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Standards Suites for Spatial Data Infrastructures

Someone left the cake out in the rain
I don't think that I can take it
'Cause it took so long to bake it
And I'll never have that recipe again
Oh no!

McArthur Park, by Jimmy Webb

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Summary

Successful implementation of Internet-based spatial data infrastructures (SDI) requires specification and adoption of a compatible suite of standards to enable interoperability. The proliferation of new standards and new versions of old standards raises issues of dependency and compatibility that may impede implementation of SDI architectures. This chapter proposes a suite of compatible geospatial standards. Application of a common set of standards for SDIs can reduce life cycle costs, enhance interoperability, decrease implementation risk, and improve services.

This white paper is designed to facilitate description and acquisition of compatible technology for SDIs worldwide, from local to regional to national to transnational to global.

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Introduction

For over 30 years, SDI activities have progressed at the local, regional, national, transnational, and global levels. Spatial data infrastructures are the realization of technical and human efforts to coordinate and provide geospatial information and services for multiple purposes. The SDI Cookbook (2004)[1] describes SDIs as follows:

The term "Spatial Data Infrastructure" (SDI) is often used to denote the relevant base collection of technologies, policies and institutional arrangements that facilitate the availability of and access to spatial data. The SDI provides a basis for spatial data discovery, evaluation, and application for users and providers within all levels of government, the commercial sector, the non-profit sector, academia, and by citizens in general.

Based on the Geospatial Interoperability Return on Investment Study, initial investment in using SDIs will add value and reduce life cycle management costs[2] (NASA, 2005).

Many SDI activities operate as independent application "silos" with little or no interoperability between them. The technical framework for an SDI, which includes effective use of standards, enables interoperability for access to and exchange of geospatial resources. Interoperability across SDIs requires consensus on which standards are used, what version of a given standard is used, what compliance tests are passed, etc. Without consensus, severe limits are imposed on our ability to implement SDIs.

Successful implementation of Internet-based spatial data infrastructures requires specification and adoption of a compatible suite of standards to enable interoperability. The proliferation of new standards and new versions of old standards raises issues of dependency and compatibility that may impede implementation of SDI architectures. This white paper proposes a suite of compatible geospatial standards. Application of a common set of standards for SDIs can reduce life cycle costs, enhance interoperability, decrease implementation risk, and improve services.

Geospatial standards-based acquisition guidance in the form of procurement language and 'boiler plate' templates does not readily exist across the geospatial community. This white paper is designed to facilitate description and acquisition of compatible technology for SDIs worldwide, from local to regional to national to transnational to global.

The core of this white paper was originally published as A Proposal for a Spatial Data Infrastructure Standards Suite: SDI 1.0, in Research and Theory in Advancing Spatial Data Infrastructure Concepts[3].

This white paper revises Chapter 10: Standards Suites for Spatial Data Infrastructure of the SDI Cookbook (2012)[4]. Enhancements include:

[1] http://gsdiassociation.org/images/publications/cookbooks/SDI_Cookbook_GSDI_2004_ver2.pdf, accessed April 18, 2017

[2] http://www.ec-gis.org/sdi/ws/costbenefit2006/reference/ROI_Study.pdf, accessed April 17, 2017

[3] https://books.google.com/books?isbn=1589481623, accessed April 18, 2017

- Reference to the UN-GGIM Guide to the Role of Standards in Geospatial Information Management and its companion document
- Updated versions of standards in the SDI standards baseline
- Addition of a section on quality considerations: service status checker; compliance testing; interoperability; and performance
- Addition of a section on APIs
- Updated bibliography (informative) that includes references to the Common Framework on Earth Observations Data and the Geospatial Interoperability Reference Architecture (GIRA), both published in 2015.
- Addition of an informative annex on Internet organizations
- Over 60 footnotes

Problem statement

SDI initiatives worldwide implement a variety of international standards for data and service discovery, data access, visualization, and analysis. Use of different combinations and/or versions of these standards limits interoperability between systems and initiatives. Guidance on best practices and approaches to solving these interoperability issues is critical to defining and implementing an SDI.

This document seeks to answer the following questions:

- What standards make up the SDI standards baseline?
- Which versions of core standards should be cited in the SDI standards baseline?
- What tests *shall* be performed to make sure that software is compliant with standards?

Scope and objectives

This white paper identifies compatible mature geospatial standards that allow maximum technical interoperability based on general evaluation criteria. It calls this set the SDI Standards Baseline. It also identifies supplemental standards for the SDI standards baseline. Lastly, it identifies candidate standards for future SDI deployments or enhancements.

Background and rationale

The SDI standards baseline is intended to manage the complexity, evolution, and compatibility of available standards and their associated versions and to encourage globally compatible solutions.

Complexity

Many standards from the information and communications technology community may be considered as part of the architecture and deployment of interoperable geospatial solutions. Selection of an

[4] http://gsdiassociation.org/images/publications/cookbooks/SDI_Cookbook_from_Wiki_2012_update.pdf, accessed April 18, 2017

appropriate technical architecture can become daunting, and independent selection of standards may lead to incompatibilities within or between SDI implementations.

An SDI standards baseline identifies basic capabilities in an SDI environment, with provision for identifying optional supplemental standards.

Evolution cycles

Standards evolve, based on factors such as new requirements, new technical trends, and implementation experience. Too often, these changes are rarely coordinated with changes in other normatively referenced standards. An SDI standards baseline that identifies standards and versions that work together is of great benefit to implementers, integrators, and adopters. Adapting to frequent changes in standards is expensive and subject to incompatibility. Minimizing the number and frequency of changes (especially version changes) is a goal of this document.

Global compatibility

Through identification of an SDI standards baseline, software that supports one SDI can be readily deployed for another SDI. This broadens the market reach of solution providers and reduces the cost of software development through targeted support of specific standard versions.

