Natural Resources Canada
Ressources naturelles Canada

CANADIAN GEOSPATIAL DATA INFRASTRUCTURE
INFORMATION PRODUCT 42e

Geosemantic Interoperability Backgrounder

GeoConnections
Hickling Arthurs Low Corporation

2015

Canada

ACKNOWLEDGEMENTS

GeoConnections would like to acknowledge the contributions made by Intelli^3– Dr. Yvan Bédard and Sonia Rivest, for providing research, writing and editing of the Backgrounder, Hickling Arthurs and Low Corporation – Ed Kennedy, for supervising the production and revision process. We would also like to thank the contribution of Great Britain Ordnance Survey's Dr. Glen Hart, Principal Research Scientist and Research Manager, and Dr. John Goodwin, Principal Scientist for sharing their pioneering experience about geosemantic interoperability. The staff at GeoConnections who provided management, input and direction for the project were Dr. Jean Brodeur, Mélodie Bujold, Simon Riopel, Cindy Mitchell and Paula McLeod. In addition Craig Eby and Alexandre Cyr provided assistance in assembling this document.

Table of Contents

1. Preamble

This guide is one in a series of Operational Policy documents developed by GeoConnections. This guide is intended to inform CGDI stakeholders about the main concepts and importance of geosemantic interoperability along with related technologies and examples of geosemantic interoperability integration in organizations.

Geosemantic interoperability is fundamental for applications using web-based geospatial data and services. Yet, it is often perceived as an abstract concept difficult to materialize. This document explains geosemantic interoperability, its concepts, technology and challenges. The first section addresses the origin and utility of geosemantic interoperability, the second section covers core concepts and examples, the third section describes the technological environment and the fourth section summarizes a case study. The document closes with challenges and a conclusion.

The ***GeoConnections*** *program is a national initiative led by Natural Resources Canada. GeoConnections supports the integration and use of the* ***Canadian Geospatial Data Infrastructure (CGDI).***

The ***CGDI*** *is an on-line resource that improves the sharing, access and use of Canadian geospatial information – information tied to geographic locations in Canada. It helps decision makers from all levels of government, the private sector, non–government organizations and academia make better decisions on social, economic and environmental priorities.*

2. Introduction

2.1 The origins of geosemantic interoperability

Humans have communicated with each other for millennia. Communication has evolved from mere sounds and gestures to articulated expressions, spoken languages and written languages. Communication is crucial to operate together (i.e., to inter-operate). To do so, we use languages to encode our messages into signs that can be perceived by the receiver. To understand our signs, the receiver must share a common language with us or use a translator. Central to successful interoperability is how the semantics (i.e., the intended meaning of the signs transmitted) is carried over. Geosemantic interoperability deals with this issue for geospatial data transmitted over the web. To do so, it relies on formal languages, ontologies and standards. Spatial Data Infrastructures (SDI), by encouraging such formal elements, facilitate geosemantic interoperability.

2.2 Geosemantic interoperability in today's society

The number of smart devices connected to the Internet (cf. the Internet of Things) exceeded the number of people on Earth five years ago and is rapidly increasing. Millions of people are becoming data generators (cf. social networks, crowdsourcing). Governments are adopting open-data policies. Hyperconnected cities are becoming smart, thanks to real-time data, location intelligence and analytics. Big Data is the hottest buzzword in Information Technology (IT), geospatial data have become ubiquitous, and the Semantic Web is replacing the document-centric Web. Very soon, we will collect more data in a single day than we have collected in our entire history insofar. According to Hoskins (in: Bertolucci, 2013), "hardware had its 20- to 30-year run, then software had its 20- to 30-year run," and we are now at the beginning of the data era. In this new era, geospatial data has become essential.

To avoid confusion and misunderstanding, systems on the Web must understand each other. They need to interoperate semantically. According to Kuhn (2005), "semantic interoperability is the only useful form of interoperability". High quality semantic interoperability is necessary to save time and costs when searching and accessing data, evaluating the quality of data for a given purpose, reusing data, integrating data, analyzing data, discovering and evaluating Web services, etc. High quality geosemantic interoperability is necessary when geospatial data are involved.

