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Editor: Ingo Simonis, Stephane Fellah

## **OGC<sup>®</sup> Testbed 10 Cross Community Interoperability (CCI) Ontology Engineering Report**

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## Abstract

Testbed 10 ontology work focused on:

- A general examination of ontologies in the context of OGC data modeling, handling, and organization. Testbed-10 has started to define a consistent set of ontologies implementing solid theoretical foundations and semantics.
- The definition of a core ontologies for representing incident information used by Incident Management Systems (IMS) and mapping symbologies used in the emergency and disaster management domain with the goal to improve interoperability between different IMS symbology sets used across multi-level jurisdiction.
- Addressed ontology mapping between hydrology feature models using SPARQL and OWL2.

## Keywords

ogcdoc, ogc documents, ows10, ontology, cci, geosparql, hydrology, uml, owl, incident mapping, emergency

## Preface

A significant part of the OGC standards development process is the Interoperability Program (IP), which conducts international interoperability initiatives such as Testbeds, Pilot Projects, Interoperability Experiments, and Interoperability Expert Services. These activities are designed to encourage rapid development, testing, validation, demonstration and adoption of open, consensus based standards and best practices.

The OGC Testbed 10 (Testbed-10) is a Testbed within the Interoperability Program. Within Testbed-10, the Cross-Community Interoperability (CCI) thread seeks to build on interoperability within communities sharing geospatial data and advance semantic mediation approaches for data discovery, access and use of heterogeneous data models and heterogeneous metadata models. This thread explored the creation of domain ontologies and tools to create, assemble, and disseminate geographic data provided voluntarily by individuals. One objective was to build integration across all OGC web services with the intent to provide a better understanding of service content and the relationships or associations that exist between OGC services and resources/content. All ontology related work is documented in this engineering report. The Testbed-10 Virtual Global Gazetteer Engineering Report (OGC document 14-029) contains further information on semantic mediation between services.

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<b>Contents</b>	<b>Page</b>
1 Introduction.....	1
1.1 Scope.....	1
1.2 Document contributor contact points.....	1
1.3 Revision history .....	2
1.4 Future work.....	2
1.4.1 <i>Ontology development</i> .....	2
1.4.2 <i>GeoSPARQL 2.0</i> .....	2
1.4.3 Core LEAPS and E&DM Domain Ontologies .....	3
1.4.4 <i>Emergency and Disaster Management Mapping Symbolologies</i> .....	3
1.5 Forward.....	3
2 References.....	4
3 Terms and definitions .....	4
4 Conventions .....	7
4.1 Abbreviated terms.....	7
4.2 Used parts of other documents.....	8
5 Introduction.....	9
6 Core Geospatial Ontologies .....	9
6.1 Overview.....	9
6.2 What is an Ontology?.....	10
6.2.1 Definition .....	10
6.2.2 Benefits of ontology.....	10
6.2.3 OWL .....	11
6.3 UML versus OWL modeling .....	11
6.4 Design Approach .....	13
6.4.1 <i>Minimal ontological commitment</i> .....	13
6.4.2 <i>Modularization of ontologies</i> .....	13
6.4.3 <i>Reusability of ontologies</i> .....	14
6.4.4 <i>Understandability</i> .....	14
6.5 OWS10 Geospatial Ontologies overview .....	14
6.5.1 <i>Common Microtheory</i> .....	17
6.5.2 <i>Mereotopology Microtheory</i> .....	17
6.5.3 <i>Temporal Microtheory</i> .....	17
6.5.4 <i>Spatial Microtheory</i> .....	18
6.5.5 <i>Measures microtheory</i> .....	18
6.5.6 <i>Event microtheory</i> .....	19
6.5.7 <i>Feature microtheory</i> .....	19
6.6 Deployment information.....	19
6.7 Next Steps .....	19