Standards considered

Geospatial standards are primarily developed by the International Organization for Standardization (ISO) Technical Committee 211 (TC 211), Geographic information/Geomatics[5] and the Open Geospatial Consortium (OGC)[6]. Geospatial standards development has advanced in context of the World Wide Web and its emerging standards and infrastructure.

Geospatial standards often depend on standards such as those of the World Wide Web Consortium (W3C)[7] and the Organization for the Advancement of Structured Information Standards (OASIS)[8], which develops e-business standards.

Identification of an SDI standards baseline is already a practice in SDI contexts. An SDI standards baseline allows for provider-operated services and data to be discovered, visualized, and accessed by Web browsers and software applications.

General evaluation criteria

Given the number and versions of geospatial standards, definition of an SDI standards baseline reduces risk and enhances interoperability among SDIs. Inclusion of a standard in an SDI is based on the following criteria:

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[5] http://www.isotc211.org/, accessed April 17, 2017
[6] http://www.opengeospatial.org, accessed April 17, 2017
[7] http://www.w3c.org, accessed April 17, 2017
[8] http://www.oasis-open.org, accessed April 17, 2017

- Open standards
- Evidence of implementation
- Dependencies
- Stability and conformance
- Core or supplemental status

Open standards

The OGC defines Open Standards[9] as standards that are:

- Freely and publicly available – available free of charge, with no license fees, and unencumbered by patents and other intellectual property.
- Nondiscriminatory – available to anyone and any organization, anytime, anywhere with no restrictions.
- Vendor neutral - in terms of their content and implementation concept. Open standards do not favor any vendor over another.
- Data neutral – independent of any data storage model or format[10].
- Defined, documented, and approved by a formal, member driven consensus process no single entity controls the standard.

Evidence of implementation

Many factors come into play when considering the adoption of a standard. Factors include simplicity of the standard, market need, availability of educational materials and tools, and policy guidance. Stability and maturity of a standard are equally necessary.

Software solutions and documentation (publications, how-to guides, and workbooks) help identify mature standards. The OGC web site lists products that have implemented OGC standards. Evidence of implementation helps determine which standards and versions need to be included in the SDI standards baseline. This approach focuses on reducing costs and risks while increasing value by leveraging existing services and implementations.

Dependencies

Standards often have dependencies on other standards. The latest version of a standard might not work with other standards.

Dependencies on other standards that are not mature or widely adopted may cause problems with interoperability. Minimizing the number of dependencies can facilitate migration to newer versions of standards, as related standards may evolve on an independent schedule.

[9] https://wiki.osgeo.org/wiki/Open_Source_and_Open_Standards#Open_Standards, accessed April 10, 2017.
[10] While the selection of data formats is outside the scope of this white paper, open data formats are recommended.

Stability and conformance

Implementation of technical standards to ensure interoperability requires that implementations be assessed or tested for conformance or compliance against the standards. Availability of tests — testing service, assessment methodology, model assertions, or testing software — promotes adoption of interoperable solutions.

Compliance testing determines that product implementation of a particular standard complies with all mandatory elements specified in the standard and that these elements operate as described. Successfully completion of compliance testing enables software developers to be licensed to use a trademark or certification mark, which can inform users that the product complies with specific standards and has passed compliance testing for those standards.

Availability of compliance tests for a standard is a sign of stability of a standard. It reduces risk and enhances interoperability among and between SDIs, and hence is an important criterion in considering the inclusion of the standard in a coordinated suite of SDI standards.

Core or supplemental status

Core standards should be viewed as widely implemented standards that provide baseline functionality in an SDI. An SDI standards baseline is the primary reference for core standards.

Supplemental standards may not be required for SDI implementation, but they may identify optional, well-known capabilities.

Internet and IT standards

Section 6.1, General IT and Internet Standards, of the companion document[11] to the UN-GGIM Guide to the Role of Standards in Geospatial Information Management identifies "foundational" standards that are generally required to implement web or internet based solutions. Not all standards listed in Section 6.1 are required for implementation, but they may be required or expected to be present in a community's operating environment. Most OGC standards reference one or more of these foundational standards.

Annex B identifies organizations that make the Internet and World Wide Web work together.

SDI standards baseline

Table 2 lists core standards for the SDI baseline.

Implementation specifications tell software developers how to express information or requests on the World Wide Web. Two kinds of implementation standards may apply:

- **Information transfer standards**
- **Service invocation standards**

[11] http://ggim.un.org/docs/Standards%20Guide%20for%20UNGGIM%20-%20Final.pdf, accessed April 17, 2017

This standards classification is adapted from the Geospatial Interoperability Reference Model (GIRM).[12]. The GIRM classifies information transfer and service invocation standards as implementation specifications.

Table 1 identifies information transfer standards, while Table [insert] identifies service invocation standards in the SDI standards baseline

Information viewpoint
Information transfer standards
ISO 19115/ISO 19139
OGC Geography Markup Language (GML) 3.2.1
OGC KML 2.2
OGC Filter Encoding (FE) 2.0
GeoRSS-Simple, GeoRSS GML
Web Map Context (WMC) 1.1
GeoPackage

Table 1 - Information transfer standards

Computation viewpoint
Service invocation standards
OGC Catalogue Service 2.0.2 HTTP protocol binding (CS-W) ISO Metadata Profile
OGC Web Processing Sevices (WPS) 1.0 + corrigenda
OGC Web Feature Service (WFS) 2.0/ISO 19142:2010
OGC Web Map Service (WMS) 1.3/ISO 19128:2005
OGC Web Coverage Service (WCS) 2.0 + extensions

Table 2 - Service invocation standards

Information transfer and service invocation standards are intertwined. Information content isn't useful without services to transmit and use it; conversely, invoking a service requires that underlying information be available and clear in its meeting.

