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Geospatial Web Services, Open Standards, and Advances in Interoperability: A Selected, Annotated Bibliography

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Cynthia Dietz

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Cynthia Dietz (e-mail: cynthia.dietz@stonybrook.edu) is Science/Map Librarian at the University of Stony Brook (SUNY), Stony Brook, New York.

Abstract: This paper is designed to help GIS librarians and information specialists follow developments in the emerging field of geospatial Web services (GWS). When built using open standards, GWS permits users to dynamically access, exchange, deliver, and process geospatial data and products on the World Wide Web, no matter what platform or protocol is used. Standards/specifications pertaining to geospatial ontologies, geospatial Web services and interoperability are discussed in this bibliography. Finally, a selected, annotated list of bibliographic references by experts in the field is presented.

Keywords: Web services, geospatial data, data processing, spatial data infrastructures, metadata, ontology, interoperability, geoinformatics, grid computing

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INTRODUCTION

In the last few years, the fields of geospatial visualization of and geoprocessing have grown dramatically because of:

- the wide availability of aerial and satellite imagery, vector representations and statistical data on the Internet,
- the growth of geospatial Web services,
- the development of open standards for geospatial information, and
- the growth of Web mapping services (e.g. Google Maps).

Geospatial Web services (GWS) use language(s), vocabulary (ies), message styles, and program coding to publish objects on the Web. Most geospatial Web services adhere to geospatial standards, developed primarily by the International Standards Organization/Technical Committee 211 (ISO/TC211), the Open Geospatial Consortium (OGC), and the Federal Geographic Data Committee (FGDC) (FGDC 2009), which promotes the National Spatial Data Infrastructure and has endorsed several open standards. Current geospatial standards have been extended by standards developed by the World Wide Web Consortium (W3C), the Internet Engineering Task Force (IETF) (http://www.ietf.org) and the Organization for the Advancement of Structured Information Standards(OASIS) (http://www.oasis-open.org/home/index.php).

Just a decade ago, information specialists, including Geographic Information System (GIS) and Map librarians, did well to understand the theory behind geoprocessing and technical issues pertaining to GIS software. Today, they will serve their clients/patrons better if they maintain an understanding and/or proficiency in several additional areas, including: semantic issues introduced by geoprocessing, geospatial Web service interfaces, open source tools, open standards, and Web 2.0.

Most of the resources selected for this annotated bibliography have been published within the last three years. They were selected from subscription databases, WorldCAT, and the Internet. These works, many by renowned researchers, are meant to provide an introduction to developments and research topics in the field.

The resources below have been organized into three sections, the first two of which are "Introduction to Geospatial Web Services", and "Standards for Geospatial Web Services." The third section, "Geospatial Web Services," highlights approaches to improve interoperability, approaches to improve geoprocessing, GWS integrations with mass market applications, and GWS integrations with e-infrastructures. Except where noted, resources within each section are arranged alphabetically. Each work is annotated to include details pertaining to scope, special features, and author affiliation. A complete alphabetical list of all materials cited in this article is located at the end of this bibliography.

1. OVERVIEW OF GEOSPATIAL WEB SERVICES (GWS)

This section describes four resources that introduce GWS to readers. They are well written and touch on concepts discussed throughout this article.

- Kralidis, Athanasios Tom. "Geospatial Web Services: The Evolution of Geospatial Data Infrastructure." In *The Geospatial Web: How Geobrowsers, Social Software and the Web 2.0 Are Shaping the Network Society*, edited by Arno Scharl and Klaus Tochtermann, 223-228. London: Springer-Verlag, 2007.

  Kralidis is Senior Systems Scientist at Environment Canada in Toronto. In general terms, he describes geospatial Web services (GWS) and the benefits they offer for data interoperability. As introduced, GWS provide users a vehicle to query data and receive it at the granularity they request. They can discover, access, visualize and evaluate geospatial data dynamically. That data is apt to be current and is retrievable, usually from authoritative sources maintained by partner communities. WFSs support data transactions, enabling users to modify retrieved information, regardless of platform. Web 2.0 clients, such as Google Earth, benefit.

  Only a minority of users use GWS, since the majority access geospatial data using proprietary software or through file transfer requests. Usually when users make GWS requests the transactions are simple ones. For complex or customized applications, users need to collaborate with information technology specialists and providers.

  The author anticipates future research in GWS pertaining to advanced processing and semantics for improved interpretations of content models. The development of professionals trained in programming and geomatics is a concern, as are the methods to address issues of copyright and authoritativeness.

- Morris, Steven P. "Geospatial Web Services and Geoarchiving: New Opportunities and Challenges in Geographic Information Services." *Library Trends*, 55 no. 2 (Fall 2006): 285-303. (Accessed August 1, 2009 from Wilson Web database.)

Morris, formerly Department Head of Digital Libraries Initiatives at North Carolina State University, addresses two issues: the library's role with regard to geospatial Web services, and the procedures that libraries should make for long term archiving, given the distribution systems available now. A discussion of these roles starts in the third section: *Data Interoperability and Emerging Geospatial Web Services*. Both the attraction and drawbacks of geospatial Web services are well described. The integration and management of GWS may be problematic. GWS may be difficult to discover and select in a comprehensive and exhaustive way: the tasks, applications and domains of Web services are not described consistently. Some services are transient, or have multiple versions—not all of which are compatible. Libraries may choose to support the discovery and selection of GWS by providing links in their catalogs. Additionally, they might designate a server to access frequently used GWS, and to build new services on top of them, appropriate for a region or discipline.

Morris notes that roadblocks to cascading Web services abound: incompatibility of GWS versions, variation in symbolization across services, different scale restrictions, annotation differences and/or missing metadata. Yet both community building and technical interoperability specifications can contribute to regional solutions.

New viewers—such as Google Maps, Google Earth, MSN Virtual Earth, and Yahoo Maps— may act as WMS clients. Using APIs, third party developers and the public map expand upon the offerings. Using AJAX (asynchronous JavaScript and XML) and other technologies, mashups are born. Libraries may decide to expose archived content to such environments for time-related studies.

Libraries are exploring the use of OGC Web services for geospatial data archiving and preservation. The North Carolina Geospatial Data Archiving Project (NCGDAP) is investigating using OGC specifications to capture data resources from remote servers.

Several geoarchiving challenges persist. For one, the Spatial Data Transfer Standard (SDTS), an open vector format, is not in wide use. Secondly, a single relational database often stores data on such topics as topology, relationships and behaviors. That data is not easily exported for use in GWS. Saving statistical geodata and time-versioned content is problematic, as is packaging the output of a myriad of GWS for archiving. Still GWS via a WFS could be used to automatically create, transport and extract geodata in inventories.

- Nebert, Doug, Carl Reed, and Roland M. Wagner. "Proposal for a Spatial Data Infrastructure Standards Suite: SDI 1.0." In *Research and Theory in Advancing Spatial Data Infrastructure Concepts* , edited by Harlan Onsrud: 147-159. Redlands, CA: ESRI Press, 2007.

The authors all have strong geospatial credentials. Nebert is the Clearinghouse Coordinator of the Federal Geospatial Data Committee (FGDC) Secretariat and head of four OGC working groups, Reed is the Chief Technical Officer of OGC, and Wagner is affiliated with Con Terra GmbH in Munster, Germany. They propose a compatible suite of geospatial standards referred to as Spatial Data Infrastructure (SDI) Standards Suite Version 1.0. The suite is proposed so that SDIs worldwide may interoperate seamlessly in terms of geospatial data discovery and access. They indicate that most SDIs operate as silos, with a unique set of best practices, where interoperability is assured only within that silo's community. They claim, as does Kiehle, Heier and Greve (2007), that a high level architecture is lacking to define an interoperable framework of standards so that data and services pertaining to a variety of themes, applications and tasks may work together seamlessly. Not infrequently, it is discovered that the standards and content models used for thematic data, such as those for land cover, or parcel ownership, differ.

To establish SDI 1.0, the authors establish evaluation criteria for standards, and recommend compatible, widely implemented geospatial standards to maximize interoperability. They also indicate standards that they consider candidates for future suites.

Six criteria used to define top candidates for SDI 1.0 include: evidence of implementation, stability and conformance, core or supplemental status, reference matrix, information content standards, and service and interface standards. Core standards are identified for OGC's WMS, WFS, Filter Encoding (FES), WCS, Geography Markup Language (GML), Catalogue Service and protocol binding, and the FGDC Content Standard for Digital Geospatial Metadata. Supplemental standards have been identified to include ISO metadata standards 19115 and 19139, and OGC's standards on Styled Layer Descriptor, and Web Map Context. Some supplemental standards would update the core standards. Future candidates for core standards also are listed.