6.7.1	<i>Path to standardization</i> .....	19
6.7.2	<i>GeoSPARQL 2.0</i> .....	20
7	Incident ontology for E&DM.....	20
7.1	Overview.....	20
7.2	Core incident ontology overview.....	21
7.3	Controlled vocabulary in the emergency and disaster management domain.....	23
8	Emergency and Disaster Management Symbology .....	25
8.1	Introduction.....	25
8.2	Semiology of Maps.....	27
8.3	Symbol Types .....	27
8.4	Symbol Comprehension.....	27
8.4.1	<i>Theory of Affordances and Other Cognitive Factors</i> .....	28
8.4.2	<i>Culture and Gender</i> .....	28
8.4.3	<i>Sensory Issues and Differences</i> .....	28
8.5	FGDC HSWG Symbol Set.....	29
8.6	Symbology ontology.....	29
8.7	Datasets investigated.....	31
8.8	Recommendations.....	31
9	Hydro Model Interoperability .....	32

<b>Figures</b>	Page
<b>Figure 1: Overview of the Testbed-10 OGC ontologies .....</b>	<b>15</b>
<b>Figure 2: Microtheory excerpt .....</b>	<b>17</b>
<b>Figure 3: Core incident ontology model .....</b>	<b>22</b>
<b>Figure 4: Semantic layer with adapters to the core incident model and derived profiles .....</b>	<b>23</b>
<b>Figure 5: Homeland security symbology for natural events .....</b>	<b>30</b>

## Tables

<b>Table 1: HSWG Incident taxonomy encoded using incident ontology and SKOS.....</b>	<b>24</b>
<b>Table 2: VolcanicEruption event encoded in ontology .....</b>	<b>30</b>



# OGC® Testbed 10 Cross Community Interoperability (CCI) Ontology Engineering Report

## 1 Introduction

### 1.1 Scope

Testbed-10 ontology work focused on three aspects: First, the general examination of ontologies in the context of OGC data modeling, handling, and organization. Though huge efforts have been invested in modeling geographic information by publishing abstract models (ISO 191xx) and implementation specifications for these models (GML, KML, etc.), as well as application schemas (e.g. CityML), no implementations of these abstract models using taxonomy languages (SKOS) and ontology languages such as RDF/S or OWL have been developed in OGC. Testbed-10 has started to define a consistent set of ontologies implementing solid theoretical foundations and semantics.

Second, Testbed-10 examined the definition of a core ontologies for representing incident information used by Incident Management Systems (IMS) and mapping symbologies used in the emergency and disaster management domain with the goal to improve interoperability between different IMS symbology sets used across multi-level jurisdiction.

Third and fully documented as part of the hydrology engineering report, Testbed-10 addressed ontology mapping between hydrology feature models using SPARQL and OWL2.

### 1.2 Document contributor contact points

All questions regarding this document should be directed to the editor or the contributors:

Name	Organization
Ingo Simonis	iGSI GmbH
Stephane Fellah	Image Matters LLC
Genong Yu	George Mason University

### 1.3 Revision history

Date	Release	Editor	Primary clauses modified	Description
2014-04-27	0.1	IS	all	all
2014-05-02	0.2	IS	6	Ontology work added
2014-05-06	1.0	IS	All	Final version
2014-05-14	1.1	IS	8	Additional information on symbology mapping and recommendations for future activities added
2014-05-16	1.2	Stephane Fellah	All	Reorganization of Incident and Symbology related sections.

### 1.4 Future work

Future work is envisioned as follows:

#### 1.4.1 *Ontology development*

The core geospatial ontologies have been result of eight years of Research and Development at Image Matters in the domain of geospatial semantic. Image Matters decided to release these ontologies for the broad community seeking to facilitate semantic interoperability between systems using geospatial information. The logical next steps are a critical review of the provided ontologies and the application of necessary refinements and extensions to achieve a comprehensive set of base ontologies. To favor the adoption of the geospatial ontologies, improve the robustness and completeness of the microtheories, we suggest for the next testbed exercising the ontologies by converting existing geospatial data into geospatial knowledge, creating catalogs for unit of measures, CRSs and feature types (for gazetteers). The ontologies can also be exercised by creating ontologies for more specialized domain that leverage the core geospatial ontologies, as it was done for this testbed for E&DM. The result of these activities should lead to identifying best practices and provides a rich set of examples how geospatial ontologies could be used for different vertical communities and be queried using open linked data standards and protocols (Linked Data Platform, GeoSPARQL).