Information transfer standards

Information transfer standards define content of geospatial information or its encoding for transfer between different processing systems. In GIRM parlance, this is the information viewpoint. information

[12] https://www.fgdc.gov/standards/organization/GIRM, accessed April 17, 2017

transfer standards described below rely on the Extensible Markup Language (XML)[13], an open, machine-readable data format.

Core standards

ISO 19115/TS 19139 metadata standards

ISO 19115-1:2014

ISO 19115-1:2014, Geographic information - Metadata[14], defines the conceptual schema for describing geographic information and services in metadata. The conceptual schema is expressed in the Unified Modeling Language (UML)[15]. Metadata provides information about identification, extent, quality, spatial and temporal aspects, content, spatial reference, portrayal, distribution, and other properties of digital geographic data and services. ISO 19115-1:2014 does not provide guidance on encoding or exchange of metadata.

ISO 19139:2007

ISO 19139:2007, Geographic information -- Metadata -- XML schema implementation[16] provides encoding rules for transforming UML conceptual models into Extensible Markup Language (XML) encoding. XML defines rules for encoding documents in a format that is both human-readable and machine-readable.

ISO/NP TS 19139-1, a project to revise ISO/TS 19139:2007, has been approved.

ISO 19115-3:2016

ISO 19115-3:2016, Geographic information -- Metadata -- Part 3: XML schema implementation, for fundamental concepts[17], applies the encoding rules defined in ISO 19139 to encode ISO 19115-1:2014 UML into XML. It has a number of conformance classes that define levels of conformance to ISO 19115-1:2014. The XML implementation model does not alter the semantics of the conceptual model.

OGC Geography Markup Language

The OGC Geography Markup Language (GML)[18] provides a means of encoding geographic features and their properties using XML. GML is the expected packaging for features requested from an OGC Web Feature Server (WFS). Data encoded in GML can be validated using XML schemas published with the standard and maintained in a schema repository by OGC. GML 3.2.1 is equivalent to ISO 19136:2007[19]. It is compatible with Web Feature Service 1.1.

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[13] https://www.w3.org/XML, accessed April 17, 2017
[14] http://www.iso.org/iso/iso_catalogue/catalogue_ics/catalogue_detail_ics.htm?csnumber=53798, accessed April 17, 2017
[15] http://www.omg.org/spec, accessed April 17, 2017
[16] http://www.iso.org/iso/catalogue_detail.htm?csnumber=32557, accessed April 17, 2017
[17] http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=32579, accessed April 17, 2017
[18] http://www.opengeospatial.org/standards/gml, accessed April 17, 2017
[19] https://www.iso.org/standard/32554.html, accessed April 18, 2017

OGC KML

KML[20] is an XML language that focuses on visualization of geographic data in earth browser applications (for example, Google Earth). It uses a tag-based structure with nested elements and attributes for specific display purposes. KML can be used to:

- Annotate the Earth
- Specify icons and labels to identify locations on the surface of the planet
- Create different camera positions to define unique views for KML features
- Define image overlays to attach to the ground or screen
- Define styles to specify KML feature appearance
- Write HTML descriptions of KML features, including hyperlinks and embedded images
- Organize KML features into hierarchies
- Locate and update retrieved KML documents from local or remote network locations
- Define the location and orientation of textured 3D objects

KML can carry GML content and GML can be "styled" to KML for presentation[21]. KML instances may be transformed losslessly to GML; however, roughly 90% of GML's structures (such as metadata, coordinate reference systems, horizontal and vertical datums, etc.) cannot be transformed to KML. Numerous GML-to-KML and KML-to-GML transform applications are available.

OGC Filter Encoding specification

The filter encoding standard[22] describes XML encoding of a system neutral syntax for a query expression. A filter expression is used to constrain the property values of an object type in order to identify a subset of object instances. FE is used in the request messaging sent to Web Feature Services and in the query sent to the OGC Catalogue Service CS-W. This standard applies to the development of systems that use the interfaces specified by the OpenGIS® Web Feature Service Implementation Specification.

Any OGC web service that requires the ability to query objects from a web-accessible repository can make use of XML filter encoding: for example, a web feature service may use the XML filter encoding in a GetFeature operation to define query constraints.

XML can be readily validated, parsed and transformed into whatever language is required to retrieve or modify object instances stored in a persistent object store: for example, an XML encoded filter could be transformed into a WHERE clause for a SQL SELECT statement to fetch data stored in a SQL-based relational database. OGC hosts reference XML schema documents that can be used to validate queries structured according to the standard.

ISO published ISO 19143, Geographic information - Feature encoding in 2010[23]. OGC published ISO 19143:2010 as OpenGIS Filter Encoding 2.0 Encoding Standard in November 2010.

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[20] http://www.opengeospatial.org/standards/kml, accessed April 18, 2017
[21] http://www.digitalpreservation.gov/formats/fdd/fdd000296.shtml, accessed April 18, 2017
[22] http://www.opengeospatial.org/standards/filter, accessed April 18, 2017
[23] https://www.iso.org/standard/42137.html, accessed April 18, 2017

GeoRSS

Rich Site Summary (RSS) is a simple, brief, and structured XML format that includes only key descriptive elements like author, date, title, narrative description, and hypertext link, elements which help a reader (or an RSS "aggregator" service) decide what source materials are worth examining in more detail.

GeoRSS[24] enables RSS feeds to be geotagged or described by location. GeoRSS serves as an easy-to-use geotagging language that is extensible and upwardly-compatible with more sophisticated formats like GML.