The suite is recommended to support life cycle management, backward compatibility, and to support SDI regional or "zone" interoperability, thought to be a key in marketing applications. To define and manage the standards, the authors recommend an international consensus process to provide governance.

SDI networks are seen as the next evolutionary stage in SDI for such things as emergency preparedness and environmental monitoring. Portions of that network might come from efforts at geospatial fusion.

- Zhao, Peishing, Genong Yu and Liping Di. "Geospatial Web Services." In *Emerging Spatial Information Systems and Applications*, edited by Brian N. Hilton: 1-35. Hershey, PA: Idea Group, Inc., 2007. Also available online at http://www.laits.gmu.edu/geo/nga/doc/geoWebService.pdf

The authors, all from the Laboratory for Advanced Information Technology & Standards at George Mason University, have written extensively on geospatial Web services (GWS). Here they describe how GWS diverges from general Web services and from traditional GIS in their design and development. GWS fully implement OGC specifications: they standardize the data/message exchange pertaining to a particular function, whether for geospatial discovery, retrieval, use or geoprocessing. In a broader interpretation, GWS are described as those services that handle and process geospatial data.

The article describes both the ISO/TC211 abstract standards and the role of OGC specifications in standardizing the implementation of geospatial Web services (GWS). The ISO/TC211 standards detail how geodata might be accessed, processed, analyzed, visualized and transferred between remote locations, users and systems via tools, methods and services. The OGC specifications for data (e.g., DLG, DRG, SDTS, GML, and XML), type (e.g., XSD, DTD, and OWL schema), messaging (via interfaces), metadata (e.g., service description, data description, or cataloging) and process form a loose architecture for GWS implementations.

Since OGC standards are evolving, the authors anticipated the adaptation of information models, protocols, profiles or applications outside of OGC. They anticipated the approval of binding of services via SOAP and the search for services via a Registry using the ebXML (electronic business XML) information model.

GWS services are discovered via a registry (or catalog of services or metadata), index or peer-to-peer network. CSW catalogs GWSs and is easily extended, as with ebXML, to detail information models, data and services.

In GWS orchestration, a service chain is constructed to represent complex geoprocessing and/or knowledge discovery. In service chains, the matching requirements for data and service discovery may fall short, due to a lack of or incomplete semantics, or to a lack of relationship semantics. Ontology standards for data and functional semantics are evolving to facilitate the construction of complex geospatial models.

Hundreds of GWS applications developed on both the server side (e.g., MapServer, GeoTools Web Map Server and LAITS OGC WCS, Web Image Classification Service (WICS) and WMS, and on the client side (Gaia 2) are listed.

The authors conclude that GWS research needs to address several areas: geospatial semantics, performance and security issues, and methods to handle transactions in applications involving multiple interactions.

They have provided an excellent and comprehensive description of the benefits, problems and methodologies of GWS. The references cited list is the best seen for resources available as of 2007.

2. STANDARDS FOR GEOSPATIAL WEB SERVICES

2.1 ISO/TC211 Standards

- ISO/TC211. Standards Guide: ISO/TC211 Geographic Information/Geomatics. http://www.isotc211.org/Outreach/ISO_TC%20_211_Standards_Guide.pdf (accessed on August 16, 2009).

The ISO/TC211 is a technical committee of the International Standards Organization (ISO) that describes its mission as “establishing a structured set of standards for information concerning objects or phenomena that are directly or indirectly associated with a location relative to the Earth” (quotation from the statement under "scope" at http://www.isotc211.org/). Recently, the TC 211 Advisory Group on Outreach published this Standards Guide. Abstract geospatial standards and specifications are grouped into six categories. Within each category, some of the standards and specifications pertaining to GWS are introduced.

The infrastructure for geospatial standardization, detailed in ISO 19101, defines the semantics and structure of geospatial data for management and exchange. Additionally, the behavior of service components for geoprocessing is defined by the Domain Reference Model (DRM) and the Architectural Reference Model (ARM). Datasets, application schemas and metadata datasets are elements in the DRM, while information technology services and geographic information services are distinguished in the ARM.

The data model for geospatial standardization includes ISO 19107, ISO 19109, ISO 19111, and ISO 19123. ISO 19107 defines spatial operators, spatial operations and operator algebra for the creation, modification and deletion of spatial objects. ISO19109 integrates geospatial elements into features and offers rules for incorporating them into an application schema for sharing. ISO 19123 defines a conceptual schema for coverages: the data structure for rasters, triangulated irregular networks, or other mappings from a spatial domain to attribute values. Continuous phenomena, such as temperature, often are represented in coverages, which map data in a spatial, temporal or spatiotemporal domain. Interfaces for each type of coverage are specified in ISO 19123, as are coverage interchanges for the exchange of data.

Information management for geospatial standardization includes ISO 19110, ISO 19115, and ISO 19131. ISO 19110 outlines a framework for feature cataloging, useful for the development of feature catalogs in specific application domains. The framework is designed to promote the sharing of data across domains. Feature types are identified, along with their functions, attributes and relationships. ISO19115 provides a schema and metadata elements for a geospatial dataset. The standard establishes ways that metadata, (applicable to datasets, aggregations of datasets, features or feature attributes) identifies a dataset, and its extent, quality, schema characterization (as spatial or temporal), distribution and spatial referencing. Extension procedures are addressed as well. ISO19131 describes a framework for geographic data product characterization, specifying the content and structure, and occasionally methods of data capture, maintenance and portrayal.

Services for geospatial standardization include positioning services. These describe the content and structure of an interface between devices sending and receiving geospatial positions (ISO 19116), portrayal services that help users understand an image portraying geographic information (ISO 19117), and location-based services, which usually involve mobile devices on a variety of networks (ISO 19132, ISO 19133, and ISO 19134). ISO 19125 describes an architecture for simple feature geometry, and defines a structured query language schema for storing, retrieving, querying and updating feature data and attributes. The services standard (ISO 19119) gives developers the opportunity to create software to enable the access and processing of geospatial data from a variety of sources across a distributed and open environment.

Encoding for geospatial standardization includes GML (ISO 19136) for the transport and storage of geospatial data and Geographic Metadata XML (ISO/TS 19139) for improving interoperability for exchanging metadata of datasets, dataset series, features, feature attributes etc.

Implementation standards for geospatial Web services are specified by the data product specification (ISO 19131) and simple feature standards (ISO 19125) mentioned earlier, and Web map server interface standards (ISO 19128) (Kresse and Fadaie 2004). The ISO 19128 standard, defines three operations of the Web map server interface: the return of service metadata, the return of a map, and the return of information about features shown on the map. Via the interface, distributed map servers may be networked. The WMS classes geospatial data into layers, using predefined styles to display the layers.

Thousands of developers use the open application programming interfaces (APIs) of Google and Microsoft, and the application development tools of Oracle and IBM, to help people visualize data accessed, managed and processed via open standards. Establishing a framework for location based services is seen by some as urgent to prevent “stove pipe” solutions from businesses not adhering to ISO/TC 211 or OGC standards.

2.2 Open Geospatial Consortium Standards

Founded in 1994, the Open Geospatial Consortium, Inc.® (OGC) is a non-profit, international, voluntary consensus standards organization, which is leading the development of interface standards for geospatial and location based services. OGC standards are designed to be implemented in applications and products. Many OGC standards use ISO 19000 series Standards as their abstract model. The resources are arranged to facilitate an understanding of the topics covered.

- Open Geospatial Consortium (OGC). OpenGIS Standards and Specifications. http://www.opengeospatial.org/standards (accessed on August 16, 2009).

In several cases, OGC and ISO/TC211 have joined to produce standards on a particular topic. Note that several OGC topics have been considered jointly with ISO standards: “Feature geometry” with ISO 19107, “Metadata” with ISO 19115, and “Open GIS Service Architecture” with ISO 19119. The OGC, promotes international standards/specifications for geospatial services and content. It implements conceptual standards established by ISO/TC 211. Services may have one function or several. OGC’s Abstract Specification describes information technology services in six classes that categorize geospatial services, five of which are currently used: geographic human interaction services, geographic model/information management services, geographic workflow/task services, processing services and communication services.

Geographic human interaction services provide a means for users to view such things as a catalog for browsing, locating and managing metadata, or to view animation, mosaicing, imagery, spreadsheets and data structures. The services allow a user to control a processing service, such as composing a service chain, or to invoke a service.

Geographic model/information management services pertain to such things as feature access, map access, coverage access, catalog service, registry service, and feature type service. Many of these services manage a store, which might be a store of feature type definitions.

Geographic workflow/task services could include a service to define a chain, or a service to interpret the chain, control service instantiation, or the sequencing of activities.