#### 1.4.2 *GeoSPARQL 2.0*

Based on feedback from the OGC Geospatial Semantic WG and lessons learned from Testbed-10, there is a need to modularize and simplify GeoSPARQL specification. The Testbed-10 geospatial ontologies address many of these aspects (for example modularization of spatial relations), and could be used as a starting point.

The next testbed should demonstrate the feasibility and robustness of the approach by implementing the specifications.



### 1.4.3 Core LEAPS and E&DM Domain Ontologies

We recommend building a set of core domain ontologies for the law enforcement and public safety as well as the emergency and disaster management domain.

As it is important to accommodate jurisdiction-specific and mission-specific profile requirements, it is necessary to identify *key points of interoperability* in a given service oriented architecture. As an example, the next test bed might investigate Abu Dhabi Police's (ADP) System of System (SoS) architecture, defining the required interoperable service APIs and models, as well as the roadmap for achieving a prioritized implementation of these key interfaces and models. The Abu Dhabi Police have submitted a comprehensive set of domain models to OGC for Law Enforcement and Public Safety (LEAPS). These models can be used to derive a set of foundational ontologies that serve as the basis for interoperability throughout ADP's system of systems LEAPS domain. The purpose of this task is to formalize and semantically-ground ADP's LEAPS domain models as ontologies. These ontologies will be built upon OGC's Geospatial Ontology, and they will define the minimum-essential core set of concepts, properties and relationships for the LEAPS community.

The LEAPS ontologies must be designed to accommodate any jurisdiction/mission profile specific information (taxonomies, specialized concepts and relationships), using the built-in extension mechanisms of OWL. The ontologies will be exercised by building "ontology profiles", mapping existing ADP data to the new domain ontologies, and accessing these data through GeoSPARQL endpoints (as highly interoperable and useful LEAPS Linked Data).

### 1.4.4 Emergency and Disaster Management Mapping Symbologies

The definition of the symbol and the incident ontology described in this report addresses the challenges of semantic mapping between different symbologies used in neighboring organizations. During the next testbeds, it is important to further explore this approach with at least two symbol sets. To ensure correct semantics, it is important to develop the formal model for these sets in cooperation with organizations responsible for those symbologies. Otherwise, the risk of incorrect mappings is high.

This approach would allow further refinement of the formal semantic model outlined in this report and in consequence it would allow symbology mediation at conceptual level between different sets.

## 1.5 Forward

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aware that might be infringed by any implementation of the standard set forth in this document, and to provide supporting documentation.

## 2 References

The following documents are referenced in this document. For dated references, subsequent amendments to, or revisions of, any of these publications do not apply. For undated references, the latest edition of the normative document referred to applies.

- Gazetteer ER [https://portal.opengeospatial.org/files/?artifact\\_id=57226](https://portal.opengeospatial.org/files/?artifact_id=57226)
- Hydrology ER: [https://portal.opengeospatial.org/files/?artifact\\_id=57121](https://portal.opengeospatial.org/files/?artifact_id=57121)

## 3 Terms and definitions

### 3.1 Attribute <XML>

name-value pair contained in an **element**

[ISO 19136:2007]

NOTE In this document an attribute is an XML attribute unless otherwise specified.

### 3.2 client

software component that can invoke an **operation** from a **server**

[ISO 19128:2005]

### 3.3 coordinate

one of a sequence of n numbers designating the position of a point in n-dimensional space

[ISO 19111:2007]

### 3.4 coordinate reference system

**coordinate system** that is related to an object by a datum

[ISO 19111:2007]

### 3.5 coordinate system

set of mathematical rules for specifying how **coordinates** are to be assigned to points

[ISO 19111:2007]

### 3.6 element <XML>

basic information item of an XML document containing child elements, **attributes** and character data

[ISO 19136:2007]

### **3.7 feature**

abstraction of real world phenomena

[ISO 19101:2002]

NOTE A feature can occur as a type or an instance. The term "feature type" or "feature instance" should be used when only one is meant.

### **3.8 feature identifier**

identifier that uniquely designates a **feature** instance

### **3.9 filter expression**

predicate expression encoded using XML

[ISO 19143]

### **3.10 GeoSPARQL**

SPARQL with a standardized set of geospatial functions that are needed to manipulate geospatial information.