There are two encodings of GeoRSS:

- GeoRSS-Simple is a very lightweight format that developers and users can quickly and easily add to their existing feeds with little effort. It supports basic geometries (point, line, box, polygon) and covers typical use cases when encoding locations.
- GeoRSS GML is a formal GML Application Profile, and supports a greater range of features, notably coordinate reference systems other than WGS-84 latitude/longitude.

GeoPackage

The OGC® GeoPackage Encoding Standard[25] defines GeoPackages for exchange and GeoPackage SQLite Extensions for direct use of vector geospatial features and/or tile matrix sets of earth images and raster maps at various scales. Direct use is the ability to access and update data in a native storage format without intermediate format translations. This guarantees data model and data set integrity and identical access and update results in response to identical requests from different client applications.

GeoPackages are interoperable across all enterprise and personal computing environments. They are particularly useful on mobile devices like cell phones and tablets in communications environments with limited connectivity and bandwidth.

A GeoPackage is a SQLite[26] database file. SQLite is the most used database engine in the world.

Supplemental standards

Table [insert] lists supplemental standards for the SDI baseline.

Supplemental standards
Information transfer standards
OGC Styled Layer Descriptor (SLD) 1.1
Symbology Encoding (SE) 1.1.0
Web Map Tile Service (WMTS) 1.0.0
Web Map Context (WMC) 1.1.0

Table 3 - Supplemental standards

[24] http://www.georss.org, accessed April 18, 2017
[25] http://www.geopackage.org/spec/, accessed April 18, 2017
[26] https://www.sqlite.org/index.html, accessed April 18, 2017

OGC Styled Layer Descriptor

The OGC Styled Layer Descriptor (SLD) standard[27] defines the structure of an XML file that applies rendering or symbolization rules to features. An SLD can be invoked as an argument to a Web Map Service to present a requested map according to style rules. The current version is SLD 1.1.

SLD support is an optional feature of WMS, and therefore, SLD 1.1 is a supplemental standard in the SDI standards baseline.

Symbology Encoding

Portrayal transforms raw information into an explanatory or decision-support tool. Fine-grained control of graphical representation of data is a fundamental requirement for any mapping community.

The Symbology Encoding (SE) Standard[28] defines: (1) an XML grammar for styling information independent of any service interface standard and (2) styling language rules that clients and servers can understand to portray the output of Web Map Servers, Web Feature Servers and Web Coverage Servers.

Web Map Tile Service

A Web Map Tile Service (WMTS) enabled server application serves map tiles of spatially referenced data using tile images with predefined content, extent, and resolution. It trades the flexibility of custom map rendering that WMS offers for the scalability made possible by serving static data where the bounding box and scales have been constrained to discrete tiles.

The WMTS standard[29] provides a standard based solution to serve digital maps using predefined image tiles. It describes the semantics of the resources offered by the servers and requested by the client.

Web Map Context

Web Map Context[30] (WMC) is a companion specification to WMS 1.1.1. It shows how to describe a grouping of one or more maps from one or more map servers in a portable, platform-independent format for storage in a repository or transmission between clients. This description is a “Web Map Context Document." A WMC document includes information about the server(s) providing layer(s) in the overall map, the bounding box and map projection shared by all the maps, sufficient operational metadata for client software to reproduce the map, and ancillary metadata to annotate or describe the maps and their provenance. A WMC document is structured using eXtensible Markup Language (XML).

This specification applies to creation and use of documents that unambiguously describe the state, or "Context," of a WMS Client application. In some cases, reference is made to the Styled Layer Descriptor specification [SLD].

This specification does not address archival, cataloging, discovery or retrieval of Context XML documents.

[27] http://www.opengeospatial.org/standards/sld, accessed April 18, 2017
[28] http://www.opengeospatial.org/standards/se, accessed April 18, 2017
[29] http://www.opengeospatial.org/standards/wmts, accessed April 18, 2017
[30] http://www.opengeospatial.org/standards/wmc, accessed April 18, 2017

Service invocation standards

Service invocation standards define interfaces that allow different systems to work together (interoperability). The GIRM call this the computation viewpoint.

OGC Web Service (OWS) Standards define Protocols that can be implemented as WebAPIs. The OWS standards define a protocol and in some cases, a data model. OWS standards include CSW, WMS, WFS, WCS, and WPS.

The OGC Web Services Common Standard[31] specifies aspects that are or should be common to multiple OGC Web Service (OWS) interface Implementation Standards. These common aspects are primarily parameters and data structures used in operation requests and responses. Use of these common aspects increase commonality and discourage non-essential differences, thereby enabling interoperability among OGC standards.

OGC Catalogue Service specification

The OGC Catalogue Service specification[32] provides an abstract model and protocol-specific solutions for discovery of geospatial resources. Catalogues contain searchable metadata and a query interface for returning the metadata properties to the requestor. The OGC Catalogue standard defines the OGC Common Query Language (CQL), a human-readable text format. Links to actual data or services are often embedded in the metadata.

Although Catalogue Service version 2.0.2 describes three protocol bindings, only the HTTP binding, known as Catalogue Services for the Web (CS-W), is in wide usage. CS-W specifies a baseline set of operations, query terms, and response payloads. Communities should specify The OGC CS-W for the ISO Metadata standard to maximize information exchange and interoperability. Schemas for metadata responses that are published with the profile document support limited validation testing.

OGC Web Map Service

The OGC Web Map Service (WMS) standard[33] supports the request and display of maps derived from data accessed by the web map service. Maps may be requested from one or more WMSs and delivered as graphical images (GIF, JPEG, TIFF, etc.) overlaid in browsers or client applications. Features"behind" the map can also be queried, and their properties can be returned to a requesting client.

ISO 19128:2005, Geographic information -- Web map server interface[34] is harmonized with WMS version 1.3.