3. Core definitions for geosemantic interoperability

Geosemantic interoperability between geospatial applications on the web is analogous to human communication and cooperation (Brodeur, 2012; Brodeur et al, 2003; Kuhn, 2005). Consequently, there are risks of misunderstanding (Sboui and Bédard, 2012). To comprehend the geosemantic interoperability process, its limitations and its solutions, straightforward explanations are required about the way we abstract the world to communicate in a web-based environment, and about concepts, models, symbols, languages, semantics, ontologies, interoperability, contexts, and geosemantics. Relationships with traditional sources of definitions such as dictionaries and thesauri are explained as well as the relationships with domain-specific standards.

3.1 What are "concepts" and how do we communicate them to interoperate?

The real world is complex. To understand the real world, humans create cognitive models, which are abstract views of this world (e.g., a mental image of a house). These abstract representations retain only distinctive elements (e.g., walls, roof, doors, windows, material, size, location on a parcel, proximity to a road, adjacency to other houses, entering, living in, exiting). This abstraction process begins with the categorization of phenomena having common characteristics and behaviors (e.g., houses, parcels, owners and roads can be considered as four distinct categories). For each category, we remember characteristics and behaviors of interest that allow us to distinguish an individual phenomenon from the group (e.g., house address, color, location, type of roof, inhabited periods). We also remember some relations they have with other members of the same category (e.g., House H1 is the neighbor of House H2) or with members of other categories (e.g., house H1 is on Road R1). All such abstract elements are called "concepts".

Concepts are not the phenomena per se, they are their surrogates that exist in our brain. They allow us to understand our world, to remember and to communicate. Although computers do not have a brain like ours, we design their structure and operations in a similar way and we teach them the rules to perform automatic reasoning using the concepts of their inner model.

To communicate and "inter-operate", humans and machines need to encode the concepts of their inner models into a form that can be perceived and understood by other humans or machines. The resulting physical model consists of organized symbols (e.g., written words, sounds) which are physical surrogates to real-life phenomena.

The triad "concept-symbol-phenomenon" is known as the "semantic triangle": we express our abstract concepts (e.g., the "houses" category of our cognitive model) with physical symbols (e.g., the word "house" written on a page) which refer to the real-world phenomena (e.g., houses) that are abstracted as concepts in our mind (e.g., the "house category"). In other words, humans and computers use symbols to express their conceptualization of something in the real world.

The way we organize symbols is known as syntax. Symbols and syntactic rules are core elements of a language (e.g., English, Java, XML). An individual who knows several languages can use a different symbol (e.g., "maison", "casa") to express the same phenomenon. If the human or machine receiving this symbol uses the same language, the interpretation of the symbol will work, communication will take place and they may interoperate.

3.2 Traditional sources to communicate meaning

We use various ways to explicitly express the agreed upon meaning of the symbols used. For example, dictionaries, thesauri, lexicons and glossaries give meanings of words used in natural languages (e.g., English). However, their definitions may vary, leading to potential variations in their correspondence to real-life phenomena. For example, the on-line Oxford Dictionary defines the concept "road" as "a wide way leading from one place to another, especially one with a specially prepared surface which vehicles can use" while the WordNet on-line lexical database defines this concept as "an open way, generally public, for travel or transportation". Such general definitions often are insufficient for geospatial applications. For example, when digitizing a road, where do I start and where do I stop if a road goes through several places? What about a closed road unusable by vehicles, is it still a road? Should we include it in our map?

Semantic database schemas, data dictionaries and feature catalogs describe in more detail the meaning, content, format and structure of data for computer applications. For example, the Feature Catalog of the Canadian GeoBase defines "road" as "a linear section of the earth designed for or the result of vehicular movement. A Road Element is the representation of a road between Junctions. A Road Element is always bounded by two Junctions. A Road Element is composed of one or more than one contiguous Road Segments" (Natural Resources Canada, 2012). This Feature Catalog also includes a detailed description of data types (e.g., the identifier must have 32 digits), codes (e.g., 1 = same direction, 2 = opposite direction, 3 = not applicable), instructions (e.g., the value “0” is used when no value applies; the value “-1” is used when the value is unknown), and examples (e.g., 80-EST, 80-E, 80E). They all contribute to properly understanding the meaning of concepts. A feature catalog can be detailed to a point sufficient to serve as data acquisition specifications (e.g., the road geometry is its centerline, except for highways where a centerline is required for each lane).