Processing services involving spatial, thematic, temporal, or metadata content may include services for coordinate conversion, thematic classification, temporal reference systems, transformation services, statistical calculation services, route determination, or proximity analysis.

Communication services address encoding, messaging and transfer services.

- OGC. OGC Reference Model (ORM). http://www.opengeospatial.org/standards/orm (accessed on December 12, 2009)

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The OGC Reference Model (ORM) describes a standards baseline consisting of abstract and implementation standards. Interface, Encoding, Profile and Application Schema standards are included, as well as best practice documents. The ORM, a resource for defining application architectures, provides the user with an outline and details of the workings of OGC.

Several OGC Web Services, or geospatial Web services (GWS), are detailed including the WMS, the WFS, and the WCS. The WMS makes visualizations of products produced using the WFS and WCS.

The Web Processing Service (WPS) implementation specification defines an interface that permits clients to find and bind processes. The processes supported, whether simple or complex, may include a calculation, an algorithm, or a model. WPS is critical to the grid-enabling of GWS discussed later.

Another key standard is the Catalogue Service standard, which is widely implemented to facilitate interoperability.

- OGC. Catalogue Service (CAT). http://www.opengeospatial.org/standards/cat (accessed on August 18, 2009).

The OpenGIS® Catalogue Services Interface Standard (CAT) supports the publication and searching of collections of descriptive information (metadata) about geospatial data, services, and related resources. Providers of resources use catalogues to register metadata that conform to the provider's choice of an information model; such models include descriptions of spatial references and thematic information. Client applications can then search for geospatial data and services in very efficient ways.

Current work involves the extension of CAT using the OASIS ebXML registry information model, modularization of the Catalogue standard, and providing an OpenSearch binding. OGC CAT and Catalogue Services for the Web (CSW) offer interfaces by which metadata about geodata and GWS may be discovered, browsed and queried. See how Yue et al. (2006), and Zhao et al. (2009), have used the ebRIM model. The hyperlinks to the CSW- ebRIM Registry Service, Parts 1, 2 and 3 will introduce you to the interfaces' code.

2.3 Additional Standards Resources

OGC is making every attempt to extend its standards in ways that accommodate the needs of its members. The following resources describe standards that have either been adopted by OGC, or are used in combination with OGC standards

- Lake, Ron, David S. Burggraf, Milan Trninic, and Laurie Rae. *Geography Mark-Up Language (GML).* Chichester: John Wiley, 2004.

  The authors, all from Galdos Systems, Inc., describe the role of the Geography Mark-up Language (GML) for Web services, and cover topics pertaining to GML 2.0 and 3.0. An introduction describes geospatial Web services, the Geo-Web, and the connections between ISO TC/211 and GML. The role of GML in application schemas and geospatial Web services is detailed. In 2007, GML became an international standard (ISO19136-2007).

  In the technical reference section, descriptions, illustrations and commentary are given of GML instances, schemas, objects, features, geometry, topology, temporal elements, dynamic features, coordinate reference systems, coverages, default styling, relational databases, and GIS. This is an excellent resource for understanding GML.

  Ron Lake is the original creator of GML, chair of the OGC GML domain working group, and the founder and CEO of Galdos Systems Inc.

- Moellering, Harold, Henri J. G. L. Aalders, and Aaron Crane. *World Spatial Metadata Standards: Scientific and Technical Descriptions, and Full Descriptions With Crosstable.* San Diego: Elsevier, 2005.

  Although published in 2005, this book provides information not readily available elsewhere. In an introduction, several concepts are discussed: metadata modularity and extensibility, metadata element sets, directory metadata, dictionary metadata, and metadata services (for discovery, inventory and models). Subsequently, initiatives on regional and national scales are summarized. To assess metadata standards, scientific and technical characteristics are presented. National and international spatial metadata standards are assessed, as are metadata standards/profiles pertaining to subject matter. Particularly unique is a large format spreadsheet of national and international spatial metadata standards, and their associated characteristics.

  Moellering, from Ohio State University, is the Chair of the ICA Commission of Spatial Data Standards, and Aalders is associated with Delft University, and Crane with NAVTEQ.

- World Wide Web Consortium (W3C). OWL-S: Semantic Markup for Web Services. 2004. http://www.w3c.org/Submission/2004/SUBM-OWL-S-20041122/Overview.html (accessed on August 16, 2009).

  The World Wide Web Consortium (W3C) developed a standard, not actually considered a geospatial one, that has been adopted by the OGC: OWL-S, the Semantic Markup for Web Services. OWL-S (formerly DAML-S) outlines the three main parts of a service ontology: the service profile, the process model and the grounding. Code and illustrations provide both the specifics and overview that readers will find helpful. OWL-S permits binding that was used in the Geospatial Semantic Web Interoperability Experiment (OGC 2006), and by Yue et al. (2006), and Yue, Di, Yang, Yu & Zhao (2007).

3. *GEOSPATIAL WEB SERVICES—SPECIAL TOPICS*

Several approaches have been taken to improve the speed, flexibility, and reusability of GSW. In Section 3.1 works are described that may store semantic relationships in CSW, or use an ontology architecture, ontology language, and/or reasoning rules. Automatic and/or semi-automatic services pertaining to geospatial queries, assembly and computations may be suggested or provided, many within a service chain. In Section 3.2 works are described that recommend or provide more complex geoprocessing functions of GSW via service chaining, algorithims, and/or a Web service orchestration framework.

The resources described here are not arranged alphabetically, but in a sequence designed to introduce the reader to concepts that are developed in later references.

3.1 Approaches to Improve Interoperability

- Di, Liping. "A Framework for Developing Web-Service-Based Intelligent Geospatial Knowledge Systems." Paper presented at the annual international meeting of the Association of Chinese Professionals in Geographic Information Science (CPGIS), June, 2005. http://www.iseis.cuhk.edu.hk/downloads/full_paper/2005-24-28.pdf (accessed on July 26, 2009).

Di is the Director of the Laboratory for Advanced Information Technology and Standards (LAITS), a branch of the Center for Spatial Information Science and Systems (CSISS) at George Mason University. He discusses a framework, tested in GeoBrain, for building intelligent geospatial knowledge systems in a Web environment. He asserts that the proposed framework should fully automate the geoquery and geo-assembly steps in geospatial knowledge discovery, fully automate the geocomputation step in limited geospatial domains, and facilitate complex geoprocessing and modeling.

Geo-objects and geo-trees have been developed to characterize geoprocessing functions, which are key to a geospatial knowledge system. A geo-object consists of data, a set of attributes, or a set of methods. A geotree is a processing workflow, with the root formed by geo-objects. Several concepts about geo-objects and geo-trees are introduced. A service chain is a workflow process that could be represented by a geo-tree. It requires a geospatial processing model, a geoprocessing algorithm, a geospatial service module, an archived geo-object and a user geo-object.

Key concepts critical to geospatial knowledge systems are described including data transformation and subsetting, domain-specific ontologies, service catalogs, and query interfaces.

Both a common data environment, such as specified in the OGC WCS, WFS, WMS and Catalog Services, and a common service environment are required so that users' requests for geospatial data and services can be completed. If extended or profiled for the geospatial domain, Web services from the W3C environment, including Web Service Description Language (WSDL), SOAP, XML and HTTP, may be part of the solution to create a geospatial knowledge system. The prototype GeoBrain tests the functionality of the approach. GeoBrain has been described also by (Zhao et al., 2009) and (Han, Di, Zhao, Wei and Li, 2009).

- Yue, Peng et al. "Semantic Augmentations for Geospatial Catalogue Service." In: *Proceedings of the 2006 IEEE International Geoscience and Remote Sensing Symposium*. Denver, CO. (2006): 3486-3489. Also available online at http://www.laits.gmu.edu/geo/nga/doc/semanticCatalog.pdf

Although the CSW helps users find geospatial data and Web services, via metadata keyword searches, users lack a way to search for data semantically. Here the authors explore the semantic representation of geospatial data and services using the Ontology Language for Web (OWL/OWL-S). The authors use an extension of the ebRIM profile to store semantic relationships in CSW. They present a "Data Type" service chaining process to produce a composite service responding to user requirements. This paper is a precursor to Yue, Di, Yang, Yu and Zhao (2007), which builds upon the processes described here.

The service chaining process is built in part by expanding the ebRIM class tree and adding new attributes from ISO 19115 via the "Dataset class", or from ISO 19119 by using "Slots" to hold the attributes. Both approaches aid in the identification of service instance, service metadata, and service type.

