attribute names and corresponding value types and ranges). GetLayerLegend operation returns a map or diagram legend for a specific layer. Finally, the GetStyle operation allows the clients to retrieve the symbology associated with any layer available on the server, which opens new possibilities not only for exchanging cartographic rules but also for collaboratively improving the cartographic output.

2.3. Connection to open standards

The Map and Diagram Service Specifications represent an open standard and are modelled according to the Reference Model for the ORCHESTRA Architecture. Even though the specifications are structured in a different manner in comparison with OGC standards, they can be mapped to the current OGC standards in straightforward manner. For example, the basic parameters of the GetMap request are mapped in the WMS standard, and the operations not present in the OGC standards can be mapped to the OGC way of presenting specifications. For example, the Get Style Operation can be described in an OGC-Style as shown in Fig. 4.

The specifications can be also directly mapped to other protocols as the ones defined in the OGC standards. The current HTTP GET interface defined for WMS has some major limitations preventing to use the full power of web services in the cartographic domain. Not only that it is not possible to transport large SLD and GML messages but also dynamic discovery and integration of such services is reduced due to the absence of a machine-understandable standard interface description.

The W3C recommendation for web services is WSDL/SOAP/ UDDI (Web Services Description Language/Simple Object Access Protocol/Universal Description, Discovery and Integration). Among the standards for Web services, the combination WSDL/SOAP/
3. Cartography with open standards

3.1. Cartographic rules

The Map and Diagram Service Specifications extend the WMS/SLD standards with cartographic features such as various diagram types (e.g., pie diagrams, bar diagrams), definition of complex point symbols, data distributions, transparency levels for individual layers, patterns, advanced texture mapping and feature masking with spatial operators. Symbology Encoding (SE) is the grammar for styling map data independent of any service interface specification. As symbology encoding is independent of the data itself, it provides a powerful basis to build the cartographic extensions. From the cartographic point of view, the symbology (that is to be applied to a feature type) is defined by a Feature TypeStyle containing rule definitions.

On a conceptual level, cartographic rules need three parts: generic conditions when cartographic rules are to be applied considering the overall suitability for a specific map (e.g. scale-dependent map symbolization), specific conditions for selecting (and expressing) the geometric features to be symbolized, and finally the definition of symbology. This conceptual classification can be directly mapped to the SE, as Rules are used to group rendering instructions by feature-property conditions and map scales. Therefore SE Rules are an appropriate mechanism to express cartographic intentions.

The elements present inside a Rule can be assigned to the conceptual classes discussed above: generic matching conditions (se:MinScaleDenominator, se:MaxScaleDenominator), specific matching conditions (ogc:Filter) and the symbology definition (se:Symbolizer).

The MinScaleDenominator and MaxScaleDenominator elements represent the minimum and maximum ranges of scale (denominators) of maps for which a rule should apply. The minimum scale is inclusive and the maximum scale is exclusive. The absence of a MinScaleDenominator element means there is no minimum scale term to the condition or logically that the default value is 0. The absence of a MaxScaleDenominator element means that there is no maximum scale term to the condition of logically that the default value is infinity. The definition is the same as in the OGC standard, but due to the additional DPI parameter added to the Map and Diagram Service Interface, the values used for the scale denominators are not necessarily expressed relative to the standardized rendering pixel size of 0.28 mm × 0.28 mm (common pixel size for contemporary video displays). If the DPI parameter is specified, no additional conversions to the standard pixel size are required and the scale calculation follows the known algorithm. For example, the computation for DPI = 100 is: 100 dpi ≥ 1/100 inches × 25.4 mm/inch = 0.254 mm (pixel size) ≥ 0.254 mm × 1000 mm/m = 0.000254 m (pixel size in meters). In the absence of the DPI parameter, it is used the standardized rendering pixel size of 0.28 mm corresponding to the resolution of the contemporary video displays.

3.2. Feature selection and masking with cartographic rules

The Filter element of a Rule allows a detailed expression and selection of features. In order to enable cartographers to describe complex cartographic rules, the use of this element is extended with manipulation of geometries to enable cartographic masking rules. As a result, it goes beyond the simple feature selection controlled by attribute conditions present in the current SLD/SE standards while keeping the conformance with the OGC Filter Encoding Specifications.

