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Geospatial services in the Cloud

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ABSTRACT

Data semantics play an extremely significant role in spatial data infrastructures by providing semantic specifications to geospatial data and enabling in this way data sharing and interoperability. By applying, on the fly, composite geospatial processes on the above data it is possible to produce valuable geoinformation over the web directly available and applicable to a wide range of geo-activities of significant importance for the research and industry community. Cloud computing may enable geospatial processing since it refers to, among other things, efficient computing resources providing on demand processing services. In this context, we attempt to provide a design and architectural framework for web applications based on open geospatial standards. Our approach includes, in addition to geospatial processing, data acquisition services that are essential especially when dealing with satellite images and applications in the area of remote sensing and similar fields. As a result, by putting in a common framework all data and geoprocesses available in the Cloud, it is possible to combine the appropriate services in order to produce a solution for a specific need.

1. Introduction

One of the main goals of the Semantic Web during the previous decade was to create a common framework that allows data to be shared and reused and – most importantly – to be processed automatically. In the case of spatial data, the Geospatial Semantic Web identifies which parts of geospatial information need to receive semantic specifications in order to achieve interoperability (Kuhn, 2005). Semantic interoperability refers to data transmission between computer systems with unambiguous, shared meaning. In terms of spatial data, once availability of and access to them is facilitated they conform to the standards of Spatial Data Infrastructures (SDI) (Nebert, 2004).

Besides the software components required to develop and deploy a SDI, a range of technical standards that allow interaction between these components is also necessary (Steiniger and Hunter, 2012). Among those are geospatial standards defined by the Open Geospatial Consortium (OGC) and include ones that deal with data expression such as the Geography Markup Language (GML) that is based on Extensible Markup Language (XML), data identification such as the Catalog Service for the Web (CSW), and data provision services such as the Web Mapping/Feature/Coverage Service (WMS/WFS/WCS). For data processing over the internet, the Web Processing Service (WPS) specification was released on 2005 by OGC (Schut, 2007), in order to provide spatial processes through a standardized service interface based on the Hypertext Transfer Protocol (HTTP) (Foerster and Stoter, 2006). Many of the aspects, which are, or should be, common to all or multiple standards are specified in the OGC Web Service (OWS) interface implementation standards (Whiteside, 2007). OWS standards generate great expectations regarding the hottest web topic, Cloud Computing, since they were developed in order to integrate geospatial data and services with web-based distributed applications, and so they are ready-made for the Cloud (McKee et al., 2011). In the first OGC compliant Cloud service ever presented (Baranski et al., 2009), the scalability feature of Cloud Computing is evaluated through a comparison of a WPS implemented in the Cloud with one implemented locally. Also, significant effort is being spent regarding SDIs integration with Cloud Computing: a thorough analysis of the basic concepts along with the design and test of a Cloud-enabled SDI is examined by Schäffer et al. (2010) while Baranski et al. (2011) made use of a hybrid Cloud by combining local and public IT-infrastructure in order to meet Quality of Service requirements set by INSPIRE directive (European Commission, 2007).

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Notable and continually updated OGC WPS specification implementations are the 52° North Initiative for Geospatial Open Source Software (52 North, 2013) and the ZOO open WPS platform (Fenoy et al., 2012), while existing server GIS platforms have embedded such capabilities. One can find numerous use cases in a wide range of expertises that implement geospatial processing services, mainly by reusing shared libraries, e.g., water resource management applications (Díaz et al., 2007). An attempt to demonstrate WPS integration into geospatial mass-market applications through a forest fire assessment use case has also been proposed (Foerster et al., 2009). There exist several significant recent implementations that contain geoprocessing services aggregation. The term Composite-WPS that is used to invoke all other services involved is introduced in the case of a bomb threat scenario (Stollberg and Zipf, 2007). In addition to service definition and aggregation, further efforts include the establishment of semantic interoperability, in order to achieve data exchange between services in a meaningful way and reduce human intervention (Manso and Wachowicz, 2009). In this context, a transparent vertical and horizontal semantic enablement layer for spatial data infrastructures has been introduced (Janowicz et al., 2010). Finally, we mention a recent attempt to investigate available servers conforming to the OGC WPS standard and to evaluate its implementation (Lopez-Pellicer et al., 2011) as well as an overview about the state-of-the-art architecture and technologies governing the geoprocessing web (Zhao et al., 2012).