Three ontologies are built: the "DataType" ontology, using keywords from the Global Change Master Directory (GCMD), the "Service Type" ontology from the GMCD keyword list of services, and the "Association" ontology, which describes relationships between data and services. OWL/OWL-S in embedded into the ebRIM-CSW model. Steps are presented that detail how OWL/OWL-S semantics are registered in ebRIM-CSW.

Via subsumption reasoning, semantic matches on hierarchical relationships use EXACT, SUBSUME and RELAXED. The matches are used to create semantically-augmented search functions so that user requests for data and services are satisfied.

In the future, the authors, all associated with the Center for Spatial Information Science and Systems (CSISS) at George Mason University, seek to develop richer ontologies and improve the precision of data and service discovery.

- Yue, Peng et al. "Semantics-Based Automatic Composition of Geospatial Web Service Chains." *Computers & Geosciences* 33 (2007): 649-665. http://laits.gmu.edu/~gyu/pdfs/cg2007.pdf (accessed on August 21, 2009).

This article develops concepts introduced in Yue et al. (2006). The authors, all from the Center for Spatial Information Science and Systems at George Mason University, promote the use of geospatial Web ontologies with Web services so that a user may exchange geospatial data and information, and execute programs over a network dynamically, quickly and efficiently. In a use case, they propose a new service composition operation in the service-oriented architecture (SOA). In particular, they design and implement the automatic composition of geospatial Web service chains using "Data Type" and "Service Type" ontologies to generate a landslide susceptibility index value. As designed, the "composer" application tool built using the OWL-S composite process automatically combines services into a dependent series and executes the chain. The wrapping of computation services serves as a generalized design for use by a myriad of models beyond the landslide susceptibility product.

Individual services to be chained automatically by the registry are identified: landslide susceptibility, slope, slope aspect, ETM NDVI (enhanced thematic mapper normalized difference vegetation index), WICS and WCS. The data to be chained automatically, where appropriate, would be DEM (digital elevation model), and images (e.g., ETM and Near Infrared (NIR)).

High-level domain ontologies pertain to objects, events or the geospatial domain. For automatic knowledge discovery by the catalog service/composer, the authors propose to bridge application ontologies to high-level domain ontologies using three developed ontologies: “Data Type”, “Service Type”, and “Association”. Here the “Data Type” and “Service Type” ontologies pertain to data types (e.g., terrain elevation and topology) and services (e.g., image processing and data analysis and visualization), respectively. The relationship between services and data, whether direct or relaxed, is described by “Association” ontologies.

To chain Web services having heterogeneous interfaces and messages, schema match tools are required. In many cases, those tools involve reasoning rules related to relationships of class hierarchy. The composer tool sets the match options for the “Data Type” and “Service Type”. The mediated RDF framework registers mappings in the grounding information of OWL-S.

See Alameh (2003) and Lutz et al. (2009) for discussions on mediation .

- Lutz, M., J. Sprado, E. Klien, C. Schubert and I. Christ. “Overcoming Semantic Heterogeneity in Spatial Data Infrastructures.” *Computers & Geosciences*. 35 (2009): 739-752, doi:10.1016/j.cageo.2007.09.017. (Accessed on August 25, 2009 from Academic Search Complete database.)

The authors, affiliated with the European Commission, and other geomatics centers in Germany, present an ontology-based method involving an ontology architecture, an ontology language, and reasoning procedures to improve interoperability in spatial data infrastructures (SDI). They introduce two scenarios, from the geology and hydrology domains, to illustrate the benefits of such a method for the discovery, retrieval, interpretation, and integration of information at three levels: metadata, schema and data content. They also show how the method can be encapsulated in services and client applications.

In the geology scenario, the scientist is required to formulate a Styled Layer Descriptor. In the hydrology scenario, the scientist is attempting to implement a Web service chain.

To facilitate the retrieval of relevant sources, ontologies, rather than queries, are used in search and retrieval processes to avoid the need to get user confirmation. Specifically, the approach uses subsumption relationships to build ontologies, allowing no gradual differentiation. The method contrasts with feature-based approaches to ontology used in the OGC Interoperability Experiment.

In the hybrid ontology approach described, a shared vocabulary of a common domain is built using concepts from each application. The selected knowledge representation language is a Description Logic (DL) notation, the basis of OWL. Tests for subsumption reasoning are used for “matchmaking”. Other tools are used as well (e.g., mediation, semantic descriptions involving two parts, and context transformation rules) to build the model to ensure that terms used are explicit and comparable.

To produce consistent results, the methods described above are encapsulated in software components. They support dynamic service chaining. In all cases, an Ontology-based Reasoner, and a Client Workflow Service (which acts as a Web service client), are used. If contextual heterogeneity persists, other components are activated: a semantic translation specification service (for deriving a transformation), a translation service (for executing the transformation), and an interpolation service (for interpreting WFSs data output).

Related projects (BUSTER, SEWASIE, SEEK, GEON and HarmonISA) are discussed and compared to the proposed architecture. In the future, more complex and heterogeneous scenarios will be tested, as well as those where “scale” matters. They will address complications in the semantics of services, the use of templates to describe service chains, and formal geodata description automation.

- Bai, Yuqi, Liping Di and Yaxing Wei. “A Taxonomy of Geospatial Services for Global Service Discovery and

Interoperability." *Computers & Geosciences* 35 (2009): 783-790, doi: 10.1016/j.cageo.2007.12.018 (accessed on August 25, 2009 from Academic Search Complete database).

The authors, from the Center for Spatial Information Science and Systems at George Mason University, propose a taxonomy of geospatial services so that services may be discovered by service category and version. The system captures information about service interfaces, and their inputs and outputs. Its strength lies in two aspects: it facilitates accurate service discovery, and describes how the service may be reused. Use of the taxonomy for the Global Earth Observation System of Systems (GEOSS) is introduced.

The authors discuss service taxonomies used by ISO, NASA's GCMD, and OGC. None provide the discovery capabilities of the taxonomy proposed. The model proposed is hierarchical with six layers: service category, service type, version, profile, binding, and uniform resource name (URN). Each classification node, identifying one classification concept, may be identified by its position in the classification tree, or by an URN. The use of such a taxonomy facilitates discovery, evaluation for fitness, and dynamic integration.

There appears to be no equivalent taxonomy to facilitate global service discovery for geospatial services based on the interoperability of interfaces. Still, the proposed service taxonomy is limited in that it does not represent service content. The system would benefit from user evaluation and feedback.

- Zhao, Peisheng et al. "Semantic Web-Based Geospatial Knowledge Transformation." *Computers & Geosciences* 35 (2009): 798-808, doi: 10.1016/j.cageo.2008.03.013 (accessed on August 25, 2009 from Academic Search Complete database).

When geospatial Web services, Web services and ontologies are used together, as described here, large volumes of data in a scientific work-flow may be analyzed. This article is tough reading for those who have not mastered Web service terminology. The authors use common formats for data interchange and a Web ontology language in combination with a system of Web services and knowledge management technologies, known as GeoBrain, so that users may collaborate to develop executable service chains that produce the products desired. The authors describe geospatial knowledge transformation, a geospatial domain ontology, an ontology-based knowledge base, and a semantically enabled catalog service. They detail steps in geospatial knowledge transformation, and mention related work. For other discussions on GeoBrain, see Di (2005) and Han, Di, Zhao, Wei and Li (2009).

In geospatial knowledge transformation, three phases translate expert knowledge into a data product: geospatial modeling, model instantiation (obeying rules and constraints to generate a workflow) and model execution (to generate data products). To address semantic heterogeneities (e.g., issues of geospatial classification, representation and relationships) and structural heterogeneities (e.g., differences in geospatial data formats, projections, and computing platforms) four ontology models are offered that specify the syntax of geospatial objects, relationships and services: General Ontology, Geospatial Domain-Specific Ontology, Geospatial Data Ontology, and Geospatial Process Ontology.

Dublin Core Metadata provides the core upper-level vocabulary for the general ontology. The Geospatial Domain-Specific Ontology is provided by experts and covers spatiotemporal factors, physical facts, disciplines, and platforms. It provides scientific meanings to data resources.

Geospatial Process Ontology is a model conceptualizing service types: it depicts feature processes, classes them, and documents relationships and constraints. Concepts of methodology, algorithms, and input-output are incorporated. A semantically enabled OGC CSW, and an ebRIM profile, are used to discover and access the geodata.

In geospatial knowledge transformation, the domain expert sets a goal, finds a service type, and registers the model. Web services may be classified as a geospatial process service (e.g., OGC WPS), a geospatial fusion service, or a geospatial data service (e.g. WCS, WFS, and WMS). In GeoBrain, the Business Process Execution Language for Web

Services (BPEL4WS) is used to represent the service chain, because model reusability is critical. In the service chain, service types are mapped, geospatial data services are joined, and geospatial fusion services make the data discoverable. Composite service bindings execute the service chains.