An important cartographic requirement of testing spatial relationships between two geometric objects is supported by relational operators as defined by the OGC Filter Encoding Specifications. They are Boolean methods that are used to test for the existence of a specified topological spatial relationship between features as they would be represented on a map. The available spatial operators are Equals, Disjoint, Touches, Within, Overlaps, Crosses, Intersects, Contains, DWithin, Beyond, BBOX.

However, cartographers are usually using complex geometry manipulations for various symbolization masking purposes and thus the current usage of the Filter for selection of features is inherently restrictive. Fortunately, the Simple Features Implementation Specifications have all the concepts required to enable the descriptive modelling of cartographic manipulation of UDDI have gained strong industry support, and represent a standard way for doing Web services (Cerami, 2002). Alongside the HTTP GET request method for the Web Map Service, the Map and Diagram Service Specifications introduce a SOAP binding which together with the service description in WSDL tries to follow and improve the latest change proposals of the OGC to offer support for WSDL and SOAP. This approach allows building clients directly from service interfaces expressed in WSDL. The Map and Diagram Service provides a SOAP interface for all its operations with the goal of making Web map services more accessible to a large variety of applications requiring integration of mapping components based on dynamic discovery.

The complete description in prose, UML, WSDL and XML schema of the MapDiagramInterface, its operations and their parameters, can be found in (Iosifescu, 2007). The interested reader may refer also to the ORCHESTRA Book (Klopfer and Kannellopoulos, 2008) for a complete picture of the Map and Diagram Service and its role as a Cartographic Web Service in the ORCHESTRA/SANY Architectures (Usländer, 2007).

<table>
<thead>
<tr>
<th>Request Parameter</th>
<th>Mandatory/Optional</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>VERSION=1.x.x</td>
<td>M</td>
<td>Request version.</td>
</tr>
<tr>
<td>REQUEST=GetStyle</td>
<td>M</td>
<td>Request name.</td>
</tr>
<tr>
<td>LAYER=layer_name</td>
<td>M</td>
<td>Name of one layer for which the style should be returned.</td>
</tr>
<tr>
<td>STYLE=style_name</td>
<td>O</td>
<td>Comma-separated list of one or more rendering styles per requested layer.</td>
</tr>
<tr>
<td>FORMAT=output_format</td>
<td>M</td>
<td>Output format for the returned style (default = SLD/SE).</td>
</tr>
<tr>
<td>EXCEPTIONS=exception_format</td>
<td>O</td>
<td>The format in which exceptions are to be reported by the WMS (default=XML).</td>
</tr>
</tbody>
</table>

Fig. 4. GetStyle request parameters presented in the manner of the WMS 1.3 specifications.
geometries as long as in addition the relationship between symbolized features and geometry is enforced.

In addition the Binary Spatial Operators presented above, the spatial operators can be extended with Geometry Spatial Operators as presented formally with the XML schema fragments. First the new Geometry Spatial Operator XML type is defined:

```xml
<xs:complexType name="GeometrySpatialOpType">
  <xs:complexContent>
    <xs:extension base="ogc:SpatialOpsType">
      <xs:choice>
        <xs:element ref="gml:Geometry"/>
        <xs:element ref="gml:Envelope"/>
        <xs:element ref="sld:NamedLayer"/>
        <xs:element ref="sld:UserLayer"/>
      </xs:choice>
    </xs:complexContent>
  </xs:complexType>
</xs:complexType>
```

Based on the above type the following well-known geometry manipulation operators can be defined:

```xml
<xs:element name="Intersection" type="ogc:GeometrySpatialOpType" substitutionGroup="ogc:spatialOps"/>
<xs:element name="Union" type="ogc:GeometrySpatialOpType" substitutionGroup="ogc:spatialOps"/>
<xs:element name="Difference" type="ogc:GeometrySpatialOpType" substitutionGroup="ogc:spatialOps"/>
<xs:element name="SymDifference" type="ogc:GeometrySpatialOpType" substitutionGroup="ogc:spatialOps"/>
<xs:element name="Distance" type="ogc:GeometrySpatialOpType" substitutionGroup="ogc:spatialOps"/>
```

The semantics of the above operators are described in detail in the Simple Features Implementation Specifications. The effect of several operators is very well illustrated in, JTS Technical Specification ([http://www.vividsolutions.com/jts/jtshome.htm](http://www.vividsolutions.com/jts/jtshome.htm)) from which we refer Fig. 5.