Domain-specific standards exist; they propose a common vocabulary and organization of data to facilitate their sharing between systems. For example, the CGIS-NRN2 standard for Canada outlines rules for the identification and description of geographic features of the national road network. The more universal those standards are (e.g., IHO S-101 international standards in hydrography), the more global interoperability is. The absence of standards renders communication very difficult (e.g., the absence of traffic sign standards would make the decoding of these signs difficult when driving in jurisdictions with different languages because one could not interpret correctly their meaning without learning this new language).

3.3 What is “semantics” and what is its role in a web-based environment?

Semantics is about understanding the meaning of symbols and their arrangement (syntax). Semantics analyzes the relationships between the language used by machines or humans, and the phenomenon it refers to in real life. For example, the symbol “pipe” may refer to a man-made cylindrical structure used under or outside the road to transport water, gas or oil. However, it may also refer to a device for smoking tobacco, to the cylindrical tubes by which notes are produced in an organ, or to a command in computer science. The same symbol in French is associated only to the smoking device, while it has no meaning at all in Italian or Spanish. Thus, one symbol may have several meanings or none depending on the language used. The opposite also exists (i.e., several symbols may be used for the same phenomena). For example, “conduit”, “duct”, “tuyau”, “conduite” and “conducto” can be used for the cylindrical structure above.

With computer applications, we formalize semantics to minimize the risks of misinterpretation. Formal semantics uses mathematics-based languages to control the relationships between symbols and meanings. The number of concepts is low and the result is often specific to an application or a domain as it results from an agreed-upon convention between stakeholders. It is common to talk about three levels of vocabulary (Guarino, 1998): application-specific (e.g., city road database), domain-specific (e.g., CGIS-NRN2 standard) and global (e.g., WordNet). The former has more specific semantics, the latter has a higher risk of misinterpretation.

In the Semantic Web, “something is considered as having semantics when it can be processed and understood by a computer” (Almeida et al, 2011). This “allows content, i.e., data, to be shared and reused across applications, enterprises, and community boundaries” (World Wide Web Consortium (W3C), 2013). Semantics is necessary to find data of relevance.

3.4 What is a “formal ontology”, its roles and languages?

Codifying formal semantics agreements in a web environment usually leads to creating computer-based ontologies. In computer science, ontologies are explicit specification mechanisms to express concepts in a computer-readable language (Gruber, 1993; Guarino, 1998). A formal ontology is “a formal representation of phenomena with an underlying vocabulary including definitions and axioms that make the intended meaning explicit and describe phenomena and their relationships" (Brodeur et al, 2003). Components of an ontology are concepts, relations and axioms (Agarwal, 2005). Building a formal ontology is a useful first step towards semantic interoperability on the Web (Kuhn, 2001). Using automatic reasoning, it allows machines to discover data, to assess and match similar ontologies, to properly integrate and transform data coming from various systems, to discover and compose Web services, etc.

Graphical representations and languages have been developed to define formal ontologies for the Web. To facilitate the writing of ontologies, tools exist such as Protégé (Stanford University), Semaphore Ontology Manager (Smartlogic) and Vitro (Cornell University) to name a few.

3.5 What is "interoperability"

Interoperability is the ability of systems to cooperate (inter-operate). Interoperability allows for the exchange of data and services over the Web. For example, if one wants to develop a new pizza delivery application for the Province of Quebec, the system could automatically discover the road network from Natural Resources Canada web services, individual house addresses from Addresses Québec web services, and traffic data from Transports Québec web services. Using formal ontologies, these data could be integrated automatically and routing algorithms applied.

Interoperability takes place at two levels: (1) technical (e.g., communication protocols, data formats, computer languages), and (2) semantic (i.e. to properly interpret the meaning of data to produce useful and accurate results). Standardization bodies focus on the former (the "how"), on the latter (the "what") or cover both. However, without the latter, the former is meaningless.