[31] http://www.opengeospatial.org/standards/common, accessed April 10, 2017
[32] http://www.opengeospatial.org/standards/specifications/catalog, accessed April 18, 2017
[33] http://www.opengeospatial.org/standards/wms, accessed April 18, 2017
[34] http://www.iso.org/iso/home/store/catalogue_tc/catalogue_detail.htm?csnumber=32546, accessed April 18, 2017

Web Feature Services

The OGC Web Feature Service (WFS) standard[35] defines interfaces for data manipulation operations on geographic features using HTTP as the distributed computing platform. Data manipulation operations include the ability to:

- Create a new feature instance
- Delete a feature instance
- Update a feature instance
- Get or Query features based on spatial and non-spatial constraints

These interfaces allow a client to retrieve geospatial data encoded in GML 3.2.1 from multiple Web Feature Servers.

OGC® Web Feature Service 2.0 Interface Standard – With Corrigendum [09-025r2][36] (accessed February 21, 2017) is recommended for use. WFS 2.0 is equivalent to ISO 19142:2012, Geographic information -- Web Feature Service[37].

OGC Web Coverage Service

The term "coverage" takes on different meanings in different geographic information contexts: here, coverages support mapping from a spatial, temporal or spatiotemporal domain that consists of a collection of direct positions for which feature attribute types are common to all geographic positions within the domain. Examples of coverages include rasters, triangulated irregular networks, point sets and polygon coverages. Sometimes, data in a coverage can be represented as features.

The OGC Web Coverage Service (WCS) specification[38] supports electronic retrieval of coverages. A WCS provides access to coverage data in forms that are useful for client-side rendering, as input into scientific models, and for other clients.

As with WMS and WFS, a WCS allows clients to choose portions of a server's information holdings based on spatial constraints and other query criteria. WCS 2.0 is a core standard in the SDI standards baseline for exchange of raster or gridded data (not rendered imagery).

Coverages can be encoded in any suitable format, such as GML, JSON, GeoTIFF, NetCDF or GMLJP2. They are independent from service definitions and therefore can be accessed through a variety of web based services types.WCS 2.0 is recommended. Extensions to the core WCS 2.0 meet additional requirements that are required to completely specify a WCS for implementation.

OGC Web Processing Service

The OGC WPS Interface Standard[39] provides rules for standardizing requests and responses (inputs and outputs) for invoking geospatial processing services as Web services. It defines how a client can request

[35] http://www.opengeospatial.org/standards/wfs, accessed April 18, 2017
[36] http://docs.opengeospatial.org/is/09-025r2/09-025r2.html, accessed April 18, 2017
[37] https://www.iso.org/standard/42136.html, accessed April 18, 2017
[38] http://www.opengeospatial.org/standards/wcs, accessed April 18, 2017

the execution of a process and how the output from the process is handled. It defines an interface that facilitates the publishing of geospatial processes and clients' discovery of and binding to those processes. Data required by the WPS can be delivered across a network or available at the server. WPS can describe any calculation (i.e. process), including all of its inputs and outputs, and trigger its execution as a Web service.

WPS provides standard interfaces to a broad range of geoprocessing functions, such as the entire GRASS API and applications ranging from typnonomy to buffering to weather modeling.

OGC WPS 1.0 and its corrigendum are core standards in the SDI standards baseline.

Future standards

Table [insert] lists future standards for the SDI standards baseline.

Future standards
Information transfer standards Coverage Implementation Schema KML 2.3 **Service invocation standards** CAT 3.0 OGC® Catalogue Services 3.0 Specification - HTTP Protocol Binding OGC® Catalogue Services 3.0 Specification - HTTP Protocol Binding - Abstract Test Suite

Table 4 - Future standards

GML 3.3

GML 3.3 extends GML 3.2.1 with additional schema components and requirements. It is backwards compatible with GML 3.2.1 and ISO 19136:2007, as all extensions are made in separate XML namespaces to support modular use of components from the GML schema. ISO 19136-2:2015, Geographic information -- Geography Markup Language (GML) -- Part 2: Extended schemas and encoding rules[40], builds on ISO 19136:2007 and extends it with additional schema components and requirements. GML 3.3 is identified as a future standard for the SDI standards baseline.

KML 2.3

The main KML enhancements provided in version 2.3[41] are:

- Addition of a new feature, KML Tour, which enables a user to specify aspects of a controlled virtual flight through a series of geographic locations, including speed, mode of flight (smooth or bounce), sound tracks and how KML features are updated throughout the tour.

[39] http://www.opengeospatial.org/standards/wps, accessed April 18, 2017
[40] https://www.iso.org/standard/61585.html, accessed April 18, 2017
[41] http://www.opengeospatial.org/pressroom/pressreleases/2237, accessed April 18, 2017

- Addition of new geometries: Track and MultiTrack. A KML Track can capture and display the path and other aspects of a moving object over a specified period of time.
- Enhancements to KML's Extension Mechanism, allowing for the direct use of XML content from third-party schemas. KML 2.3 is now based on XML Schema 1.1 enabling authors of KML Application Profile extensions to experimentally add foreign element and attribute content interleaved among existing KML elements.

ISO 19123-2 Geographic information — Schema for coverage geometry and functions — Part 2: Coverage implementation schema (CIS)

The definition of coverages contained in GML 3.2.1 did not contain sufficient information to describe coverage instances in GML. ISO 19123-2[42] specifies a GML coverage structure that extends the definition of GML 3.2.1. ISO 19123-2 specifies the coverage structure to be used by ISO geographic information standards and OGC standards, in terms of GML. Although ISO 19123-2 makes heavy use of GML, it does not prescribe that a coverage instance document be encoded in GML.

ISO 19123-2 is a data model whereas WCS is a service model. Both are tentatively separate, thereby allowing different services such as WFS, WCS, WCPS, WPS, etc. to process and deliver coverages.