For layer masking purposes, the remaining spatial methods defined by in Simple Features Implementation Specifications for creating buffers, or the convex hull are also introduced. Therefore cartographers are now able to manipulate geometries in a descriptive way for styling purposes. Conceptually, all Geometry Spatial Operators apply to the immediate geometry definition, either the layer itself or to the geometry above in the nesting of a complex expression. Most Geometry Spatial Operators take as input a geometry and provide as output a geometry that can be used in every expression that expects a gml:Geometry or gml:Envelope. Similarly the Distance operator can be use in place of an ogc:Literal in other more complex expressions.

A most important aspect for cartographers can be evidenced in the syntax of the GeometrySpatialOpType which allows the use of symbolized layers in Geometry Spatial Operators. When the parametrized geometry is defined by the sld:NamedLayer or the sld:UserLayer elements, it is possible to include the reference to an sld:NamedStyle or sld:UserStyle. In such cases, the geometry of the symbolized features referred by the sld:NamedLayer or the sld:UserLayer elements must be used in the expressions instead of the simple feature geometry. For example, in a Difference operator as previously illustrated, the A geometry is represented by the input layer to which cartographic rule directly applies, and the B geometry is represented by another layer (symbolized or not) as referenced by sld:NamedLayer or sld:UserLayer elements. The advanced used of the proposed extension not only provides cartographers with the expressiveness and flexibility required for the creation of cartographic rules but it is envisioned that will play an important role in the detection and elimination of cartographic conflicts.

The usefulness of spatial operators is shown by example. In a topographic map we want to overlay height contours on top of other based layers. If such contours (available as a line geometry layer or generated from the DEM) are directly added to the map the result is not satisfactory. For example contours should not be displayed on top of cliffs due to the high variance in height. Therefore, in a first step we must extract only the contours that do not intersect areas covered by cliffs. For this purpose we can make use of the defined Difference spatial operator, which eliminates the contours on top of the cliff areas. Moreover in order to improve the visual contrast of the contours we would like to assign a different symbolization for the contours on top of barren land than for the remaining relevant contours. This can be achieved by combining the Difference spatial operator with the Intersection operator to symbolize only the relevant contours according to our cartographic requirements. The constructed Filter defines that the features

![Fig. 5. Effects of spatial operators on polygon geometries (after Vivid Solutions).](image-url)
present in the contours layer are to be clipped with the rock areas and in addition to be intersected with the barren_land areas before being symbolized as shown in Fig. 6:

As a result of this cartographic rule, the desired masking of features is obtained dynamically, without the need for manual processing or intermediate datasets.

The comparison, logical and spatial operators can be used to build complex rules. They are built by nesting the operators as described in the Filter Encoding Specifications. With the use of the extended spatial operators and considering also the added power provided by the Arithmetic Operators (Add, Sub, Mul, Div), the expressiveness of the OGC Filter is enhanced beyond the

```xml
<Filter xmlns="http://www.opengis.net/ogc">
  <And>
    <Difference>
      <NamedLayer xmlns="http://www.opengis.net/sld">
        <Name xmlns="http://www.opengis.net/sld">Vegetation</Name>
        <UserStyle xmlns="http://www.opengis.net/sld">
          <FeatureTypeStyle xmlns="http://www.opengis.net/sld">
            <Rule xmlns="http://www.opengis.net/sld">
              <Filter xmlns="http://www.opengis.net/ogc">
                <PropertyIsEqualTo xmlns="http://www.opengis.net/ogc">
                  <PropertyName xmlns="http://www.opengis.net/ogc">VEGE_TYPE</PropertyName>
                  <Literal xmlns="http://www.opengis.net/ogc">rock</Literal>
                </PropertyIsEqualTo>
              </Filter>
            </Rule>
          </FeatureTypeStyle>
        </UserStyle>
      </NamedLayer>
    </Difference>
    <Intersection>
      <NamedLayer xmlns="http://www.opengis.net/sld">
        <Name xmlns="http://www.opengis.net/sld">Vegetation</Name>
        <UserStyle xmlns="http://www.opengis.net/sld">
          <FeatureTypeStyle xmlns="http://www.opengis.net/sld">
            <Rule xmlns="http://www.opengis.net/sld">
              <Filter xmlns="http://www.opengis.net/ogc">
                <PropertyIsEqualTo xmlns="http://www.opengis.net/ogc">
                  <PropertyName xmlns="http://www.opengis.net/ogc">VEGE_TYPE</PropertyName>
                  <Literal xmlns="http://www.opengis.net/ogc">barren_land</Literal>
                </PropertyIsEqualTo>
              </Filter>
            </Rule>
          </FeatureTypeStyle>
        </UserStyle>
      </NamedLayer>
    </Intersection>
  </And>
</Filter>
```

![Fig. 6. Improved contours legibility with the use of spatial operators (a), (b).](image)
definition of a combination of one or more symbols that evaluate to single Boolean value of true or false. The enhanced OGC Filter can now be used not only to select features from the original layer, but also to modify the features according to the cartographic requirements.

