An approach for the development of context-driven Web Map solutions based on interoperable GIS platform

Miloš Bogdanović*, Aleksandar Stanimirović*, Leonid Stoimenov*

* University of Niš, Faculty of Electronic Engineering, Niš, Serbia
milos.bogdanovic@elfak.ni.ac.rs, aleksandar.stanimirovic@elfak.ni.ac.rs, leonid.stoimenov@elfak.ni.ac.rs

Abstract—In this paper we will define and describe a novel approach for the development of context-driven Web Map solutions. Our approach relies on an architecture we define and present in this paper as an enhancement of GIS application interoperability platforms. The enhancement is performed through introduction of a specific architectural layer which enables the development of context-driven Web Map solutions. A novel architectural layer we introduce consists of two central components: Web Map Context Service and Context Proposal Service. These services take advantage of existing GeoNis framework for interoperability of GIS applications and enable users to get appropriately visualized geospatial data depending on their context. The enhanced platform is capable of adapting to different users’ needs without changing its internal structure and improves the level Web Map solution usability.

I. INTRODUCTION

Interoperability has been long foreseen as an ultimate mean for resolving geospatial data source heterogeneity. Over the years, scientists and engineers have struggled to develop an interoperable geo-information dissemination environment through the development of ontology-driven geo-information integration architectures (platforms) [1]. Ontology-driven geo-information integration architectures (platforms) are designed to describe the semantics of geo-information sources and to make their content explicit through means of ontologies. They provide powerful semantic reasoning capabilities and utilize ontologies for the discovery and retrieval of geo-information [1][2]. Mostly, the retrieval of geo-information is based on utilizing connections (mappings) between ontologies and geo-information sources [3][4][5]. Geo-information sources used within these architectures can be accessed through means of geospatial services conforming to OGC specifications. Thus, if the geo-information sources within these architectures expose their interface as Web services conforming to OGC specifications, then the problem of geo-information service discovery can be transferred into the problem of discovering geo-information sources within ontology-driven geo-information integration architectures.

Nevertheless, if this approach is used, searching for suitable geo-information source for a particular user is still a challenging task. Such task is particularly hard when implemented within Web Map solutions which have a significant number of different users and rely on a number of heterogeneous information sources. Each user expects Web Map (Web GIS) solution to be capable of displaying a particular subset of geo-information and maps – the geo-information and maps he/she is currently interested in. Among all available data (services, geospatial layers, documents, etc), Web GIS users need a mechanism to easily find (discover) what they are searching for – using their own words, their own language [6]. This information determine user context within Web Map (Web GIS) solution in terms of displayed geo-information and maps. For that reason, Web Map (Web GIS) should rely on an infrastructure which enables discovery and usage of appropriate geo-information sources, integration of information from appropriate geo-information sources and storing of user context information in terms of displayed geo-information and maps.

A novel approach, which we define and describe in this paper, foreseen to be used for these purposes, is an enhancement of GIS application interoperability platforms through introduction of a specific architectural layer which enables the development of Web Map context-based Web GIS solutions. We have defined this layer by specifying and developing its two main components: Web Map Context Service (WMCS) and Context Proposal Service (CPS). Web Map Context Service is foreseen as a mediator between users and GIS application interoperability platforms. In particular, we will present an architecture which takes advantage of existing GeoNis framework for interoperability of GIS applications [7][8] to demonstrate the advantage introduced by WMCS and CPS services. WMCS helps users get appropriately visualized geospatial data depending on their context. User context information is stored in a context document which is created according to Open Geospatial Consortium (OGC) specification. Context documents are created, maintained and manipulated through Web Map Context Service operations. The creation of the initial map context proposal of a new Web-based GIS user, based on the description of the data that the particular user is interested in, is the basic functionality of Context Proposal Service.

The rest of this paper will present WMCS and CPS services and their specification used for selection of the most appropriate geospatial content for a particular user. We will also present a brief overview of most prominent similar solutions and conclude with a discussion and an outlook to future work.

II. RELATED WORK

Context-driven Web Map solutions can be observed as a member of a group of personalized software. The fundamental problem of personalized software
development is an approximation of user preferences with a little amount of relevant information [9]. This information represents the foundation of the user context. The reported techniques used for user context extraction are mostly based on determination of user preferences and categorization of users according to their behavior [10][11][12]. In the field of GIS methodologies, context-driven GIS have been studied mostly within the development of mobile applications [13][14]. These proposals emphasize the need for different levels of adaptation within the geospatial data presentation process [14][15], as well as the need for the development of methodologies that would consider different contextual dimensions together [7]. All together, these approaches share a goal – to make GIS able to automatically determine and derive its content.