Ideally, a Cloud-enabled system where any geospatial process could be executed through a WPS implementation and the involved spatial data conform to the standards of an SDI could satisfy on demand provision of valuable geoinformation. In such a system, one first has to define the exact Geographic Information Systems (GIS) functions that can produce the desired geoinformation.

In this paper, we attempt to provide a design and architectural framework for web applications based on open geospatial standards. Our approach, in addition to geospatial processing, also includes data acquisition services which are essential, especially when dealing with satellite images and applications in the area of remote sensing. In any case, regardless the exact field of application, first, raster datasets of the area of interest (AOI) must be obtained. Therefore, prior to identifying web processing services concerning data analysis tasks specific to the case under study, a set of imagery data acquisition web processes is also required (Evangelidis et al., 2012). The imagery "Acquisition" stage introduced hereby, is achieved by embedding shared web services implementing major data acquisition tasks such as data discovery, validation and download (U.S. Geological Survey, 2010). Then, imagery "Analysis" stage may contain web processing services performing essential functions related to image display, subsetting and re-projection, as well as transformation functions concerning spectral enhancements, such as band ratios to facilitate vegetation mapping or mineral exploration and image subtraction to provide the ability of tracking changes over time.

2. Review

2.1. Review of data search and acquisition services

In recent years, Earth Observation (EO) data have become available from governmental agencies as a result of the ever increasing technological capabilities of the web. Several web portals that provide options for data search, order and download, are identified, such as:

i) NASA's Earth Observing System Data and Information System (EOSDIS, 2013) which is the core capability for exploring and managing multi source NASA's Earth data. In relation to data search and acquisition there are several options to discover data of interest which are: near real-time data products from the MODIS, OMI, AIRS, and MLS instruments, from the Land Atmosphere Near real-time Capability for EOS (LANCE)[1]; the directory level information from the Global Change Master Directory (GCMD)[2] that provides search capabilities by specific field of interest (e.g. agriculture, atmosphere, etc.), instruments, platforms, providers, projects etc.; Cross-Data Center searches through Reverb[3], a client web service for search and ordering cross-discipline data from all of EOS Clearing House (ECHO) metadata holdings, which facilitates even those users without EO data knowledge and experience; Custom client software using ECHO metadata repository[4] and NASA's Data Centers specific search tools and services[5] which have been developed in order to provide unique services for users of a particular type of data client like USGS Earth Explorer[6].
ii) European's Space Agency (ESA) Earthnet Online portal[7] which provides services for search and request of EO data from ESA EO Missions (ERS-1, ERS-2, Envisat, GOCE, SMOS, CryoSat), Third Party Missions (TPMs), ESA Campaigns, the GMES Space Component (GSC), as well as sample and auxiliary data from a number of missions and instruments. The data browsing can be performed by mission and instrument, or by Earth topic, typology and processing level.
iii) Canadian Space Agency provides capabilities of searching and downloading open access data[8] which are comprising and EO data over Canada such as Landsat imagery. The data search can be performed through free text form and filters by Organization, Data Type and Subject etc.
iv) National Remote Sensing Center (NSRC) of Indian Space Research Organization (ISRO) distributes open EO data archive of ISRO's satellite products (Resourcesat-1: Ortho AWiFS and LISS III data; IMS-1: HySI Spectral Binned data) for India via the Bhuvan geoportal[9].
v) Argentina's National Commission on Space Activities (CONAE) provides catalog imagery data search under different states of access and downloading[10].
vi) Brazilian's National Institute for Space Research (INPE) has a catalog search for imagery products (CEBERS, Landsat, MODIS TERRA, MODIS AQUA, Resourcesat-1) and also provides the capability of imagery data acquisition after registration[11].