3.6 What is "context"?

The meaning of symbols always relates to a given context. For example, someone using data from a Winnipeg municipal map could infer that the symbol "pipe" previously mentioned refers indeed to the cylindrical structure used under or outside the road to transport water, gas or oil. Knowledge of the context (municipal map, English is the language used in Winnipeg) allows one to reject the other potential meanings of this symbol. "Context provides relevant information related to the circumstances in which data have been defined and can be used" (Sboui and Bédard, 2012), some could say context is in fact metadata organized into an ontology. Consequently, such context information helps assessing the quality of semantic interoperability. Context-aware interoperability reduces the risks of data misinterpretation and faulty operations.

3.7 What is "geosemantics"?

Geosemantics refers to the semantics of geographic phenomena, including the semantics of their geometry. The semantics of geometry involves two components: definition of the type of geometric primitive (e.g., line), definition of the meaning of this geometry (e.g., road centerline).

Geosemantics is essential to geospatial systems since without the semantics of geometry, several interoperability problems are likely to happen. A common example deals with houses on large-scale maps. In such datasets, houses are typically represented by a single polygon; however, this polygon can represent the roof of the house if measurements have been made with photogrammetry, or it can represent the footing of the house if measurements have been made with land surveying. In such cases, the very own meaning of “house polygon” differs. Furthermore, if the data acquisition specifications require to include all the details of a house polygon larger than 1 meter (e.g., balconies, entrances), the meaning of such house polygons is different than the ones where such details do not have to be measured.

The meaning of geometric primitives in various datasets may also impact geosemantic interoperability. For example, in one dataset, “house polygon” may refer to a single surface with its perimeter, while in another dataset it may refer to a closed line without interior, or it may consider as a unique polygon the aggregation of adjacent sub-polygons (e.g., considering as a single polygon the series of individual properties within a townhouse or condominium). The definition of geometric primitives typically differs among software packages (e.g., Geographical Information Systems (GIS), Computer-Assisted Design systems (CAD)). The use of geomatics standards (e.g., OGC, ISO/TC-211) is strongly encouraged by Geospatial Data Infrastructures since it helps reduce the difficulties related to this aspect of geosemantic interoperability.

The differences in the semantics of geometry and in the meaning of geometric primitives exist not only between diverse systems, but they also exist between different epochs of a system since specifications evolve over time in response to the evolution of needs. Such differences, if unnoticed, will mislead the automatic search for the best source of house data, the assessment of geospatial ontologies matching, the integration and transformation of geometric data, etc. It will also deliver faulty or inconsistent analyses (e.g., number of houses, distance between a house and the street line, density of inhabitants per square meter of houses). Too often, it is assumed that semantic interoperability is sufficient for geospatial data and that using a common spatial reference system is enough; this is a faulty assumption and one must always think about geosemantic interoperability when dealing with geospatial data.

3.8 What is “geosemantic interoperability”?

Geosemantic interoperability is the ability of systems using geospatial data and services to cooperate (inter-operate) at the semantic and geometric levels. Geospatial interoperability allows for the exchange and semantically-compatible use of geometric and non-geometric data and services over the Web. It automatically properly interprets the semantics of geometric data as well as the type of geometric primitives to produce useful and accurate results. Geosemantic interoperability is the richest form of interoperability for geospatial data and services.

3.9 Languages for web-based geosemantic interoperability

Web-based geosemantic interoperability requires that humans express their concepts in languages usable by computers. The Semantic Web provides two elements to deal with the technical and semantics sides of interoperability: 1) common formats for integration and combination of data from diverse sources, and 2) a language, called Resource Description Framework (RDF) for recording how the data relates to real world objects and to other data. RDF links a Web abstract syntax to formal semantics/ontologies. It is a character-based equivalent of object-class or entity-relationships diagrams (Wikipedia, 2014). It uses complex “subject-predicate-object” triplets (similar to “entity-attribute-value”) to explicitly associate the data (object) to specific aspects (predicate) of a web resource (subject). An RDF triplet uses a long character string to uniquely identify the subject and predicate web resources with Uniform Resource Identifiers (URIs). These URIs typically comprise URL addresses. Consequently, this straightforward triplet model allows machines to start searching for data in one database or web resource, and then move through a set of databases or resources that are connected by their content and semantics to find other, related data. Such a collection of interrelated datasets on the Web is known as Linked Data (World Wide Web Consortium (W3C), 2013). It can be viewed as a global database that can be queried using SPARQL, a query language used to express queries across diverse RDF data sources (World Wide Web Consortium, 2013) and GEOSPARQL, a geographic query language for RDF data (Open Geospatial Consortium, 2012).