4. Cartographic symbolization rules with applicability for sensor management

4.1. Cartographic symbolization

The Cartographic Rules contain Symbolizers which describe how the geometries are to be represented on the map. When a cartographic rule is matched, the target features are applied a specific symbolization. And the expressiveness of the symbolization is one of the major concerns in cartography. The concepts of SLD and SE are inherited and enhanced in order to achieve the goal of providing expressive means for map symbolization (OGC, 2004).

Cartographic symbolization can be achieved with the following symbolizers: Raster, Polygon, Line, Point, Text and Diagram Symbolizers. Beside the newly defined Diagram Symbolizer, all the other symbolizers are inherited from SE in order to achieve a complete compatibility with the existing standards. In the following the enhanced capabilities of the Symbolizers are to be explained restrictively regarding cartographic representation.

Before map symbolization with the use of Symbolizers is presented, it is necessary to understand the underlying model of rendering as each matching rule is applied following the painters model. This model of rendering is best explained by the SVG standard (W3C, 2003). Paint represents a way of putting color values onto the canvas and it might consist of both color values and associated alpha values which control the blending of colors against already existing color values on the canvas. For cartography it is important to notice that paint is applied in successive operations and that each operation paints over some area of the canvas. When the new area overlaps a previously painted area the new paint partially or completely obscures the old. When the paint is not completely opaque the result on the output device is defined by the rules for compositing.

4.1.1. Symbolization of reference data

Reference maps must usually follow the traditional cartographic theory: the base layer represented by topography is followed by land cover, hidrology, transportation network, buildings, and finally labels. The topographic base layer is normally represented by a shaded relief. For cartographers especially, the production of a shaded relief is of outmost importance.

A shaded relief can be obtained starting from DEM (digital elevation model) available as a raster data source. The shaded relief can be produced using a Raster Symbolizer. The definition of the Shaded Relief is enhanced with parameters like Azimuth and Altitude which better specify the direction and the altitude angles of the illumination used in shading algorithms. The ReliefFactor maintains the role of specifying the value (vertical) exaggeration to use. Furthermore, the geometry element that is present in the Raster Symbolizer (either as GML or computed with the aforementioned spatial operators) can be used to specify detailed areas where the parameters take effect. In case of several rules containing relief shading of the same DEM but for different areas (as specified by the geometry), then the system default behaviour should be to ensure a smooth transition between the shaded areas. Cartographers also have the freedom to experiment with more complex rules. For example rules can be created for enhancing a shaded relief in both contrast and detail by averaging two shaded relief representations with different vertical exaggerations of the height or by producing coloured shaded relief.

In the definition of the Raster Symbolizer are also defined new elements like Isolines (Fig. 3), Aspect and Slope. For example the MinValue and MaxValue specify the values between which the contours are represented. Equidistance specifies the difference between the values (interval) on which the contours will be drawn. The offset parameter allows the user to specify an offset so that the contours can be drawn also between the round values specified by the equidistance, i.e. contours are drawn in the position defined by equidistance plus offset.

Another important topic is the availability of encodings for patterns and gradients as shown in Fig. 7. Patterns and gradients are normally encountered in a variety of cartographic representations therefore a vector-based solution for expressing them is an important addition to the SE standard. The definition of the patterns and gradients are based on the widely accepted standard Scalable Vector Graphics (SVG 1.1, 2003). The SE makes use already of several SVG/CSS2 parameters with identical names and semantic. SVG has been used successfully for cartography due to its good graphic description capabilities. The chosen solution for the definition of patterns and gradients is to enhance the Fill element with the corresponding SVG syntax. Being based on SVG, it is possible to create complex and seemly random patterns as the ones

Fig. 7. Patterns for various polygon (a) and line (b) features.

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needed for scree representation on topographic maps as illustrated in Fig. 7a. Such patterns can be created in a straightforward manner by using vector graphic programs such as Inkscape (open source) or Adobe Illustrator (commercial).