ISO 19123-2 is derived from the OGC standard previously called GMLCOV, which has been renamed to Coverage Implementation Specification 1.0.

CAT 3.0 + HTTP protocol binding

CAT 3.0[43] specifies interfaces and a framework for defining bindings and application profiles for publishing and accessing digital catalogues of metadata for geospatial data, services, and other resources. CAT 3.0 describes abstract conformance classes for catalogue services. Changes made in CAT 3.0 relative to version 2.0.2 (OGC document 07-006r1) are summarized in Annex C.

Another part of CAT 3.0 describes the HTTP protocol binding known as Catalogue Service for the Web (CSW). Protocol-specific bindings and application profiles provide concrete tests and validation in conformance with CAT 3.0 abstract conformance classes. Conformance test suites realize the CAT 3.0 abstract conformance classes.

Quality considerations

Geospatial service monitoring

Geospatial services are designed to be interoperable, so it is critical that they are operational.

[42] https://www.iso.org/standard/70948.html, accessed April 17, 2017
[43] http://www.opengeospatial.org/standards/cat, accessed April 18, 2017

The Federal Geographic Data Committee (FGDC) provides a Service Status Checker (SSC)[44] web service to validate, test and score geospatial web services. The SSC supports WMS, WFS, WCS, and CSW service types. It returns summary and diagnostic information about the tests performed on each service.

Services are scored for speed performance and reliability:

- Speed performance is the time taken in seconds to do the test.
- Reliability is calculated as a factor of the Speed performance and the correctness of the response.

Organizations may set up an account with and provide a list of services to the SSC to obtain daily results and monitoring.

59,155 services were tested daily as of March 24, 2017.

Compliance testing

If tests are available you shall ensure that your software passes compliance testing.

The OGC Compliance Program[45] provides a process for testing OGC standards for compliance. Users and buyers of software that implement OGC- compliant standards can be assured that the software follows mandatory rules of implementation as specified in the standard.

Interoperability

Although (1) OGC standards provide a standard API between the client and server and (2) server implementations pass the tests for compliance with those standards, there often remain interoperability problems between vendor implementations. *Compliance does not always equate to interoperability*.

The purpose of the OGC Interoperability Program[46] is to rapidly develop, test, validate and demonstrate new standards or enhancements to existing standards based on real world use cases.

The OGC Interoperability Program utilizes several types of initiatives: testbeds, experiments, pilots, plugfests and OGC Network. OGC conducts the various initiatives to move from experimentation with draft specifications in a Testbed or Interoperability Experiment to focused testing of adopted OGC standards by the community in a Plugfest and the refinement of the specifications in near-operational environments in a Pilot or in operational activities of the OGC Network.

The OGC Standards Program is a main source for ideas to be developed in OGC-IP Initiatives. Each OGC IP Initiative considers Standards Program discussions as a basis for requirements in planning of an initiative and for potential solutions during the execution of an initiative.

Performance

TBSL

[44] https://statuschecker.fgdc.gov/, accessed April 18, 2017
[45] http://cite.opengeospatial.org, accessed April 18, 2017
[46] http://www.opengeospatial.org/ogc/policies/ippp, accessed April 18, 2017

Application program interface (API)

The OGC® Open Geospatial APIs - White Paper[47] defines an API (Application Programming Interface) as an interface that is defined by a set of functions and procedures.

APIs support modularity. Well defined APIs separate functionality into independent, interchangeable modules. They allow an organization to publize their APIs for reuse. Public APIs enable developers from other organizations to access functionality provided behind the APIs.

Open APIs are managed as a public good and in an open process. Open APIs adhere to open principles such as those defined by OpenStand[48].

In most situations, the use of OGC standards is enabled through some sort of API. The API allows developers, client applications and other services to access the functionality provided by implementing one or more OGC standard(s) as part of an API.

Discussions within the OGC have identified value in recommending small bits of OGC specifications for API providers to use. OGC API Essentials are a small subset of items specified in OGC standards and other open standards that would be very useful to software developers. OGC API Essentials highlight how modules such as Well Known Text, GeoJSON, WMTS, CQL/Filter, and GeoPackage are useful in building Web APIs, as an alternative to a full-fledged service interface. Reuse of OGC API Essentials will lead to consistency, accuracy and reuse across the various APIs.

Discussion

This section discusses fundamental relationships that illustrate the need for a well-defined and -managed SDI and market and policy forces that dictate requirements for an SDI standards baseline.

Evolution of the SDI standards baseline

Lack of coordination between release cycles of various standards can impede maintenance of operational capabilities. The problem is compounded when interdependent standards are not revised and released in a coordinated manner. These issues are similar to issues related to software product development and release cycles. A well-defined and agreed-to SDI standards suite supports software and standards life cycle management.

To determine if is worthwhile to update to a revised SDI standards baseline, consider software update costs, added value of the new SDI standards baseline, return on investment in data or service migration, the ability to enhance SDI applications in a timely manner, and backward compatibility.

SDIs versus SDI applications

The interface between an infrastructure and an application can be defined at a specific point in the value chain on the basis of organizational and economic criteria.

[47] http://docs.opengeospatial.org/wp/16-019r4/16-019r4.html, accessed April 18, 2017
[48] https://open-stand.org/, accessed April 18, 2017

The distinction between computer operating systems (OS) and applications provides an analogy. This distinction is defined by application programming interfaces (APIs) that connect programs and allow software applications to be written. Suppliers of operating systems are often not suppliers of applications. In operating systems, a specific function can be augmented and made reusable if many applications use it. Classic examples are video and audio drivers. These functions were once considered application specific, but because they were used by many applications, a standardized API was eventually included in the operating system.