Richer languages than RDF are also used for interoperability. For example, using RDF constructs, RDFS (RDF Schema) supports additional semantics while the Ontology Web Language (OWL) uses RDFS constructs to add even more expressive power. On the services side, WSDL (Web Service Description Language) describes the syntax of Web services while OWL-S (OWL Service ontology) supports the semantic specification of services.

3.10 Standards to support geosemantic interoperability

Several standardization bodies develop standards to support geosemantic interoperability. The ISO/TC-211 publishes numerous standards related to data models for geographic information, geographic information management, geographic information services, and encoding of geographic information (International Organization for Standardization, 2009). The Open Geospatial Consortium (OGC) proposes standards for the interoperability of geospatial Web services (e.g., WMS, WFS, WCS, WPS), KML, GML, and GeoSPARQL. OGC also proposes standards for application communities (e.g., aviation, defence, emergency, facilities). The World Wide Web Consortium (W3C) proposes many specifications for the Semantic Web and Linked Data: several series of standards (RDF, OWL, SPARQL, WSDL), RIF and SKOS, to name a few. Many highly-regulated domains have specialized standards such as hydrography (International Hydrographic Organization, 2008), transportation (cf. ISO/TC 204; International Organization for Standardization, 2014), and aviation (cf. AIXM; Eurocontrol or European Organisation for the Safety of Air Navigation, 2014).

4. Case Study: Ordnance Survey

Ordnance Survey (OS) is Great Britain’s national mapping agency. OS is known as a pioneer in geosemantic interoperability. This case study is based on an interview with Dr. Glen Hart and Dr. John Goodwin and the documentation they provided.

OS started working on ontologies and interoperability to facilitate data integration in 2004, and they tested various tools and strategies to build ontologies until 2006. In 2007-2008, OS built its first ontologies, increasing its knowledge of the data and allowing new quality checks. In 2009, OS started to convince businesses and governments, in the context of United Kingdom (UK) open data initiatives, to publish their data as Linked Data. In 2010, the first dataset that was transformed in the Linked Data format (i.e., RDF) was the OS boundaries (e.g., counties, districts). OS built an ontology for spatial relations and explicitly included topologic relationships to facilitate spatial queries (e.g., contain, within, touch). This first dataset included no coordinates in order to protect their commercial value. Following this release, the team worked on a platform for publishing Linked Data. OS then released 3 datasets as Linked Data: OS Boundary Line (i.e., administrative limits), Code point (i.e. postal code units), and a 50K Gazetteer (i.e. the list of geographic names from the 1:50,000 mapping, tagged to points representing 1 km^2 map tiles). In addition, the 3 published datasets are now available as a combined Ordnance Survey Linked Data set. Positive feedback translated into continued growth in the use of these datasets (e.g., to link the Boundary Line Linked Data with statistical data from another government organization).

OS has developed the “See UK” application (http://apps.seme4.com/see-uk/) to provide various Linked Data (e.g., crime, schools, transportation) by clicking on a map at various levels. Two companies, Talis and Iconomical, and the data.gov.uk team have developed the Research Funding Explorer to show how linked data techniques can bring real benefit when it comes to joining and analyzing data from a number of different sources. The application allows a user to browse funded research projects by subject, organization, and geography, by linking to the OS Code point Linked Data (by replacing the postcode text with a postcode URI).