Moreover, several projects/initiatives can be found in literature dealing with EO data access and management through the web (Lee et al., 2011):

i) The Digital Earth Community project (GENESI–DEC) aims to facilitate the world wide user communities with access to EO data through a single access point that makes use of a simple web portal and web services[12].

[1] Accessed through https://earthdata.nasa.gov/data/near-real-time-data.
[2] Accessed through http://gcmd.nasa.gov/index.html.
[3] Accessed through http://reverb.echo.nasa.gov.
[4] Accessed through https://earthdata.nasa.gov/echo/.
[5] Accessed through https://earthdata.nasa.gov/data/data-tools.
[6] USGS Earth Explorer, http://earthexplorer.usgs.gov/.
[7] Accessed through https://earth.esa.int.
[8] Canada's Open Data portal, http://data.gc.ca/eng.
[9] Accessed through http://bhuvan.nrsc.gov.in.
[10] Accessed through http://www.conae.gov.ar/index.php/es/catalogo-de-imagenes.
[11] Accessed through http://www.dgi.inpe.br/CDSR/.
[12] Accessed through http://www.genesi-dec.eu.

ii) The Grid Processing on Demand (G-POD) for Earth Observation Applications initiative provides a grid based platform where the user can search the available data products (ERS-1 and ERS-2 satellites, and the Envisat ASAR and MERIS sensors) and also can exploit the platform's tools and algorithms in order to process the selected data[13].
iii) The Global Earth Observation Grid (GEO Grid, 2013) project provides a platform for worldwide Earth Sciences community including among others a set of services for accessing remote sensing (ASTER; MODIS) and geological data through a geoportal[14].
iv) The Global Earth Observation System of Systems (GEOSS) aims to develop an international infrastructure for EO data access and that way to provide decision support tools to a wide range of users in nine societal benefit areas (disaster management, health, energy, climate, water, weather, ecosystems, agriculture, and biodiversity). The GEOSS Common Infrastructure (GCI) facilitates the end users with access, search and use of the data, information, tools and services thought the Group on Earth Observations (GEO, 2013) web interface.
v) EUROGEOSS project is the European contribution to GEOSS and provides an initial operating capability, via a single access point, the EuroGEOSS Broker[15], for a European Environment Earth Observation System in the three strategic areas of Drought, Forestry and Biodiversity.

2.2. Review of geospatial processing interface implementations

Spatial data servicing standards have been thoroughly documented and applied in numerous research and commercial projects (Sayar et al., 2006; Tu and Abdelguerfi, 2006; Yang et al., 2007; Chang and Park, 2006). An attempt was made to identify existing open source or proprietary software products that contribute to the implementation of OGC WPS interface specification standard (OGC, 2013). Some of the software products were specifically developed to implement the WPS interface standard, while others were developed for different purposes and later adopted and incorporated functionality in the WPS context. Based on the functionality of each identified software and its role in the implementation of the WPS interface the following software classification was adopted:

- Client software provides users with a graphical user interface (GUI), and enables them to explore information about the capabilities of a WPS server and the offered processes, make requests and receive responses from the server. The client software provides the environment where the processed output is displayed.
- Server software includes all the core functions needed to develop and make available a WPS server over the Internet. The WPS server acts as an access point that handles all the client requests and responses. Usually, the WPS server software integrates with other types of software such as libraries, plugins and desktop GIS processing modules in order to process the input parameters passed through client requests and responses back to the client with an output.
- Libraries are the collections of classes and other modules that can be manipulated by programming languages, link to existing software and create processing modules. By manipulating libraries, in the context of WPS, it is possible to build an entire client software from scratch, link the WPS server to the web server software and develop processes.
- In the context of WPS, desktop GIS software can act as a thick client and/or provide all its processing functionality through the processing modules that it contains.