Likewise, an SDI is a transport mechanism for spatial data and services. Therefore, a defined gateway is needed to act as the organizational interface between the SDI operator and the SDI application customer. A list of "standard" applications is beyond the scope of this current guidance for a SDI standards baseline.

Governance

SDIs require a consensus process to properly define, document, and manage the standards framework, in order to ensure that the needs of the many constituents are properly represented. A structured and open process facilitates dialogue, approval of the SDI framework and future revisions, and effective life cycle management.

e-government initiatives such as the Global Spatial Data Infrastructure (GSDI)[49], Infrastructure for spatial information in Europe (INSPIRE)[50], ANZLIC (Australia and New Zealand)[51], Canada's Spatial Data Infrastructure (CGDI)[52], and the National Spatial Data Infrastructure (US)[53] provide fora for refining SDIs and identifying best practices for developing standards-based SDIs.

Standards lifecycle management will ensure that the SDI standards baseline is coordinated effectively and revisions are carefully considered and documented.

Conclusion

SDIs are a major resource for discovery of and access to geospatial data and services. SDIs contribute to sound decision making, enhanced e-government applications, and better services.

Interoperability can be achieved only through consistent and structured implementation of service interface and encoding standards. This document has proposed an SDI standards baseline identifying core, supplemental, and future standards.

An SDI standards baseline should be considered an important work item for all levels of the SDI community, from local to regional to national to transnational to global. SDIs benefit from a well-defined

[49] http://www.gsdi.org/, accessed April 18, 2017
[50] http://inspire.jrc.ec.europa.eu/, accessed April 18, 2017
[51] http://www.anzlic.gov.au/, accessed April 18, 2017
[52] http://www.nrcan.gc.ca/earth-sciences/geomatics/canadas-spatial-data-infrastructure/10783, accessed April 18, 2017
[53] https://www.fgdc.gov/nsdi/nsdi.html, accessed April 18, 2017

and -managed suite of standards. SDI communities should take responsibility for identifying and defining standards for the SDI standards baseline.

Acknowledgements

[TBSL]

Annex A (informative): For further reading

OGC Market Report: Open Standards and INSPIRE (2012)

This market report[54] provides an overview of OGC, CEN and ISO standards in INSPIRE and clarifies INSPIRE Implementing Rules with respect to standards. INSPIRE Implementing Rules do not specify particular standards or technologies. Technical Guidance documents that accompany the Implementing Rules provide implementation details and identify OGC, ISO and other standards. INSPIRE Implementing Rules are legally binding, while Technical Guidance documents are not.

The section OGC Standards in Support of INSPIRE (pages 18-24) provides short descriptions of select OGC standards, including standards in the SDI standards baseline. It also cites Observations and Measurements (O&M) and Sensor Web Enablement (SWE) standards, which are not covered in this white paper.

Geospatial Standards and Operational Policies (2015)

Canada's Spatial Data Infrastructure classifies standards[55] into the following categories:

- Semantics
- Syntax and Encodings
- Services

Common Framework for Earth Observations Data (2015)

The Common Framework for Earth Observations Data (CFEOD)[56] provides guidance to data producers in Federal agencies for improving and standardizing their data management practices. The following aspects of data management are covered in the CFEOD:

- Data search and discovery services
- Data access services
- Data documentation
- Compatible formats and vocabularies

[54] www.opengeospatial.org/pressroom/marketreport/inspire, accessed April 18, 2017

[55] http://www.nrcan.gc.ca/earth-sciences/geomatics/canadas-spatial-data-infrastructure/8902, accessed 2017-02-28

[56] https://obamawhitehouse.archives.gov/sites/default/files/microsites/ostp/common_framework_for_earth_observation_data.pdf, accessed 2017-02-28

Recommended best practices include:

- Standards and Protocols—officially endorsed standards for use in Earth observation data management.
- Methods and Practices— recommended ways to use the endorsed standards
- Implementations— software to use in realizing the standards and examples of use of the standards at Federal agencies

The CFEOD was developed by The White House Office of Science and Technology Policy (OSTP) through an interagency effort led by the Data Management Working Group of the United States Group on Earth Observations (USGEO).

Geospatial Interoperability Reference Architecture (2015)

According to Section 8.6 Standards-based Acquisition Guidance: Reference Sources, of the Geospatial Interoperability Reference Architecture (GIRA)[57] [58]:

Geospatial standards-based acquisition guidance in the form of procurement language and 'boiler plate' templates does not readily exist across the SDI community.

Section 8.6[59] identifies "[several] attempts to identify 'base-line' or 'essential' geospatial standards that could be included in scopes of work or procurement compliance language have been made." It identified Chapter 10: Standards Suites for Spatial Data Infrastructure of the SDI Cookbook, the predecessor to this white paper, as one of those attempts.

Other attempts that Section 8.6 discusses are: Geospatial Interoperability Reference Model (GIRM); Geospatial Profile of the Federal Enterprise Architecture, Version 2.0; Federal Geospatial Architecture Guidance, Version 1.0; Federal Geographic Data Committee (FGDC) endorsed standards; GEOINT standards; Defence Geospatial Information Working Group (DGIWG) standards; Open Geospatial Consortium (OGC) Reference Model; and United Nations Global Geospatial Information Management (UN-GGIM).

The GIRA does not favor one attempt to identify baseline standards over another.

INSPIRE Implementing Rules and Technical Guidance

INSPIRE Implementing Rules are European Commission Decisions or Regulations that are binding in their entirety.