Previously reported contextual cartographic visualization system proposals are in most cases based on client–server architecture. A solution for adaptive visualization of geospatial information on mobile devices proposed in [16] performs adaptive cartographic visualization on the server side. The limitations introduced by the environment of this system resulted in client being responsible only for the presentation of geospatial data [16]. The context types used by this solution are predefined. Another proposal based on client-server architecture can be found in GiMoDig project [17]. The architecture of GiMoDig project uses extensions of OGC Web Map Service and Web Feature Service specification. These extensions are introduced for the purpose of establishing communication between client and server sides. The elementary context types used by GiMoDig solution are invariant.

An implementation encountered in the field of contextual cartographic visualization which we consider in some extent similar to our proposal is named Sissi – Contextual Map Service [18]. Sissi is a Web-based server application which provides context-aware maps for Web GIS clients. Although it is also based on client-server architecture, Sissi differs in more that few characteristics when compared to previously described solutions. We consider these characteristics to be very significant. Sissi does not have a predefined set of elementary context types which is how it differs from the previously described solutions. This characteristic makes Sissi capable of supporting different contexts. Sissi specification represents an extension of Web Map Service specification with extending requests – GetElementContextType and GetMapWindows. Another difference compared to Web Map Service specification is the modification of GetCapabilities request in order to include an additional context parameter. Context parameter is used for user context encoding in the form comma-separated context values. Symbology used for the rendering of adapted (contextual) maps is an integral part of Sissi and is defined using Styled Layer Descriptor styling language [19].

Hereby presented contextual cartographic visualization solutions, which we consider to be the prominent ones, indicate that though significant research and development results exist in this field, a significant effort should be put into improving the usability of contextual cartographic visualization systems. For instance, although a majority of these systems rely upon the usage of OGC standards (mostly Web Map Service and Web Feature Service implementation specifications), user context information is not created and maintained according to the existing (OGC) standards which decreases the interoperability level of the presented systems. Also, a majority of adaptive cartographic visualization systems imposes a tight coupling between a map rendering services and symbology used for the visualization of geospatial information. Therefore, evaluated systems do not provide their users with ability to determine the styles which should be used for the visualization of geospatial information that they are interested in. Rather, the presented system uses internal style development formats or integrated Styled Layer Descriptor documents. Further, the usage of WFS services is not provisioned in the majority of these solutions. The direct usage of WFS services can be very significant if clients are capable of adapting geospatial data presentation according to the style provided on the basis of the user context.

The focus of our research was the defining and development of a general architecture of contextual Web Map solution which overcomes the determined problems with a purpose of improving the level of usability of contextual geospatial information visualization systems. The architecture we have developed takes advantage of the existing GIS application interoperability platforms for user context creation purposes. Our architecture relies on GeoNis interoperability platform and its taxonomy to determine user preferences and perform 'on-demand' integration of selected information from multiple heterogeneous information sources. Also, architecture we present in this paper utilizes existing Web Map solution components and introduces an additional architectural layer which contains Web GIIServices capable of supporting contextual geospatial visualization. A newly added layer does not influence the existing Web Map solution architectures, e.g. the omission of this layer will not influence the usual functioning of the existing Web Map solutions. Therefore, this layer will add contextual geospatial information visualization capabilities to the existing Web Map solutions without introducing any modification of the existing functionalities.

III. ARCHITECTURE

The main goal while specifying and developing architecture for contextual geospatial data visualization was to design Web Map Context Service (WMCS) as a Web service that has an ability to integrate itself into the existing GIS environments in order to transform such systems into contextual geospatial visualization environments. Most of the existing GISs are built upon service-oriented architecture (SisA) principles and use GIServices which provide geospatial data (such as Web Feature Service), perform visualization (such as Web Map Service) and maintain styles. WMCS is a Web service designed as a mediator between these services and end-users. The main purpose of WMCS is to maintain user context document and to combine the existing services according to user context information in order to provide users with the appropriate maps and features. The design of WMCS and its operating environment, along with additional Web services, was the main objective of our research and development. The result was named after the specification used for the development of context documents – Web Map Context Service.
Web Map Context Service is also designed as a context document repository and it does not have the capability to match user's preferences with the existing context. In order to allow context approximation, we propose another service that allows third-parties to customize this service with their own matching algorithm. The architecture of the system that WMCS can operate in is shown in Figure 1.