The software products listed in Table 1, contribute to the WPS implementation directly via the components they contain or indirectly via plugins, developed for this purpose. The software components can also support different platforms and be manipulated and extended by a wide range of common programming languages.

Some notable cases of the above WPS implementations are briefly presented below:

52° North initiative for free and open source geospatial software was founded in 2004 and is organized in research and development communities covering a wide range of collaborative software development processes. The geoprocessing community of 52° North, provides standardized software and prototype implementations with the aim to enable processing of geo-data in Spatial Data Infrastructures. North 52 WPS includes OGC compliant java-based open source implementations acting as plugins for the Java Tomcat servlet container as well as plugins for open source clients such as uDig, Jump and OpenLayers.

ZOO is a WPS open source project released in 2009 under the MIT/X-11 license. It implements an OGC WPS in a developer-friendly framework that allows creation and chaining of WPS services. Its main goals are to gather existing open source libraries and to make them communicate in a standardized way, but also to simplify the end-developer's job by providing an easy method to create new web services. ZOO is made of a powerful server-side C Kernel, which makes it possible to manage and chain Web services coded in different programming languages. A growing suite of example Web Services based on various open source libraries and a server-side JavaScript API able to call and chain the ZOO Services, make the development and chaining of processes easier (Fenoy et al., 2012).

PyWPS (Python Web Processing Service) is a project with primary purpose to make GRASS-based processing available to web clients. It started developing in 2006 and is released under the terms of GNU General Public License (GNU/GPL). PyWPS can be considered as a translation library receiving incoming requests compliant to OWS standards, dispatching them to GRASS or any other tool developed in Python and returning back the results. The project is built on a simple CGI script providing the appropriate functions for defining inputs and outputs of the requested process to be executed. The process itself is implemented by the class Process, and executed by the mandatory method execute, which can use GRASS modules directly (Cepicky and Becchi, 2007).

The Deegree project is a standards-based Java framework for spatial data infrastructures implementing the major geospatial IT standards, and providing among others sensor and processing services. It was born in 2002, is distributed under the GNU Lesser General Public License (LGPL) and after many upgrades has become an OSGeo project.

Other remarkable commercial solutions that have very recently implemented WPS, include, without being limited to, ERDAS APOLLO 2010 and ESRI ArcGIS Server. The WPS in APOLLO enables a modeler engine called IMAGINE, which provides the capability of graphically designing complex spatial models and algorithms, to create chained spatial model workflows and publish these workflows for consumer end users. A similar feature called Model Builder was introduced in 2006 by ESRI that in its latest GIS server edition supports WPS services that can be used by any client that supports WPS.

[13] Accessed through http://gpod.eo.esa.int/.
[14] Accessed through https://eco.geogrid.org/gridsphere/gridsphere.
[15] Accessed through http://www.eurogeoss-broker.eu/

Table 1
Contributions to the implementation of OGC WPS specification standard.