The advantages OS sees for geospatial interoperability when using Linked Data are: flexibility, adaptability, and easier data integration when compared to rigid database structures and various data formats. It allows for easily breaking down data silos and exposing problems in the data. OS is working towards assigning a URI for every “place” in Great Britain and future projects include: managing data quality, trust and provenance, licensing, versioning, reasoning, automating data discovery, conversion and ingestion from the Web and sensors.

5. Challenges

The greatest challenge for successful interoperability between geospatial ecosystems is to convince organizations to invest the necessary efforts and discipline to properly describe the semantic and geometric levels of their data. Without such efforts, the formal machine-coded version of the data meaning that exists in their mind may be misinterpreted. This is especially true when contexts differ (epochs, regions, jurisdictions, domains, natural languages, culture, etc.). Furthermore, fuzziness is inherent to several phenomena. Although humans can deal with "clear-enough" concepts, machines rely on forced formal concepts. Relying on context information is a promising avenue to assess the fitness of geosemantic interoperability for given uses and to automatically warn users about the risks of misinterpretation as suggested by Sboui and Bédard (2012). Including such context-awareness in an automatic process is the key to meaningful and safer geosemantic interoperability.

From a technical point of view, Goodwin and Hart from OS have identified two key elements: (1) the expression of time and of relevant metadata in a way usable as Linked Data, and (2) to include proper context information to reduce errors. They also identified today's lack of mature standards and technologies with regards to the Semantic Web.

6. Conclusion

Geosemantic interoperability involves both the semantic and geometric aspects of geospatial data. The geometric aspects include the type of a geometric primitive and its meaning based on its acquisition specifications. Contexts surrounding data may vary widely and render geosemantic interoperability unsuitable for given usages. The automatic assessment of the quality of geosemantic interoperability is feasible using context information. High-quality geosemantic interoperability is the richest form of interoperability for geospatial data and services. High-quality geosemantic interoperability is the necessary basis towards the GeoSemantic Web. Developing the GeoSemantic Web is necessary for tomorrow's technological ecosystem brought by the Internet of Things, Smart Cities and the Spatially-enabled society.

Appendix 1: List of Acronyms

The following table presents the meaning of acronyms used in this document.

Acronym/abbreviation	**Meaning**
AIXM	Aeronautical Information Exchange Model
AIS	Aeronautical Information Services
API	Application Programming Interface
CGIS-NRN2	Canadian Geographical Information Standard - National Road Network 2.0
DAML+OIL	DARPA Agent Modeling Language +_Ontology Inference Layer
DARPA	Defense Advanced Research Projects Agency
FME	Feature Manipulation Engine
GIS	Geographic Information System
GML	Geography Markup Language
HTML	HyperText Markup Language
IHO	International Hydrographic Organization
ISO/TC	International Organization for Standardization/Technical Committee
IT	Information Technology
JSON-LD	JavaScript Object Notation – Linked Data
KML	Keyhole Markup Language
OGC	Open Geospatial Consortium
OIL	Ontology Inference Layer
OS	Ordnance Survey
OWL	Ontology Web Language
OWLGrEd	Ontology Web Language Graphical Editor
OWL-S	Ontology Web Language - Service
RAGLD	Rapid Assembly of Geo-centred Linked Data
RDF	Resource Description Framework
RDFa	Resource Description Framework in Attributes
RDFS	Resource Description Framework Schema
RIF	Rule Interchange Format
SKOS	Simple Knowledge Organization System
URI	Uniform Resource Identifier
W3C	World Wide Web Consortium
WCS	Web Coverage Service
WFS	Web Feature Service
WMS	Web Map Service
WPS	Web Processing Service
WSDL	Web Services Description Language
XML	Extensible Markup Language

Appendix 2: References

Agarwal, P., 2005. Ontological considerations in GIScience. International Journal of Geographical Information Science, 19(5), 501-536.

Almeida, M.B., R.R. Souza, F. Fonseca (2011). Semantics in the Semantic Web: a Critical Evaluation. Knowledge Organization Journal, Vol. 38, No 3, pp. 187-203

Bertolucci, J. (2013, January 4). *The Age Of 'Data Ubiquity': Sensors Spread*. Retrieved from InformationWeek: http://www.informationweek.com/big-data/big-data-analytics/the-age-of-data-ubiquity-sensors-spread/d/d-id/1109327?