GIS capable of performing map adaptation should consist of several components that perform all the tasks needed to help users to get appropriately visualized geospatial data depending on the user context:

- **Clients (desktop, mobile, Web GIS)** - GIS applications capable of displaying geospatial data in the form of electronic maps. Since clients should be capable of visualizing geospatial data appropriately, these applications have to be able to perform the following tasks: acquire context documents from WMCS, extract contextual data from the received documents, and create appropriate requests to services on the basis of the extracted data and to properly visualize received data.

- **Web Map Context Service** – Stand-alone Web service responsible for maintaining information considering all registered services and style repositories in the system. Furthermore, WMCS maintains information considering registered user contexts and provides them to the clients and to the Context Proposal Service.

- **Context Proposal Service** – This service is capable of providing clients with specific context that describes the data and maps relevant to the situation which is of users’ interest.

- **GeoNis** – GIS application interoperability platform. Semantic interoperability in GeoNis, resolved by Semantic Mediator [20], is the ability of sharing geospatial information at the application level, without knowing or, understanding terminology of other systems.

- **OGC Web Map Services (WMS)[21] and Web Feature Services (WFS)[22]** – Services developed according to OGC WMS and WFS standards. The geospatial data provided from these services is used in different contexts. Clients can request data from these services only if these services are registered within Web Map Context Service.

- **Symbology Encoding Repository Services (SER Services)** – Services that provide styling documents developed using Styled Layer Descriptor [23] or Symbology Encoding styling language [24]. The information contained within these documents is used for adaptation of geospatial data visualization process. Coupled with geospatial data, these...
documents are used for the purpose of creating and registering contexts within Web Map Context Service.

Context-driven GIS architectures, including the proposed one, have shifted towards an agreement on a common interoperability architecture based on emerging GIS interoperability specifications, most of them issued by OGC. These specifications follow SOA principles and move GIS applications towards a distributed architecture based on interoperable GI services. Also, services developed according to OGC standards have standardized interfaces which provide GIS developers with a possibility to easily combine several services capable of processing and visualizing geospatial data. Combined with services that provide user context, e.g. WMCS instances, these services represent a solid foundation for the development of a distributed context-driven GIS. In this context, we consider our architectural proposal to be a significant step forward in terms of usability and modularity of contextual geospatial visualization environments.

IV. WMCS AND CPS – A FOUNDATION FOR THE DEVELOPMENT OF CONTEXT-DRIVEN WEB MAP SOLUTIONS

Web Map Context Service (WMCS) is the major component used for the development of context-driven web map solutions. The main purpose of the WMCS is to provide users with appropriate geospatial content relevant to user’s context. WMCS is used as a mediator in the process of adaptation of geospatial data representation. For these purposes, WMCS is combined with GIS clients and distributed Web services that provide geospatial data and styling documents. These services need to be registered within WMCS before they can be used.

First, a client needs to send a GetContext request to the WMCS. After receiving a context document, according to the extracted information, the client creates and sends GetFeature request to WFS services and GetStyle request to SER Services. Finally, the data received from WFS services is visualized according to styles received from SER Services and displayed to user.

WMCS creates a context document for each registered context according to OGC Web Map Context Documents implementation specification [25]. Basic information considering users’ contexts is stored in a database while the created context documents are being stored on the file system. An example of a context document is shown in APPENDIX A.

As previously stated, OGC Web Service Common Standard [26] was used as a starting point for the development of WMCS specification. According to this specification, the following operations have been specified:

- operation used in order to provide metadata regarding capabilities provided by WMCS service
- operation used in order to provide context documents to the clients

WMCS specifies additional operations that are not specified by OGC Web Service Common Standard:

- operation used for registering services that provide geospatial data and styles (WMS, WFS, SER Services)
WMCS defines the following operations:

- **RegisterService** operation – WMCS allows registration of distributed Web services that provide geospatial data and styling documents through the RegisterService operation.
- **GetCapabilities** operation – The GetCapabilities operation provides a client with metadata regarding the capabilities provided by WMCS service.
- **RegisterContext** operation – The RegisterContext operation provides users with the ability to register their context within WMCS.
- **GetContext** operation – The GetContext operation allows retrieval of a single or all context documents from WMCS.
- **UpdateContext** operation – The UpdateContext operation provides users with the ability to update the existing context within WMCS.
- **DeleteContext** operation – The DeleteContext operation allows the removing of the existing context from WMCS.
- **GetLayers** operation - The GetLayers operation allows retrieval of temporary context document from WMCS as a result of comparison of two term sets – a term set received as an argument of GetLayers operation and a term set which consists of the names of data layer which can be obtained from the WMSs and WFSs registered within WMCS. The resulting context document is not stored within WMCS service.