PROJECT		TYPE					SUPPORT	
Name	Provider download URL	Client	Server	Library	GIS	Open Source	Languages	Platforms
52o North WPS	52 North http://52north.org/		√			√	Java, Python, R	Windows, Mac OS X, Linux
ArcGIS Server	ESRI http://www.esri.com		√				.NET, Java	Windows, Solaris, Linux, VMWare
Deegree WPS	lat/lon GmbH http://www.deegree.org/		√			√	Java	Windows, Mac OS X, Linux, BSD, UNIX
disy Cadenza Professional	disy informations systeme GmbH http://www.disy.net/	√					Java	Windows, Linux, Java
disy Cadenza Web	disy informations systeme GmbH http://www.disy.net/	√	√				Java	Windows, Linux, Java
disy GISterm Professional	disy informations systeme GmbH http://www.disy.net/	√					Java	Windows, Linux, Java
disy GISterm Web	disy informations systeme GmbH http://www.disy.net/	√	√				Java	Windows, Linux, Java
Erdas Apollo Professional	ERDAS Inc. http://www.sterling-software.uk.com/	√	√				Java, C++	Windows, Linux, Solaris
GDAL/OGR	OGC http://www.gdal.org/			√		√	C++	Windows, Linux, Mac OS X
GeoMedia SDI Portal	Intergraph http://portal.ingr.briseide.eu/sdiportal/	√					.NET, ExtJS, Javascript	Windows
Geoserver	OpenGeo http://geoserver.org/		√			√	Java	Windows, Mac OS X, Linux, BSD, UNIX
Geoshield Project	IST-SUPSI https://sites.google.com/site/geoshieldproject/	√	√			√	Java	Any
GeoTools	OpenGeo, Geosolutions, Refractions Research, LISAsoft http://www.geotools.org/			√		√	Java	Any
GNIS Server	LBS Plus co. Ltd.	√	√				Java	Java
GRASS GIS	GRASS development Team http://grass.osgeo.org/	√			√	√	C, C++, Python, Unix shell, Tcl	Windows, Mac OS X, Linux, Solaris, SGI IRIX, HP UX, BSD, UNIX
HSLayers	HS-RS http://hslayers.org/			√		√	Javascript	Any
Liquid XML Data Binder	Liquid Technologies http://www.liquid-technologies.com/xml-data-binding.aspx	√	√			√	C++, C#, Java, VB.NET, VB6	Windows, Linux, Solaris, HP UX
Maplink Pro	Envitia http://www.maplinkpro.com/	√	√			√	C++, .NET, COM	windows, Linux, Solaris, VxWorks
Netgis Server	NETCAD http://netcad-netgis-server-enterprise-cvs.software.informer.com/		√				.NET, Java, C#, Delphi, VB, Javascript	Windows
OpenGeo Suite	OpenGeo http://opengeo.org/products/suite/	√	√			√	C, Java, Javascript	Windows, Mac OS X, Linux, Skygone Cloud, Amazon EC2
Openlayers	OpenGeo http://opengeo.org/technology/openlayers/			√		√	Javascript	Any
PyWPS	OGC, HS-RS http://pywps.wald.intevation.org/		√			√	Python, jython	Any
QuantumGIS	Faunalia http://www.qgis.org/	√			√	√	C++, Python	Windows, Mac OS X, Linux, BSD, UNIX
Rasdaman	rasdaman GmbH http://www.rasdaman.com/		√			√	C++, Java, rasql	Linux, Solaris, Mac OS X, Windows, HP-UX, SGI IRIX
uDig	Refractions Research http://udig.refractions.net/	√				√	Java	Windows, Mac OS X, Linux
WPS.NET	BRGM - http://swing.brgm.fr/dataaccess/wps/generic		√			√	.NET	Windows
WPSint	OGC http://wpsint.tigris.org/	√				√	Java	Windows, Linux, VMWare
ZOO-Project	ZOO-Project http://www.zoo-project.org/		√			√	C, C++, Python, Java, PHP, Perl, Fortran, Javascript	LINUX, Windows, Mac OS X

3. Design and architecture

3.1. Scenario

We demonstrate a use case scenario, where the end user can perform imagery search and acquisition as well as image processing functions. The imagery acquisition is performed by an interactive map service, such as Google maps, in which the AOI can be defined by submitting the coordinates of a polygon or a point shape feature. Then, the available image data along with its metadata is examined and the end user is able to download the desired raster image files. It is then possible to have a detailed list with the available processing services and their descriptions, that can be applied to the downloaded raster files. For demonstration purposes, popular essential and transformation functions used in major remote sensing projects have been chosen.