Non-binding Technical Guidance defines how Member States might implement the Implementing Rules. Technical Guidance documents describe implementation aspects and relationships with standards,

[57] https://www.ise.gov/sites/default/files/GIRA.pdf, accessed April 18, 2017
[58] The GIRA is also formatted for the Web: see https://gira.geoplatform.gov, accessed April 18, 2017
[59] https://gira.geoplatform.gov/gira/sbi/standards-based-acquisition-guidance-reference-sources, accessed April 18, 2017.

technologies, and practices. Implementing technical guidance will maximize the interoperability of INSPIRE services.

INSPIRE distinguishes between Network Services[60] and Spatial Data Services[61].

Network Services

INSPIRE Network Services expose services for machine-to-machine communication. It identifies five types of Network Services: (1) Discovery Services; (2) View Services; (3) Download Services; (4) Schema Transformation Services; and (5) Invoke Spatial Data Services Services. It mandates implementation of Discovery Services, View Services, and Download Services.

Discovery services enable searching metadata for spatial data sets and services and displaying the content of the metadata.

View Services allow users and computer programs to view spatial datasets.

Download services enable copies of spatial datasets, or parts of sets, to be downloaded and, where practicable, accessed directly. Pre-defined dataset download services provide simple download of pre-defined datasets (or pre-defined parts of a dataset), with no ability to query datasets or select user-defined subsets of datasets. Direct access download services include the ability to query and download subsets of datasets.

Schema Transformation Services apply to transformation of logical schemas into a common schema. Transformation services are **not** mandatory if they are transformed into the INSPIRE data models through some other means (e.g. offline transformation or on-the-fly transformation in the download service).

Invoke Spatial Data Services allows spatial data services to be invoked. Since all services can be invoked when metadata is accessed through a discovery service, there is no need to have a special service to invoke other services; instead the discovery service will take the role for invoking a service.

Spatial Data Services

An invocable spatial data service that is not a network service has at least one access point and is conformant with documented and publicly available technical specifications that provide necessary for its execution. An access point is an internet address that contains a detailed description of the spatial data service, including the Internet addresses (end points) that directly call an operation provided by a spatial data service.

[60] http://inspire.ec.europa.eu/network-services/41, accessed April 12, 2017
[61] http://inspire.ec.europa.eu/spatial-data-services/580, accessed April 14, 2017

Annex B (informative): Internet organizations

Descriptions for Internet and IT organizations were adapted from their web sites. Additionally, descriptions for the Internet Architecture Board, Internet Assigned Number Authority, Internet Engineering Steering Group, Internet Engineering Task Force, and Internet Society were adapted from the Unicode Consortium[62].

IEEE

IEEE[63] [64] develops standards for the Internet's physical connectivity.

Internet Architecture Board

The Internet Architecture Board (IAB)[65] provides long-range technical direction for Internet development so that the Internet grows and evolves as a platform for global communication and innovation.

It is an administrative and technical oversight board for the Internet Society (ISOC). It appoints the Internet Engineering Steering Group (IESG), maintains architecture oversight of the Internet, handles the Internet Standards Process and appeals, is responsible for the RFC Editor and the Internet Assigned Numbers Authority, and handles internal and external liaison for ISOC.

Internet Assigned Numbers Authority

The Internet Assigned Numbers Authority (IANA)[66] manages number spaces that make Internet protocols work. It allocates and maintains codes and numbering systems that are used in the technical standards ("protocols") that drive the Internet. It standardizes and publishes media types, formerly known as MIME types; maintains the Internet character set registry; and maintains the DNS Root Zone.

Internet Corporation for Assigned Names and Numbers

The Internet Corporation for Assigned Names and Numbers (ICANN)[67] makes policy decisions about how the domain name system is run. It is in charge of maintaining and coordinating Internet Protocol (IP) addresses and the Domain Name System (DNS).

Internet Engineering Steering Group

The Internet Engineering Steering Group (IESG)[68] is responsible for standards actions, which consist of entering a specification into the standards track, advancing it within the standards track, or removing it from the standards track.

Internet Engineering Task Force

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[62] See Alphabet Soup: Guide to Abbreviations and Other Common Terms in Standardization, http://unicode.org/faq/alpha_soup.html, accessed April 14, 2017

[63] https://www.ieee.org, accessed March 10, 2017

[64] The Institute of Electrical and Electronics Engineers is the full legal name of IEEE. IEEE's membership comprises engineers, scientists, computer scientists, software developers, information technology professionals, and many others in addition to IEEE's traditional electrical and electronics engineering core. The organization no longer goes by its full name, except on legal business documents, and is referred to simply as IEEE.

[65] https://www.iab.org/, accessed March 10, 2017

[66] http://www.iana.org, accessed April 14, 2017

[67] https://www.icann.org/, accessed March 10, 2017

[68] https://www.ietf.org/iesg/, accessed March 10, 2017

The Internet Engineering Task Force (IETF)[69] is an international community of network designers, operators, vendors, and researchers concerned with the evolution of the Internet architecture and the smooth operation of the Internet. Collectively, the IETF does most of the technical work on Internet Standards.

Internet Research Task Force

The Internet Research Task Force (ITRF)[70] is charged with bringing together researchers on Internet technologies and bringing that research into the engineering area for the IETF to standardize.

Internet Society

The Internet Society[71] is an independent international nonprofit organization that provides leadership in Internet related standards, education, and policy around the world. It is the "organization home" for the IETF and the IAB.

Public Technical Identifiers

Public Technical Identifiers (PTI)[72] performs IANA functions on behalf of ICANN.

World Wide Web Consortium

The World Wide Web Consortium (W3C)[73] develops protocols and guidelines that ensure long-term growth of the Web.

[69] https://www.ietf.org/, accessed March 10, 2017
[70] https://irtf.org/, accessed March 10, 2017
[71] https://www.internetsociety.org/, accessed March 10, 2017
[72] https://pti.icann.org/, accessed March 10, 2017
[73] https://www.w3.org/, accessed March 10, 2017