Brodeur, J. (2012). Geosemantic Interoperability and the Geospatial Semantic Web. In: Springer (ed), Handbook of Geographic Information, Chap. 15, pp. 291-310

Brodeur, J., Bédard, Y., Edwards, G., & Moulin, B. (2003). Revisiting the Concept of Geospatial Data Interoperability within the Scope of Human Communication Processes. *Transactions in GIS*, *7* (2), pp. 243-265.

Eurocontrol. (2014). *AIXM Aeronautical Information Exchange Model*. Retrieved from Eurocontrol: http://www.aixm.aero/public/subsite_homepage/homepage.html

Gruber, T.R. (1993). A Translation Approach to Portable Ontology Specification. KSL 92-71 (Knowledge Systems Laboratory, Stanford)

Guarino, N. (1998). Formal ontology and information systems. Proceedings, Formal Ontologies Information Systems (FOIS ’98), Trento, pp. 3–15

IEEE. (1991). *610-1991 - IEEE Standard Computer Dictionary. A Compilation of IEEE Standard Computer Glossaries*. New York: IEEE.

International Hydrographic Organization. (2008). *IHO Standards for Hydrographic Surveys*. International Hydrographic Organization.

International Organization for Standardization. (2014). *ISO TC 204 Intelligent Transportation Systems*. Retrieved from ISO: http://www.iso.org/iso/iso_technical_committee?commid=54706

International Organization for Standardization. (2009). *ISO TC 211 Standards Guide*. ISO.

Powell, J. (June 2011). IHO S-101, the Next Generation ENC Product Specification. TransNav International Journal on Marine Navigation. Vol. 5, No. 2, pp. 167-171.

Kuhn, W. (2001). Ontologies In Support Of Activities In Geographical Space. International Journal of Geographical Information Science, vol. 15, No 17, pp. 613-631.

Kuhn, W. (2005). Geospatial Semantics: Why, of What, and How? Journal on Data Semantics III, 1-24

Natural Resources Canada (2012). National Road Network, Feature Catalogue, Segmented View, Edition 2.0.1. 34 p.

Onsrud, H.J. (2010). Legal Interoperability in Support of Spatially Enabling Society. In A. Rajabifard, J. Crompvoets, M. Kalantari, and B. Kok, Spatially Enabling Society: Research, Emerging Trends and Critical Assessment, pp. 163-172. Entire Book at http://memberservices.gsdi.org/files/?artifact_id=902

Open Geospatial Consortium. (2012). *GEOSPARQL A geographic Query Language for RDF Data*. OG.

Sboui, T., Y. Bédard (2012). Universal Geospatial Ontology for the Semantic Interoperability of Data: What are the Risks and How to Approach them? In: Podobnikar, T. & Ceh, M. (ed(s)), Universal Ontology of Geographic Space: Semantic Enrichment for Spatial Data, Chap. 1, pp. 1-27

Wikipedia. (2013, November 11). *RDF Schema*. Retrieved from Wikipedia: http://en.wikipedia.org/wiki/RDF_Schema

Wikipedia. (2014, February 9). *Simple Knowledge Organization System*. Retrieved from Wikipedia: http://en.wikipedia.org/wiki/SKOS

World Wide Web Consortium. (2013, March 22). *RDF - Resource Description Framework*. Retrieved from W3C: http://www.w3.org/RDF/

World Wide Web Consortium. (2013, March 26). *SPARQL Query Language for RDF*. Retrieved from W3C: http://www.w3.org/TR/rdf-sparql-query/

World Wide Web Consortium. (2013, May 20). *Ontology Editors*. Retrieved from W3C Wiki: http://www.w3.org/wiki/Ontology_editors

World Wide Web Consortium. (2013, June 19). *W3C Semantic Web Activity*. Retrieved from W3C: http://www.w3.org/2001/sw/

World Wide Web Consortium. (2013, December 11). *OWL - Ontology Web Language*. Retrieved from W3C: http://www.w3.org/2001/sw/wiki/OWL

World Wide Web Consortium. (2014). *RDF Primer 1.1*. W3C