The system of our scenario provides image composition processing on raster data, by assigning each image band to one of the three primary colors (red, green, blue) or a single band (gray scale) display. It also provides image sub-setting processing capabilities, in order to delineate the imagery to the desired study area using an inquiry box tool, and image re-projection, in order to transform the imagery into another coordinate system for integration with other data. The transformation functions provided by the system include:

- Band ratio calculations to facilitate vegetation mapping or mineral exploration. As a result, new thematic bands are created that indicate the vegetation in the area in case of a vegetation index performance.
- Simple change detection functions using bands subtraction, in case of multi-temporal imagery (e.g., imagery of the same area at different years). The result is a new band that indicates the changes over the specific time period.

3.2. Design

The UML sequence diagram illustrated in Fig. 1 depicts the interaction between the component units of the System, through a series of web services that are specified by appropriate functions and rely to a generic request – response structure. The System comprises of two well-defined, discrete and integrated engines: (a) the "Data Acquisition Engine", which allows users to discover remote sensing data by querying and retrieving their metadata information, and to enable the download process, and, (b) the "Analysis Engine", which facilitates image data processing and transformations. The interactions below represent implementations of standardized services that, some or all of them, may participate in various use case scenarios and are briefly presented in six steps:

(1) The Client sends a request to the WMS Server in order to retrieve an interactive map service that allows definition of the desired AOI through appropriate map layers.
(2) A message is sent to the CSW Server requesting the available satellite images and metadata information, with regard to the AOI previously defined. The System returns a catalog with available image data and metadata.
(3) A request follows that is dispatched to the WCS Server, which in turn enables the satellite image download.
(4) Having downloaded the imagery, the user sends requests to the WPS Request Handler in order to get metadata information