Advanced graphical output as supported by SVG (vector-based definition for pattern and gradients) is also included among the extensions for line symbolization as demonstrated in Fig. 7b. The SVG pattern and gradients for line symbolization can cover a variety of cartographic situation, where scalable textures (as expressed by SVG patterns) or a gradual change between specified colors (gradients) are required to increase the expressiveness of the map symbolization. More complex line types can be created with the help of the spatial operators. Asymmetric line symbolization is possible with the use of the Displacement and PerpendicularOffset elements as defined in the SE specifications as illustrated in Fig. 8.

Point and text symbolization are also enhanced as unfortunately the SE defines only a basic Mark which has colouring applied to it. The use of standard marks are obviously restricted to “square”, “circle”, “triangle”, “star”, “cross”, and “x”. The alternative to is an external or in-lined graphic format which is handled as “a little picture”, thus limiting its scalability. A better solution is to enhance the “Mark” element explicitly with SVG (Scalable Vector Graphics) definitions, thus an SvgSymbol element can contain any valid SVG code including gradients and patterns. For example a church conventional symbol can be defined in SVG and then aligned with a building by providing an appropriate rotation angle. Text symbolization is achieved with the TextSymbolizer, which describes the representation of labels on the map (Fig. 8).

Additional features very important for cartography are Displacement and PerpendicularOffset elements that apply to geometric symbolizers. Furthermore by accepting multiple SLD “Rule” elements for a selection of features in a layer, more complex representations for topographic features according to cartographic conventions can be achieved (e.g. for road maps).

4.1.2. Symbolization of thematic data

Although diagram symbolization of geographic features is an effective way of representing thematic data in a spatial context, the current OGC standards do not support representations of multiple...
data values using diagrams. Considering the creation of choropleths, the representation of features has to be specified in a very lengthy description of the individual classes and their thresholds. There are no options like ‘graduated symbol’ or ‘unique value’ which make the creation of thematic maps straightforward in current desktop GIS software. As such, the extension of the current OGC standards with definitions to support thematic mapping was a priority for the environmental management domain.

The Diagram Symbolizer is the most important thematic extension. The core of this symbolizer is the diagram element, a graphic symbol suitable for thematic mapping (e.g. proportional symbols and diagrams) as shown in Fig. 9. The WellKnown Name element gives the type of the diagram.

Allowed values include at least “Pie”, “Bar”, “Line”, “Area”, “Ring”, and “Polar”, though map servers may have additional (specialized) ones. Some of them have additional options like normal, stacked or percent. The Category element defines one of multiple values to be represented in the diagram. The Gap element is an optional gap distance given to the Category. It is to be used by the various diagram types to define a distance in rendering the various categories (e.g. for bar diagrams it represents a gap between bars and for pie diagrams it represents how much a category should be exploded). The Scale element allows scaling the defined absolute size of the diagrams or symbols to various map scales while the scale denominators MinScaleSize-Multiplication and MaxScaleSizeMultiplication represent a multiplication factor in order to compensate for map scale changes.

The Diagram Symbolizer allows SLD/SE extension for a thematic mapping profile of SLD (for point symbols) and does not impose unnecessary changes in existing SLD/SE implementations. In addition to diagram maps, the defined DiagramSymbolizer can be extended with other types of thematic visualisations present in current cartographic literature such as proportional symbol maps and dot density maps (Hake et al., 2002; Slocum et al. 2005).

For choropleth creation, the definition of classification methods like “EqualInterval”, “NaturalBreaks”, “Quantile”, “StandardDeviation” makes the creation of choropleths maps straightforward. Classification methods allows interactive Web mapping clients to easily serve also as exploratory data visualization backend tools (a requirement in the risk management domain). It allows the user to get a first impression of the spatial distribution of the attribute data before creating more lengthy ogc:Filters definitions to manually define classes.

4.2. Applicability of cartographic rules for sensors and environmental monitoring

Sensors are an important source of spatial information in risk management. This kind of data usually is very dynamic and therefore it is appropriate to distribute it with a web service such as the OGC Sensor Observation Service (SOS). Like this, redundancy is avoided and all the clients are able to use data that is up-to-date.