The authors, from the Center for Spatial Information Science and Systems at George Mason University, mention several workflow systems designed to execute end-to-end processes, such as Taverna, Kepler, and SciFlo. They conclude that research is needed to include spatial reasoning in Web semantics. They hope to research rules appropriate for spatial inference for improved data and service discovery.

3.2 Approaches to Improve Geoprocessing

- Alameh, Nadine. "Chaining Geographic Information Web Services." *IEEE Internet Computing*. 7, no. 5 (2003): 22-29 (accessed on August 25, 2009 from IEEE Xplore database).

Alameh, associated with Global Science & Technology, Inc. describes the chaining of GIS Web services. Dynamic access to customized geographic information is becoming possible, given the availability of specialized interoperable geospatial Web services, the availability of spatial data, the applicability of the data to location-based services, and models that give users just the data they need and not more.

Geospatial Web services, which can be invoked, located or published by users, may be described in three groups: data services, processing services and registry or catalog services. They are accessed via standard protocols, including HTTP and SOAP.

Complementary services may be chained to create custom applications. The author graphically illustrates service chaining, as well as the architecture of GIS Web services. Service chaining falls into three groups: client-coordinated, static or mediated. Details of each chaining method are described well. Mediated services tend to be complex, and oriented to a specific domain. Working dynamically, they may yield inconsistent results.

DAML-S, now known as OWL-S, is described as one of several XML technologies that can support geospatial Web services, and it is perhaps the best for service chaining.

- Kiehle, Chistian. "Business Logic for Geoprocessing of Distributed Geodata." *Computers & Geosciences* 32 (2006): 1746-1757 (accessed on August 25, 2009 from Academic Search Complete database).

The author, from the University of Bonn, introduces a WPS, now an approved by OGC service, that uses grid data to generate just-in-time access and information from distributed geodata inventories. Two case studies are presented. The role of geospatial Web services (GWS) within the Spatial Data Infrastructures (SDI) is described. The underlying data can be updated without affecting user interaction. GWS provide heterogeneous and distributed access to data of the client's choice.

SDIs are typically described as having three tiers: Data tier (the backend), the Business Logic tier (an integration tier or middleware) and the Presentation tier (front-end). Within the Business Logic tier, tasks for geoprocessing occur via algorithms and interfaces designed for interoperability. Three of those common interfaces are described*: getCapabilities, describeProcess, and execute*. Both the get capabilities and describe process interfaces help generate the information needed for complex spatial processes via service chains. Each service pertains to one process, be it a spatial intersection or spatial buffer, which is executed in a certain order in the chain. Service chains, being independent of data and context, may be used on any platform, or by any implementation language.

In the first case study, a simple spatial intersection service is developed which uses two GML datasets. One service module—handling processes such as request validation, error handling, and output preparation—has the potential to be reusable. The second service module for spatial intersection was built with an algorithm. Since it required some customization, it is not as reusable.

In the second case study, geoprocessing handled data from 20 different sources that contributed to the generation of a groundwater vulnerability index. The data was represented at a variety of scales: microscale, mesoscale and macroscale. Three steps, taken to estimate overall protective effectiveness, generated "factors" (via OGC compliant services), transformed all data to grid data, computed groundwater vulnerability via an equation and Map Algebra, and provided a SOAP Web service via a WSDL interface. Each step in the process is well explained by the author.

The consumer decides whether the result from the interface should be presented inside a traditional GIS or in a mobile environment. In a WPS, the user defines the area of interest (e.g. via a bounding box), the coverages or features to be used, and the "topics" to be generated by the system. Although the process speeds processing, via just-in-time generation, complex modeling is not done in an automated way. Manual adjustments are required. Still, when a provider updates data, the WPS result is updated the next time the service is accessed.

The authors conclude that the development of WPS interfaces is time consuming, yet valuable, since interoperability results. The model presented uses GWS without excluding W3C-compliant Web services, such as SOAP.

- Kiehle, Christian, Christian Heier and Klaus Greve. "Requirements for Next Generation Spatial Data Infrastructures-Standardized Web Based Geoprocessing and Web Service Orchestration." *Transactions in GIS.* 11 no.6 (2007): 819-834 (accessed on August 25, 2009 from Academic Search Complete database).

The authors, from lat/lon GmbH, and the universities of Aachen and Bonn, use the OGC's draft WPS specification in two case studies. From the use cases they derived the technological building blocks of the Web Service Orchestration model, designed to process geodata in an OGC compliant way. In service chaining via the orchestration model, the services are loosely coupled: neither the successor nor the ancestor is exactly known.

WPS permit users to perform geoprocessing tasks, such as the spatial intersection of features, the conversion of vector data to raster data, and buffering using geoprocessing algorithms.

Case study one reflects work described in Kiehle (2006) pertaining to groundwater vulnerability. Although the workflow is not reusable, the services are. The second case study, pertaining to land parcel information, automates the workflow. The authors describe the steps to provide a service-driven automated property information system. In this case, XML-Remote Procedure Calls were used rather than SOAP messaging.

Some problems were encountered in both case studies. In the future, the authors will research flexible chaining of process units. The technical preconditions for multiple WPS service instances to be handled exist, but a model is lacking to semantically describe spatial operations.

The authors have proposed a Web service orchestration framework, calling on several services and processes (Process Repository, Service & Data Registry Services, Rules Repository, Rules Engine, Geodata Access Services, Geodata Manipulation Services, and Geodata Portrayal Services) and an orchestration engine as a central service chaining unit. The workflows and rules are programmed in a logical way.

3.3 GWS Integrations with Mass Market Applications

- Foerster, Theodor et al. “Integrating OGC Web Processing Services into Geospatial Mass-market Applications.” Paper presented at the International Conference on Advanced Geographic Information Systems & Web Services, Cancun, Mexico, February 1-7, 2009 (accessed on December 20, 2009 from the IEEE Xplore database).

The authors, from universities and geomatics institutes in Germany, integrate geoprocessing with geospatial mass-market applications. Additionally, they demonstrate the capabilities of the approach in a fire threat use case.

Features of the OGC KML standard are described, and its ability to dynamically integrate remote resources. The OGC WPS is also described, and three of its operations: GetCapabilities, DescribeProcess and Execute. Note a similar discussion of WPS in Granell (2008). WPS processes and stores data retrieved from an URL, and may deliver it as raw data, which makes integration with geospatial mass-market applications possible.

In the proposed approach, uDig, a WPS client, exports a KML file to mass-market applications (e.g. Google Earth) using one of two options: static or dynamic. Subsequently a process is referenced or executed.

In a use case scenario, an expert using uDig configures a buffering and intersecting process pertaining to a fire threat scenario, and exports the process in a KML file. A citizen loads the KML into a portal to visualize the results.

The approach presented complies with KML and WPS standards. Interfaces and encodings do not require customization. Research on the integration of more complex process chains is anticipated.

- Granell, C., L. Diaz and M. Gould. “Geospatial Web Service Integration and Mashups for Water Resource Applications.” Paper presented at the ISPRS Congress, Beijing, China, July 3-11, 2008. http://www.isprs.org/congresses/beijing2008/proceedings/4_pdf/117.pdf (accessed on July 25, 2009).

The authors, from the Universitat Jaume I in Castellon, Spain, seek to provide a distributed, scalable and easier approach to workflow pertaining to hydrological models and datasets. The solution presented integrates geospatial Web services with mass market mashup technology for improved visualization. Basic concepts are introduced, the system architecture is described, and the application scenario demonstrated.

A key to providing more complex services is the OGC WPS. WPS is an interface that describes functionalities, and may wrap off-line services as Web services. Three methods describe service functions: getCapabilities, describeProcess, and execute. The ability of WPS to wrap geospatial services with general purpose ones increases interoperability significantly.

Mapping mashups are applications that use a variety of services, and are used frequently for their visualization capabilities. Updates are shown in real time. The mashup relies on a client-side map service(s) and appropriate data access.

The general architecture used is based on the European Spatial Data Infrastructure INSPIRE. Besides the Data layer, three loosely-coupled layers (i.e. Presentation, Horizontal and Service) describe the architecture. The Presentation layer provides access to data and services, the Horizontal layer guides users through interfaces involved in configuring hydrological models and the Service layer groups service instances. The services grouped pertain to processing, downloading, and viewing. Details of operations within each layer are given.

The implementation of the hydrological modeling provides access to the specific processes and data needed for each model, saving much time and effort. Details of the implementation steps are given. Processes wrapped by WPS may include raster analysis, spatial intersections and coordinate transformations.