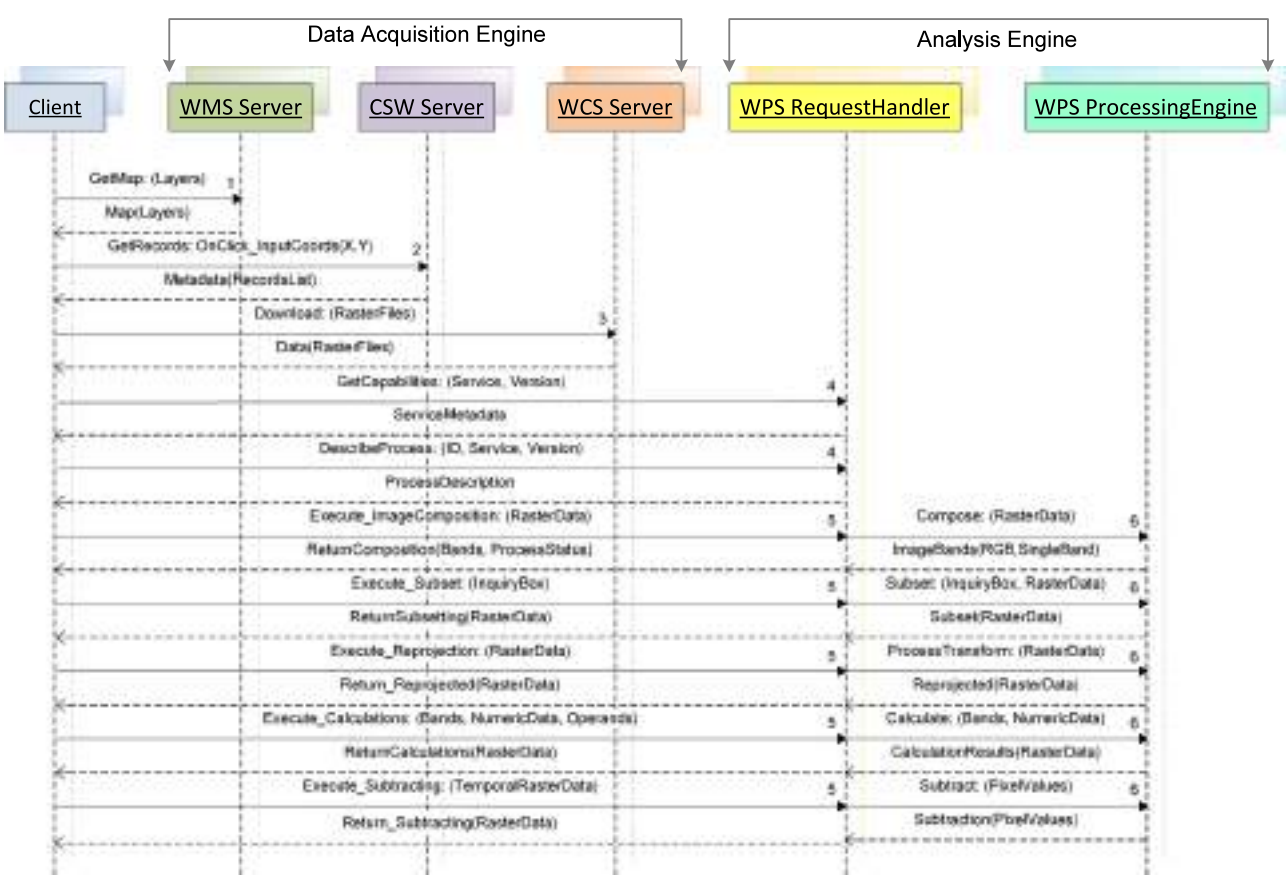

Fig. 1. An interaction UML diagram for representing services' requests and responses.

about the capabilities of the available services and processes of the Analysis Engine.

(5) After discovering the offered analysis capabilities, the user sends requests to the Analysis Engine in order to perform essential processes to the satellite image, such as image composition analysis, sub-setting using an inquiry box, re-projection, or to perform transformation processes to it, such as band rations and image subtraction.

(6) The WPS Request Handler receives these requests and directs them to the WPS Processing Engine. The modules of the WPS Processing Engine process the inputs of the requests and produce a response which returns to the Client via the WPS Request Handler.

3.3. Architecture

The System Architecture is a typical multi-tier client-server architecture customized to meet the proposed system requirements and emphasizing on the openness and interoperability between the various independent components. Fig. 2 illustrates a possible implementation scenario with selected open source software components identified in the review depicted in Table 1. It also contains servers implementing OGC web services standards interface. A notable particularity of the specific illustration is that the spatial data involved may originate from data providers conforming to the appropriate OGC web services. Other types of services satisfying geospatial processing requirements, may be provided by servers implementing the WPS standard and the whole setting comprises a framework for Geospatial Cloud Computing. A brief description of the system architecture layers follows.

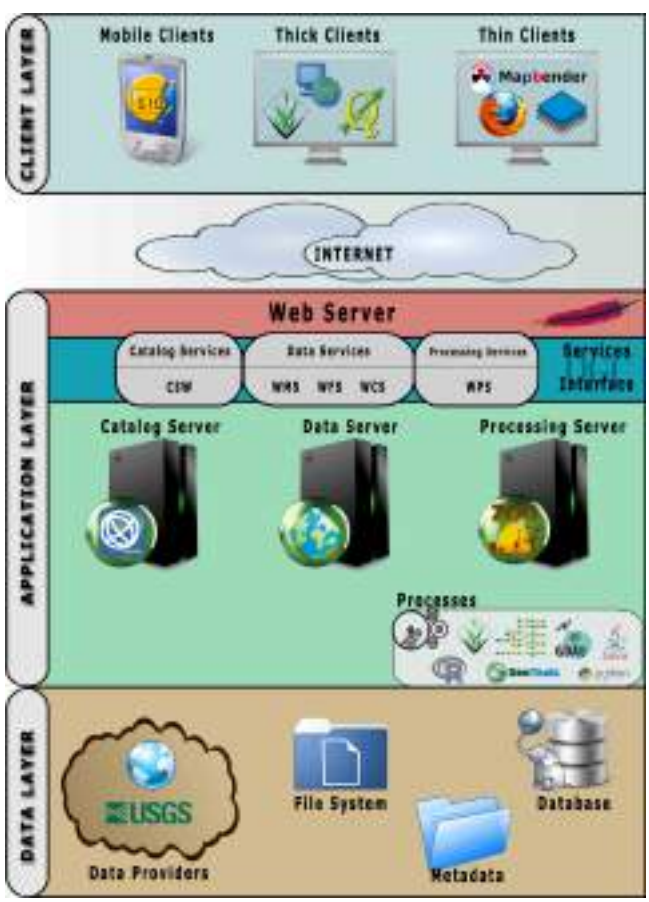

Fig. 2. An open system architecture for Geospatial Cloud Computing.