Besides the ability of obtaining the context document directly from the Web Map Context Service, client can obtain the context document from the Context Proposal Services (CPSs). CPS instances are considered to be integral parts of the proposed service-oriented architecture. CPS is a customizable service that can be implemented by a third-party. The basic functionality of CPS instance is the creation of the initial map context proposal of a new Web GIS application user based on the description of the data that the particular user is interested in.

The textual description of geographical entities which appear in WMS and WFS data layers, exposed through the data layer name, can be very different. These textual descriptions have to match user-defined keywords. Since textual descriptions of geographical entities, e.g. data layer names and keywords, will be used to identify the content suitable for a particular user, this will raise problems of using text strings in order to identify a geographical entity. These problems are well-known and are related mostly to synonymy and ambiguity. In order to partly overcome these problems, in the current development stage, a user-defined set of keywords is expanded by the CPS using WordNet lexical database. For each of user-defined terms, CPS expands user-defined set of terms with synonyms, first level hyponyms and all terms in the hypernym tree obtained from WordNet lexical database. The resulting set of terms is compared with GeoNis taxonomy e.g. it is compared to the names of GeoNis global ontology concepts. Since GeoNis ontology concepts are mapped to geospatial information sources, that in turn can be accessed through WMS and WFS interfaces, the matching process result will contain the names of WMS layers and/or WFS feature types which correspond to global ontology concepts whose names are similar to user-defined terms. The resulting expanded set of terms is submitted to WMCS service by invoking GetLayers() operation of the WMCS service whose argument is the resulting term set.

The core of the geospatial data source discovery is a matching process, based on a similarity measurement performed between terms extracted from the user-defined geospatial data description and expanded by CPS, and GeoNis global ontology concepts. The matching process is performed by Context Proposal Service. Context Proposal Service will load GeoNis global ontology, extract ontology concepts and determine similarity between the expanded term set and the ontology concepts. The similarity measurement is based on the use of a combination of unsupervised word sense disambiguation methods, which utilize WordNet computational lexicon. The GeoNis global ontology concepts, whose similarity with user-defined terms exceeds a predefined threshold value, will be used to determine the names of WMS layers and/or WFS feature types which will be added to the resulting context document. This process is automatic due to GeoNis platform which contains mappings between concepts and data sources, which in turn expose the data through WMS and WFS services.

The similarity measurement between terms extracted from the user-defined geospatial data description and GeoNis global ontology concepts is performed in through the following steps. For each pair of terms \( T_{EX} \) (from the expanded term set) and \( T_C \) (from the concept term set), perform the geospatial data discovery process by repeating the following steps:

**Measure a similarity between the terms \( T_{EX} \) and \( T_C \)**

- Compute edit distance similarity for terms \( T_{EX} \) and \( T_C \)
- Compute semantic similarity \( sim(T_{EX}, T_C) \) between the terms \( T_{EX} \) and \( T_C \) according to the algorithm described in [28]. According to this algorithm, \( sim(T_{EX}, T_C) \) is determined by considering the depths of the \( T_{EX} \) and \( T_C \) synsets in the WordNet computational lexicon, along with the depth of their least common subsumer (LCS). The LCS of synsets
TEX and TC is the most specific synset that is an ancestor of both synset \( T_{EX} \) and \( T_C \).

\[
sim(T_{EX}, T_C) = 2 \times \frac{\text{depth}(LCS_{T_{EX} T_C})}{\text{depth}(T_{EX}) + \text{depth}(T_C)}
\]

- Determine final semantic similarity according to the following equation:

\[
sen\!
\!
\!sim(T_{EX}, T_C) = \max(\text{dist}(T_{EX}), \text{dist}(T_C)) \times \min(\text{length}(T_{EX}), \text{length}(T_C)) \times \frac{\text{depth}(T_{EX}) + \text{depth}(T_C)}{\text{depth}(LCS_{T_{EX} T_C})}
\]

After a matching set of ontology concepts is calculated, CPS will utilize GeoNis semantic mediator to determine OGC Web services (WMS and WFS instances) used as interfaces of geo-information sources connected to ontology concepts from the matched set. This process uses existing connections (mappings) between global ontology and geo-information sources within GeoNis interoperability platform. Once OGC Web services instances are determined, a set of layer names and/or feature type names is sent back to WMCS for context document creation purposes in the form of an argument of GetLayers operation of WMCS service.