The geoprocessing services developed in the hydrological modeling are reusable and registered in OGC catalogs. Because WPS works with algorithms and not pre-determined datasets, they can be chained to such services as WMS and WCS, providing functionality usually only achieved via desktop packages. GML processes elevation zones, while the mashup integration logic component transforms them into KML. Results are displayed using Google Maps API.

Future research will involve a model engine to orchestrate WPS services for complex scientific models.

- Hall, G. Brent and Michael G. Leahy, eds. *Open Source Approaches in Spatial Data Handling*: *Advances in Geographic Information Science.* Berlin: Springer, 2008.

The editors, affiliated with the University of Otago, New Zealand and Wilfrid Laueir University, in Waterloo, Ontario, have produced a highly recommended book describing the modeling for and use of Free and Open Source for Geospatial (FOSS4G) software. Many GWS or OGC models are used in combination with FOSS4G software, including: MapServer, MapGuide, GeoTools, GRASS GIS, GeoVISTA Studio, MapChat and TerraLib. The variety of software integrations described indicates how powerful GWS implementations may become in the future.

- Han, Weiguo et al. "Design and Implementation of GeoBrain Online Analysis System (GeOnAS)." Paper presented at the 8th International Symposium, W2GIS, Shanghai, China, 2008. http://geobrain.laits.gmu.edu/papers/W2GIS2008_GeOnAS.pdf (accessed on August 1, 2009).

The authors, from the Center for Spatial Information Science and Systems at George Mason University, describe the design and implementation of GeOnAS, a Web service-oriented online geospatial analysis system that makes NASA's Earth Observing System (EOS) and other data available to geoscientists for access and modeling. Additionally, the authors present developments in the field, the system architecture, and details of each module. For other discussions on GeoBrain see Di (2005) and Zhao et al. (2009).

In implementing GeOnAS, Web services and AJAX have allowed the developers to maximize analysis, visualization, and modeling capabilities. The general architecture has four layers: the browser client, the interface, services, and database server. Interfaces include modules, such as User Portal, Data Management, Data Visualization, Data Analysis, Catalog, and Workflow. The Services layer includes WCS, WFS, Geographic Markup Language (GML), WMS, Web Map Context (WMC), CSW, and WPS. The database server layer includes the GMU-LAITS, and NASA-ECHO databases.

GeOnAS includes modules for management, manipulation, display, analysis and invocation. The functions of each module are described. The output could be saved, or a KML file created for integration into Google Earth or Google Maps.

The system has displayed superior performance capabilities for publishing, accessing, processing, retrieving, knowledge building, and sharing. Future improvements designed include the support for the Opera and Safari browsers, user-defined geoprocessing, and complex analysis.

3.4 GWS Integrations with E-Infrastructures

Several national and international initiatives use grid computing with semantics or ontology tools to advance interoperability including: the Geosciences Network (GEON) (Baru et al. 2009), National Science Foundation's (NSF) Ocean Observatories Initiative (Arrott et al 2007, and Farcas et al. 2008), and the Virtual Solar-Terrestrial Observatory (Fox et al. 2009). Those that use geospatial Web services are not fully OGC and ISO compliant. Attempts are being made to grid-enable GWS to improve performance and security frameworks. Several exceptional efforts to integrate GWS with Grid computing are presented in a special edition of GIS.Science *(http://portal.opengeospatial.org/files/?artifact_id=35975). Some of those and others are described and annotated here. These resources use grid computing technology, or e-infrastructures, in combination with GWS to share geospatial data, computing power, algorithms and/or other methods to handle complex multidisciplinary problems.*

- Hobona, Gobe, David Fairbairn, Hugo Hiden, and Philip James. 2009. "Orchestration of Grid-Enabled Geospatial Web Services in Geoscientific Workflows." Forthcoming in *IEEE Transactions on Automation Science and Engineering.* Available as a preprint from the IEEE at http://ieeexplore.ieee.org/xpl/tocpreprint.jsp?punumber=8856&isnumber=4358066&isYear, doi:10.1109/TASE.2008.2010626.

Hobona, Fairbairn, Hiden and James, all from the University of Nottingham, Newcastle University and the North East Regional e-Science Centre, U.K., very clearly detail an innovative proposal that uses GWS and tools supported by OGC or Open Grid Services Architecture (OGSA) standards. Their proposal integrates GWS with Grid services to enhance geoscientific workflows and uses workflow enactors to support the orchestration of geoscientific GWS. Workflows are essential to geoscientists to assist in data management, processing, and analysis.

Two enactors are tested with the SAW-GEO (Semantically-Aware Workflow Engines for Geospatial Web Service Orchestration) project: the Simple Conceptual Unified Flow Language (SCUFL) and the Business Process Execution Language (BPEL). See highlights of SAW-GEO in a presentation by Reed (2008).

Workflows are created using several geospatial Web services, including WCS, WFS, WMS and WPS. WMS provide the visualization of WFS and WCS, while WPS provide processing, computational and analytical functions, often performed using algorithms.

OGC and OGSA provide different mechanisms for publishing, finding and binding services: OGC may use GML while OGSA uses SOAP. The authors propose a work-around which involves storing a GML document in a Web-accessible folder, while using a SOAP message containing an URL to reference the document. A WPS transmits feature collections by delivering URL references to GML documents.

The authors also propose a SOAP-based service, which they call a proxy service, to wrap GWS services using SOAP-based interfaces. The interfaces import OGC XML schemas into a Web Services Resource Framework (WSRF) WSDL. Such a proposal when used with other proxy services, servlets and parameters enable the dynamic referencing of target GWS for geopocessing at runtime. The servlet provides access to a dataset during workflow enactment. Possible enactors include ActiveBPEL (a BPEL enactor) and Taverna, which uses SCUFL.

To implement the workflow, Globus Toolkit with a WSRF interface hosted the OGSA services. The open source 52 North WPS and Geoserver were used to contain OGC services. A workflow involving parallel "Thiessen" and "Union" processing and independent subprocessing was set up. Both ActiveBPEL and Taverna separately implemented the workflow. Both implementations were successful, and each had advantages. Both implementations handled large geospatial datasets, OGC data types and parallel sub-processing.

- Khalsa, Siri Jodha Singh, Stefano Nativi, and Gary N. Geller. “The GEOSS Interoperability Process Pilot Project (IP3),” *IEEE Transactions on Geoscience and Remote Sensing*, 47, no. 1 (2009): 80-91 (accessed on December 20, 2009 from the IEEE Xplore database).

The Group on Earth Observations has proposed an advanced information infrastructure for improving interoperability in the Group on Earth Observations System of Systems (GEOSS) Interoperability Process Pilot Project (IP3). GEOSS is designed to manage very large data sets across multiple Earth observing systems. IP3 offers a flexible standards-based and extensible service oriented architecture (SOA). The SOA modules address complex global monitoring functions and send structured messages between network services. SOA modules link resources using multidisciplinary best practices from different ownership domains, on different platforms, and using different languages. Prototypes and demonstrations using the data, resources, and products specified in technical specifications will test the characteristics of the architecture.

The implementation of IP3 is designed in four development phases. Phase I populates GEOSS registers; Phase II develops use cases; Phase III demonstrates use cases; and Phase IV addresses more complex interoperability issues. One use case pertaining to species response to climate change was selected for discussion, since it could be tested through Phase III. IP3 differs from other initiatives in that it deals with independent SOA modules and processes, not data-centric information systems created by a specific discipline’s community. Previously earth science communities may have built specific application metadata profiles, or data and protocol frameworks or database standards. In the multidisciplinary framework, harmonization and/or mediation may be needed to achieve needed interoperability.

In the use case demonstration, an ecological niche model (ENM) received input of species occurrence and climate model data, and produced a product displaying the impact of climate change on the geographical distribution of two species, the Canadian common roadside skipper butterfly and the American pika. The ENM model supports online discovery, access, selection and functionality. Its algorithms support parameter generation and georectification to facilitate enhanced model performance and portability. Workflows are established, and plug and play components created. An infrastructure was built to accommodate five components: the biodiversity data provider, the climatological data provider, the ENM provider, the infrastructure distributed catalogue, and the user client Web browser application. Several OGC component types were used including WMS, WCS, CSW-ebRIM.CIM, CSW-ISO and CSW-ebRIM. FGDC.

Several challenges to extending the framework exist, including the extensibility of a distributed catalog to implement mediation capabilities to federate community catalogs with special components. Usability and performance are concerns. Computer models need to create output accepted and usable by other models or interfaces, taking into account semantic, structural and syntactic issues. Future plans call for the coordination of the IP3 framework with the GEOSS AIP initiative.