The Client Layer consists of software providing the end-users with the capability of visualizing spatial information through (a) thin clients, such as browser-based web applications, (b) thick clients, such as standalone GIS applications, and (c) applications running on mobile devices. In addition, clients are able to display interactive maps and perform actions on them, such as zooming and querying as well as to discover and bind to shared data through standardized catalog services. Finally, the clients provide all the necessary tools to identify the geoprocessing capabilities of the system, compose geospatial processing requests and receive the requested geoinformation.

The Application Layer contains the core services performed by the System and also facilitates interfacing between clients and data providers. On top of this layer, a web server hosting web (map/catalog/process) services and directing requests to and responses from the application servers is considered as the access point to the system. Application services implement open OGC standards and include:

- Catalog server applications that keep records of exposed metadata information regarding data and processes provided by different sources. This is an essential part of the system due to the large amount of spatial data in the Cloud and a standard method following the publish-find-bind service framework defined on the OGC Web Services architecture.
- Data server applications that provide spatial data to the clients, categorized in standardized service forms, such as web mapping services (WMS) in the case of map images, web feature services (WFS) in the case of vector data and web coverage services (WCS) in the case of grid data.
- Processing server applications that offer a repository of geospatial processes and allow clients to apply them over spatial data through the implementation of the WPS standard. Clients can request description of each process, supply the processing service with input parameters, specify a certain area in a bounding box, and, provide inputs with complex values such as XML structures and binary data. These inputs are being manipulated by processing modules, that may be either existing tools provided by GIS software (e.g., Grass) or newly developed ones. An internal communication interface between the processing server and the processing modules is required, which, in terms of the UML sequence diagram previously introduced, implements the WPS Request Handler component.

The Data Layer consists of the providers that hold spatial data and their information. The system uses this layer in order to retrieve data and serve it as a standardized service for further manipulation. Data providers may be the international organizations (e.g., USGS), file systems, and database management systems.

4. Conclusions

Interaction UML diagrams, representing requests for and responses from OGC web services, provide a thorough design overview of a System exploiting geospatial services in the Cloud. Web processing services may vary from one specific case to another, thus a global diagram containing any implemented geospatial process in the Cloud would be very helpful. It is then a matter of combining appropriate services to provide a solution for a specific use case scenario.

So far, web-GIS applications usually exploit WPS implementations concerning vector or raster data provided by end users. Utilization of map and catalog services on SDIs for retrieving raster datasets of the AOI are common to use case scenarios applicable in the area of remote sensing and related fields of expertise, since most of them include raster discovery and acquisition services. In the proposed System Architecture, Cloud technology capabilities

make it possible to combine data services from various data providers and distribute geospatial processing to other processing service providers.

The needs for geoinformation vary from one specific scientific and research area to another and the existing interfaces implementing geospatial processes were developed to satisfy certain domain specific needs. Thus, for an expert involved in any area requiring GIS functionalities, it is a challenge to specify the needs for geoinformation and the related geoprocesses producing it, and see them included in future WPS implementations.

Geospatial web services make possible the integration of computer systems deployed in incompatible platforms and the manipulation of spatial data structures of different formats. Thus, it is possible to migrate from desktop and proprietary web applications to open systems providing on the fly geoprocessing services and producing on demand geoinformation.

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EOSDIS, Earth Observing System Data and Information System, National Aeronautics and Space Administration. 〈https://earthdata.nasa.gov/〉 (accessed 23.07.13).
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