Based on the received term set, GetLayers operation of WMCS service will create a temporary contextual document and apply appropriate ordering of results. For example, if a match is found among the keywords used in one or more of the existing contextual documents, WMCS adds all data layers from each of the contextual documents into the resulting set of data layers. For this reason, a preference in result ordering is given to data layer name matches.

V. CONCLUSION AND FUTURE WORK

In this paper, our objective was to define and develop a general architecture of contextual Web Map solutions which will improve the level of scalability and usability of contextual geospatial information visualization systems. The main result within this research and development is the ability of our proposal to apply different contexts and styles for viewing maps. This is achieved by introducing an additional architectural layer into the Web-based GIS application interoperability platforms. This layer consists of Web GIServices capable of supporting contextual geospatial visualization and we envision Web Map Context Service as its most important component.

There are few other proposals comparable to WMCS, at least not many of them which cover all functionalities specified and implemented within WMCS. However, there are prominent proposals which can be considered similar to WMCS to some extent. As we previously stated, we consider Contextual Map Service named Sissi to be the most similar solution compared to our proposal. However, WMCS differs from Sissi in more than few characteristics in terms of both surrounding architecture and specified functionalities. Although Sissi does not have a predefined set of elementary context types, a variety of user context types could be more efficiently covered if the user context is stored as a separate document and developed according to Web Map Context Documents specification. This capability is supported by WMCS. Unlike Sissi, WMCS does not perform any rendering in terms of merging images from different Web Map Services. Rather, WMCS uses the rendering capabilities of the existing Web Map Service rendering, therefore does not multiply requests towards the existing Web Map Services. This characteristic can be significant in terms of performances of the overall system. Furthermore, the usage of WFS services is not provisioned in the Sissi environment. The direct usage of WFS services can be very significant if clients are capable of adapting geospatial data presentation according to the style provided on the basis of the user context. Also, it is our opinion that the used symbology should not be restricted to SLD. Furthermore, styling rules can be provided by independent services, possibly in the form of styling document repositories [30]. These capabilities are also integrated into Web Map Context Service specification.

The architecture presented in this paper should be considered an excellent starting point for the development of service oriented GIS capable of supporting contextual cartographic visualization. Future research and development of the presented service and its environment should cover an extension of WMCS specification in terms of new operations. These operations will provide WMCS with the ability to use Context Proposal Services (CPS) developed by a third-party. This operation extension will be based on Web Processing Service OGC Standard (WPS). Currently, coupled with our implementation of Context Proposal Services, WMCS enables users to be introduced with the already-existing similar contexts which lead to a faster adaptation of geospatial data visualization and improve reusability of the existing symbology. Once extended according to WPS standard, WMCS will be able to transform direct CPSs developed for a particular domain which can be very significant for users which consider themselves experts for the observed domain. Further, the WMCS specification will be extended with operations which will allow users to register style transformation scripts. Registered scripts will perform transformation between a custom styling document and a styling document developed according to OGC specification. Thus, WMCS will be able to transform styling documents developed according to third-party styling languages into styling documents developed according to OGC specification. Each styling language developer will use WMCS operations in order to register a XSLT [30] or a procedural transformation of its styling language into SLD or SE styling language. We are convinced that these improvements will lead to our proposal becoming a solution highly applicable within any existing geospatial data visualization environment and its usage will turn such environment into an adaptive geospatial data visualization environment.

ACKNOWLEDGMENT

Research presented in this paper was funded by the Ministry of Science of the Republic of Serbia, within the project "Technology Enhanced Learning", No. III 47003.

REFERENCES


APPENDIX A

\[
\text{dist}_{\text{TEX},T_C}(i_{\text{TEX}},j_{\text{TEC}}) = \begin{cases} 
\min & \text{Max}(i_{\text{TEX}},j_{\text{TEC}}), \text{ when } \min(i_{\text{TEX}},j_{\text{TEC}}) = 0 \\
\text{dist}_{\text{TEX},T_C}(i_{\text{TEX}}-1,j_{\text{TEC}}) + 1 & \\
\text{dist}_{\text{TEX},T_C}(i_{\text{TEX}},j_{\text{TEC}}-1) + 1 & \\
\text{dist}_{\text{TEX},T_C}(i_{\text{TEX}}-1,j_{\text{TEC}}-1) + (T_{\text{EX}}[i_{\text{TEX}}]) & \text{ when } \min(i_{\text{TEX}},j_{\text{TEC}}) = 0
\end{cases}
\]

Levenshtein distance for terms TEX and TC
An example of a WMCS context document created according to OGC Web Map Context Documents implementation specification.