As anticipated for Phase IV, the proposed extended framework has several components including a GEO-portal, a distributed catalog server, data set resource providers, model resource providers, and workflow/control providers. The authors propose a typical interaction sequence, and an interoperability implementation process test. They have results from the Phase III demonstration and a working framework that should serve as a model for others.

- Lee, Craig. A. and George Percivall. “The Evolution of Geospatial E-Infrastructures,” *GIS.Science* 3 (2009): 68-70. http://portal.opengeospatial.org/files/?artifact_id=35975

(accessed on October 16, 2009).

Lee and Percivall describe e-infrastructures as platforms which support applications that may use multiple data sources, and which process and consume the data—possibly in multiple locations. Some have strong security models.

The OGC and Open Grid Forum (OGF) strive to develop geospatial applications with e-infrastructures, as in the OGC Web Services-Phase 6 Demonstration (OWS-6) (OGC 2009) airport disaster scenario.

Geospatial data needed in e-infrastructures to address complex problems, as presented by environmental monitoring, and energy and disaster management, will come from academic, industry, government, and virtual organization archives and sources in the field. Several projects have incorporated such data, including the German National D-Grid and CYCLOPS, while others are helping to facilitate such efforts, including INSPIRE, EGEE, the European and American Geophysical Unions, the National Science Foundation, and the US Federal Geographic Data Committee.

The authors suggest that both cloud computing by various governments (e.g., Japan's Kasumigaseki Cloud) and disasters such as Katrina will drive the development and interoperability of geospatial applications and infrastructures. For models to successfully predict the impacts of such disasters as Katrina, they suggest that several fields need to advance, including: atmospheric and oceanic science, computational science, operational infrastructures, and user-friendly geospatial information systems.

- Padberg, Andrew and Christian Kiehle. "Towards a Grid-Enabled SDI: Matching the Paradigms of OGC Web Services and Grid Computing," *International Journal of Spatial Data Infrastructures Research* 4. (In Press.)

Padberg and Kiehle, from the University of Bonn, and lat/lon GmBH respectively, compare the OGC and Grid computing paradigms, and describe how Grid computing can be used in an OGC context. Since many geospatial collections have been centralized, remote geoprocessing, as in an OGC WPS, is now possible. Challenges to implementing a spatial data infrastructure (SDI) with geoprocessing capability exist. Many SDIs have huge amounts of data that the the data originators/owners would like to securely process in an optimum way. Although Grid computing offers high-performance, distributed, large-scale data sharing, none provides a fully compliant SDI infrastructure.

Several characteristics of Grid computing are incompatible with conventional SDIs, including service description documents, service interfaces, "stateful services" (see definition of state in glossary), and security mechanisms. The differences are described. Several prototypes, or use cases, of a Grid-enabled SDI were tested that use the Java framework "deegree"(http://www/deegree.org) to build the SDI, and Globus Toolkit 4 to provide the Grid middleware. In all, the WCS, WFS and WPS specifications were modified. Customizations included creating a custom datastore (a database integrating data from multiple sources), creating a Grid service, inserting WPS logic into the Grid service, the use of grid-specific security settings, and enhancements to communicate with a MyProxy repository.

The modifications described were implemented in the German SDI project, known as GDI-Grid-Project. Beyond an improved capability to store and compute, the project provided Grid users the ability to integrate geospatial service calls into workflows.

Future work will involve the creation and validation of automated Grid workflows, and further integration, generalization and enrichment of data in datastores. Possible use case scenarios are described involving noise propagation, flood simulation, and emergency routing.

Some issues pertaining to grid-enabled SDIs are presented. User authentication tends to delay request cycles. Parallel processing might be difficult if no parallel algorithms are available. Grid computing may delay processing for a few hours, impacting the integration of real-time sensor data.

Possible enhancements could permit a Grid infrastructure to split storage or computing processes, and to execute the subprocesses simultaneously, which would speed processing. Virtual organizations could make use of the system simultaneously from remote locations.

- Woolf, Andrew and Stefano Nativi. "How Earth Science Can Contribute to and Benefit from the Spatial Information Infrastructure." In *Creating spatial information infrastructures* edited by Peter J. M. Oosterom and Sisi Zlatanova, 67-87. Boca Raton: CRC Press, 2008.

Woolf and Nativi are from the Science & Technology Facilities Council Rutherford Appleton Laboratory, U.K., and the Italian National Research Council, Institute of Methodologies for Environmental Analysis, respectively. They describe efforts at developing informatics systems and grid or e-infrastructures to meet the needs of earth science endeavors, which deal with global datasets in a multidisciplinary approach. They argue that e-infrastructures involving modular systems are needed to create persistent services for complex analyses. Service oriented architectures (SOA) now provide the modularity needed to transform data-centric services from "vertical stacks" to service-oriented ones that work through robust registries. Using examples, the authors discuss the challenges for Spatial Information Infrastructures (SII), for advanced earth science grid infrastructures, and for informatics. They cite the need for models and tools based on international standards that incorporate global data from multiple disciplines and describe physical processes having temporal and spatial dimensions. Such models and tools would help those seeking to respond to environmental problems such as climate change and biodiversity.

Two international initiatives and grid infrastructures for Earth science, GEOSS and GMES (Global Monitoring for Environment and Security), are mentioned as needing grid technologies for the sharing of resources in virtual organizations. Grid infrastructures provide improved distributed processing capabilities and are reliable, scalable and secure. The grid application, CYCLOPS, and aspects of NERC DataGrid, a federated data infrastructure, are described. Their efforts to integrate ISO and OGC standards with the grid infrastructures are not complete, and would benefit from best practices. Transitions from file-based to content-based information management are challenging. The GeoSciML and CSML efforts (data models and GML schemas in geosciences (Allison et al., 2008) and climate sciences) are noted for making advances in multidisciplinary modeling.

Coverages and temporal information used heavily in several earth sciences, including oceanography and meteorology, require advanced semantic processing, ontologies, feature catalogs, and the use of observation and measurement schemas and sampling strategies, as offered by Cox (2007a and 2007b). Data simulation models need to be tested using real observations. The authors describe two use cases involving an on-demand flood-risk assessment, and the measurement of a mesoscale eddy.

Several e-infrastructure efforts are noted that require the interoperability provided by geospatial service standardization. Such efforts are not fully interoperable. Substantial progress has been made in the GEOSS Architecture Implementation Pilot (Phases 1 and 2) (http://www.ogcnetwork.net/AIpilot), and in the GEOSS Interoperability Process Pilot Project (IP3), as described above. The authors' challenge to the earth science community to continue to enhance interoperability efforts is strong, and the call for integrating ISO and OGC standards, with enhancements, clear.

- Woolf, Andrew and Arif Shaon. "An Approach to Encapsulation of Grid Processing Within an OGC Web Processing Service," *GIS.Science* 3 *(*2009): 82-88. http://portal.opengeospatial.org/files/?artifact_id=35975 (accessed on November 2, 2009).

Woolf and Shaon offer an approach to use Grid processing to add value to a WPS so that the geoprocessing and analysis for models and large datasets may be scheduled, enhanced, and secure. OGC geospatial catalogs enhance Grid data movement tools. Grid computing provides a framework needed by GWS to construct complex workflows using several computing nodes if needed. Job Submission Description Language (JSDL), an OGF specification, describes the data and computational resources needed for an implementation. When combined with the WPS process description and data, a valid JSDL can be formed to manage a large computational process. The authors outline the steps to create a Grid-enabled WPS service, which involved the creation of a WPS Grid profile and a WPS SOAP /Proxy layer. They note an implementation in scene 4 of the geoprocessing demonstration in OWS-6 (OGC 2009). Future enhancements are needed, including improved integration and development of security practices, the use of the WSRF, and the use of middleware conforming to the HPC Basic Profile.