Through a cartographic interface, data symbolization can be coordinated based on cartographic rules that are independent of the physical model of the data. By abstracting the physical model, we take into consideration the basic conceptual data model from the Symbology Encoding specifications. Therefore the specific format in which the data is available is flexible. Depending on a specific implementation of the Map and Diagram Service, various data formats may be supported such as GML/WFS, PostgreSQL, Oracle Spatial, IBM DB2 with ArcSDE, or even Sensor Web Observation and Measurements.
A proof for the generality of the Map and Diagram Service Specifications is its interoperability with the SANY services for accessing, managing, processing of information and event notifications for sensors and sensor networks (SANY, 2008). The sensor-specific services defined by SANY are primarily based upon the standards of the OGC Sensor Web Enablement (SWE) initiative, and in this context the Sensor Observation Service (SOS) and Sensor Alert Service (SAS) are primarily data sources for sensor related map visualizations. A basic map with red and green pictographic icons is valuable for depicting the functioning state of the sensor (working/not working). Thematic maps that can be created using cartographic rules for choropleths, diagrams and contours are especially useful for sensor data representations.

To facilitate interpretation of sensor data, the Map and Diagram Services defines the possibility to display sensor data as coloured rasters (thematic symbolization) and with contours (topographic symbolization). In the case of point data with associated measurement values, two analysis steps are required. First, the discrete point data has to be interpolated to a raster and then contour lines are derived from the raster.

For the raster interpolation, it is possible to choose between Inverse Distance Weighting (IDW) and linear TIN interpolation. The TIN interpolation is much faster and therefore first choice for interactive viewing. IDW is more robust regarding the data distribution. E.g. it can also be applied if the sensors are placed on a line where the TIN only gives useful results inside the convex hull of the data points.

Fig. 10 shows a temperature map generated with this approach (choropleth map with color gradient from red to blue), which in addition can also include contours for an improved readability of the measurement values as well as the location and status of the sensors that generated the data. The color of the points representing the sensors can be linked with the data uncertainty (e.g. green is to be used for sensors delivering certain data and red for sensors delivering data which is below a predefined threshold).

The generic cartographic rules presented in this article can be used also for basic visualization of uncertainty of sensor measurements or kriging results, as uncertainty plays an important role in the decision making process. Uncertainty relates to accuracy, error, consistency, and reliability of information and therefore affects the outcomes of analysis. In the SANY project, it is desirable to represent uncertainty with graphic variables on maps. Several promising techniques have been identified for the visual communication of uncertainty in static maps. It should be possible to obtain representations corresponding to the amount of uncertainty by: varying transparency and color, transparency blending, color bleaching, use of fill patterns, adjusting resolution of geographic detail, varying contour widths, use of graphic filters (e.g. blurring). These possibilities will be further researched with a focus on interpolated sensor networks measurements and fusion results.

5. Conclusions

An intuitive and cartographically correct representation of environmental data supports the decision making process by providing the interpretation of environmental data in the form of maps. The concept of Cartographic Web Services based on open standards are improving the cartographic workflow for environmental management and offers an important contribution regarding the visualization of geospatial and thematic data over the Web. The Map and Diagram Service proves that much cartographic functionality can be transferred on the server side allowing an efficient and cost effective creation of light-weight Decision Support Systems (DSS) with full-fledged interactive mapping functionality that is suitable especially in multi-risk management situations.

Correct and expressive symbolization and representation of spatial data can be achieved also for dynamic and distributed spatial data sources if the representation is based on cartographic rules. The cartographic rules are inherently enforcing the conceptual separation between the symbology and the data.

Moreover, Cartographic Web Services must provide support for combined visualization of topographic and thematic data, therefore enabling creation of thematic maps.

This paper also presents some of the cartographic aspects which are neglected in Environmental Applications as well as in the existing OGC standards. The cartographic extensions for the Symbology Encoding (SE) standards allow expressing cartographic rules with spatial operators and advanced feature filtering for layer masking, flexible point symbolization, and patterns and gradients for all spatial features. Furthermore the critical point of creating thematic maps is also solved with extensions for intuitive choropleth and various diagram types generation.

The availability of cartographic rules may allow the integration of cartographic knowledge in a variety of Web applications that use spatial visualization components. The means necessary to formalize and express the existing cartographic knowledge and rules for Web cartography can potentially have a positive influence on the GIS and environmental management community. The increased awareness about cartographic reasoning for distributed Web map services and Geographical Information Systems (GISs) are triggering improvements of the cartographic capabilities for Environmental Applications.

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