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5. APPENDICES

5.1 **List of Acronyms**

AJAX	Asynchronous JavaScript and XML
API	Application Programming Interface
BPEL	Business Process Execution Language
CAT	OGC Catalog Service
CSISS	Center for Spatial Information Science and Systems at George Mason University
CSML	Climate Science Modeling Language
CS-W	OGC Catalog Service for the Web
CYCLOPS	Cyber-Infrastructure for Civil Protection Operative Procedures Project
DAML-S	DARPA agent markup language for services
DEM	Digital Elevation Model
DLG	Digital Line Graph
DRG	Digital Raster Graph
DTD	Document Type Definition
ebRIM	Electronic Business Registry Information Model
ebXML	Electronic Business Extensible Markup Language
EGEE	Enabling Grids for E-Science in Europe Project
ENM	Ecological Niche Model
FES	OGC Filter Encoding Standard
FGDC	Federal Geospatial Data Committee
GeOnAS	GeoBrain Online Analysis System developed by GMU
GeoSciML	markup language for the geosciences
GIS	Geographic Information Systems
GMCD	NASA's Global Master Change Directory
GMES	Global Monitoring for Environment and Security
GML	Geographic Mark-up Language
GMU	George Mason University
GWS	Geospatial Web service(s)
HTTP	Hypertext Transfer Protocol
IETF	Internet Engineering Task Force
INSPIRE	Infrastructure for Spatial Information in Europe (EU directive)

IP3	Interoperability Process Pilot Project of GEOSS
ISO/TC211	International Standards Organization/Technical Committee 211
JSDL	Job Submission Description Language
KML	Keyhole Markup Language
LAITS	Laboratory for Advanced Information Technology & Standards
NERC	UK's Natural Environment Research Council
NIR	Near Infrared
NSDI	US National Spatial Data Infrastructure
OASIS	Organization for the Advancement of Structured Information Standards
OGC	Open Geospatial Consortium
OGF	Open Grid Forum
OGSA	Open Grid Services Architecture
OWL	Ontology Web Language
OWL-S	Semantic Markup for Web Services
RDF	Resource Description Framework
SCUFL	Simple Conceptual Unified flow Language
SDI	Spatial Data Infrastructure
SDTS	Spatial Data Transfer Standard
SII	Spatial Information Infrastructure
SLD	Styled Layer Descriptor
SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
URL	Uniform Resource Locator
WCS	OGC Web Coverage Service
WFS	OGC Web Feature Service
WICS	Web Image Classification Service
WMS	Web Mapping Service
WPS	Web Processing Service
WSDL	Web Service Definition Language
WSRF	Web Services Resource Framework
XML	Extensible Markup Language
XSD	XML Schema Definition

5.2 **Glossary**

Word or Phrase	**Description**	**Source**
Algorithm	A sequence of instructions in computing that solves a problem effectively	http://www.wikipedia.org
Binding (computer science)	"The creation of a simple reference to something that is larger and more complicated and used frequently"	http://www.wikipedia.org
Client	"An application or system that accesses a remote service on another computer system, known as a server, by way of a network"	http://www.wikipedia.org
Dublin Core	An element set to describe metadata pertaining to web pages, documents, and multimedia	http://www.wikipedia.org
E-infrastructure	A framework to share data from distributed facilities across a network	http://www.beliefproject.org
Gaia	A geospatial viewer developed by The Carbon Project for SDI needs	http://www.thecarbonproject.com/gaia.php
Geoinformatics	"Geoinformatics is the science and technologies which develops and uses information science infrastructure to address the problems of geography, geosciences and related branches of engineering."	http://www.wikipedia.org
Geomatics	"Geomatics is the discipline of gathering, storing, processing, and delivering geographic information, or spatially referenced information."	http://www.wikipedia.org
Geospatial Web service	"A modular Web application that provides services on geospatial data, information, or knowledge."	(Di et al. 2005)
Geo-Web	Provides a way to search for information by location as well as by keyword	http://www.wikipedia.org
Globus Toolkit	"An open source toolkit for building computing grids developed and provided by the Globus Alliance."	http://www.wikipedia.org
Grid computing	"The combination of computer resources from multiple administrative domains applied to a common task, usually to a scientific, technical or business problem that requires a great number of computer processing cycles or the need to process large amounts of data."	http://www.wikipedia.org

Instantiation	"The process of creating a new object (or instance of a class) is often referred to as instantiation. "	http://www.wikipedia.org
Interface (computer science)	"A set of named operations that can be invoked by clients."	http://www.wikipedia.org
Kepler	An open scientific workflow system	http://www.wikipedia.org
Knowledge base	A database of knowledge often useful for automated deductive reasoning	http://www.wikipedia.org
Location-based services	A web service, accessible using mobile devices, that permit users to locate objects, proximities, etc.	http://www.wikipedia.org
Mashup (web application hybrid)	"A web application that combines data and/or functionality from more than one source"	http://www.wikipedia.org
Mediation	The process in which value is added to data or a service to facilitate its use in an application.	(Wiederhold 1999)
Metadata	Data about data that helps the user find the actual data	http://www.wikipedia.org
Ontology (information science)	"A formal representation of a set of concepts within a domain and the relationships between those concepts:"	http://www.wikipedia.org
Orchestration (computing)	"The automated arrangement, coordination, and management of complex computer systems, middleware, and services."	http://www.wikipedia.org
Parallel processing	"The ability of an entity to carry out multiple operations or tasks simultaneously"	http://www.wikipedia.org
Portrayal service (Web)	A Web service that renders for Web access a map feature or coverage data	http://www.opengeospatial.org
Profile	"Set of one or more base standards and - where applicable - the identification of chosen clauses, classes, subsets, options and parameters of those base standards that are necessary for accomplishing a particular function [ISO 19101, ISO 19106]"	http://wiki.services.eoportal.org/files/OGC_07_063r1_WMS_Application_Profile_for%20EO_Products.doc"
Protocol (computing)	"A set of instructions for transferring data "	http://www.wikipedia.org
Proxy server	"A computer network service that allows clients to make indirect network connections to other network services "	http://www.wikipedia.org
Reasoner	"A piece of software able to infer logical consequences from a set of asserted facts or axioms	http://www.wikipedia.org

Registry service	supports "the registration, management and retrieval of geospatial and non-geospatial information items "	http://www.opengeospatial.org/projects/ groups/ebxmlregrepswg
Remote procedure call	"Technology that allows a computer program to cause a subroutine or procedure to execute in another address space (commonly on another computer on a shared network) without the programmer explicitly coding the details for this remote interaction"	http://www.wikipedia.org
Rules engine	A business or workflow engine based on rules which "are required to build up decision trees within processes and to control the behaviour in dependency of certain events or circumstances"	(Kiehle, Heier and Greve 2007)
SciFlo	Stands for Scientific Dataflow. " SciFlo is a Grid workflow or Web Service choreography engine that is currently installed at a dozen nodes within NASA data centers "	http://wiki.esipfed.org/index.php/SciFlo_ workflows,_and_ECHO_ Client_for_space/time_granule_query
Semantic translation	"Semantic translation is the process of using semantic information to aid in the translation of data in one representation or data model to another representation or data model. Semantic translation takes advantage of semantics that associate meaning with individual data elements in one dictionary to create an equivalent meaning in a second system."	http://www.wikipedia.org
Semantics	The study of meaning	http://www.wikipedia.org
Server (computing)	"A server is any combination of hardware or software designed to provide services to clients. When used alone, the term typically refers to a computer which may be running a server operating system, but is commonly used to refer to any software or dedicated hardware capable of providing services."	http://www.wikipedia.org
Service chain	An assemblage of modular GWS "for representing a more complicated geospatial model and process flow"	(Zhao, Yu, & Di 2007)

Spatial data infrastructure (SDI)	"A spatial data infrastructure (SDI) is a framework of spatial data, metadata, users and tools that are interactively connected in order to use spatial data in an efficient and flexible way. Another definition is the technology, policies, standards, human resources, and related activities necessary to acquire, process, distribute, use, maintain, and preserve spatial data"	http://www.wikipedia.org
Spatial data transfer standard	"The Spatial Data Transfer Standard, or SDTS, is a robust way of transferring earth-referenced spatial data between dissimilar computer systems with the potential for no information loss. It is a transfer standard that embraces the philosophy of self-contained transfers, i.e. spatial data, attribute, georeferencing, data quality report, data dictionary, and other supporting metadata all included in the transfer. "	http://mcmcweb.er.usgs.gov/sdts/ whatsdts.html
State	A "set of persistent data or information items that have a lifetime longer than a single request/response message exchange between a requestor and the Web service"	http://www.devarticles.com/c/a/Web-Services/Web-Services-and-Stateful-Resources/
Subsumption relation	A "hyponym-hypernym relationship"	http://www.wikipedia.org
Taxonomy	"Practice and science of classification"	http://www.wikipedia.org
Use case	A use case in software engineering and systems engineering is a description of a system's behavior as it responds to a request from outside of that system. In other words, a use case describes "who" can do "what" with the system in question. The use case technique is used to capture a system's behavioral requirements by detailing scenario-driven threads through the functional requirements.	http://en.wikipedia.org/wiki/Use_case
Web 2.0	"Commonly associated with web applications that facilitate interactive information sharing, interoperability, user-centered design[1] and collaboration on the World Wide Web."	http://www.wikipedia.org

Web service protocol stack	"A web service protocol stack is a protocol stack (a stack of computer networking protocols) that is used to define, locate, implement, and make Web services interact with each other. A web service protocol stack typically stacks four protocols"	http://www.wikipedia.org
Workflow application	"A software application which automates, at least to some degree, a process or processes."	http://www.wikipedia.org