### **3.11 interface**

named set of **operations** that characterize the behaviour of an entity

[ISO 19119:2005]

### **3.12 Multipurpose Internet Mail Extensions (MIME) type**

media type and subtype of data in the body of a message that designates the native representation (canonical form) of such data

[IETF RFC 2045]

### **3.13 namespace <XML>**

collection of names, identified by a URI reference which are used in XML documents as **element** names and **attribute** names

[W3C XML Namespaces]

### **3.14 operation**

specification of a transformation or query that an object may be called to execute

[ISO 19119:2005]

### **3.15 property**

facet or attribute of an object, referenced by a name

[ISO 19143]

### **3.16 request**

invocation of an **operation** by a **client**

[ISO 19128:2005]

### **3.17 response**

result of an **operation** returned from a **server** to a **client**

[ISO 19128:2005]

### **3.18 response model**

**schema** defining the properties of each **feature** type that can appear in the **response** to a query **operation**

NOTE This is the schema of feature types that a **client** can obtain using the DescribeFeatureType operation (cf. Clause 9).

### **3.19 schema**

formal description of a model

[ISO 19101:2002]

NOTE In general, a schema is an abstract representation of an object's characteristics and relations to other objects. An XML schema represents the relationship between the **attributes** and **elements** of an XML object (for example, a document or a portion of a document).

### **3.20 schema <XML Schema>**

collection of **schema** components within the same target **namespace**

[ISO 19136:2007]

EXAMPLE Schema components of W3C XML Schema are types, **elements**, **attributes**, groups, etc.

### **3.21 server**

particular instance of a **service**

[ISO 19128:2005]

### **3.22 service**

distinct part of the functionality that is provided by an entity through **interfaces**

[ISO 19119:2005]

### **3.23 service metadata**

metadata describing the **operations** and geographic information available at a **server**

[ISO 19128:2005]

### 3.24 Uniform Resource Identifier

unique identifier for a resource, structured in conformance with IETF RFC 2396

[ISO 19136:2007]

NOTE

The general syntax is <scheme>::<scheme-specified-part>.

The hierarchical syntax with a **namespace** is <scheme>://<authority><path>?<query>

### 3.25 Symbol

A “symbol” is essentially a bitmap or vector image that is used to indicate an object or a particular property on a map.

### 3.26 Symbol Table

A “symbol table” or set of symbol metadata on the other hand denotes a “term referring to the storage of named objects, including line types, layers, text styles and blocks.

## 4 Conventions

### 4.1 Abbreviated terms

API	Application Program Interface
CRS	Coordinate Reference System
E&DM	Emergency & Disaster Management
ER	Engineering Report
FES	Filter Encoding Standard
GML	Geography Markup Language
GMLSF	Simple Feature Geography Markup Language
HTTP	Hypertext Transfer Protocol
KVP	Keyword-Value Pair
MIME	Multipurpose Internet Mail Extensions
LEAPS	Law Enforcement and Public Safety
NGA	National Geospatial-Intelligence Agency
OWL	Ontology Web Language

RDF	Resource Description Framework
SKOS	Simple Knowledge Organization System
SPARQL	SPARQL Protocol and RDF Query Language
UML	Unified Modelling Language
USGS	United States Geological Survey
WFS	Web Feature Service
XML	Extensible Markup Language

#### **4.2 Used parts of other documents**

This document uses significant parts of document [OGC 06-121r3]. To reduce the need to refer to that document, this document copies some of those parts with small modifications. To indicate those parts to readers of this document, the largely copied parts are shown with a light grey background (15%).

## 5 Introduction

Testbed-10 ontology work focused on three aspects: First, the general examination of ontologies in the context of OGC data modeling, handling, and organization. Though huge efforts have been invested in modeling geographic information by publishing abstract models (ISO 191xx) and implementation specifications for these models (GML, KML, etc. ), as well as application schemas (e.g. CityML), no implementations of these abstract models using taxonomy languages (SKOS) and ontology languages such as RDF/S or OWL have been developed in OGC. Testbed-10 has started to define a consistent set of ontologies implementing solid theoretical foundations and semantics.

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Third and fully documented as part of the hydrology engineering report, Testbed-10 addressed ontology mapping between hydrology feature models using SPARQL and OWL2.

## 6 Core Geospatial Ontologies

### 6.1 Overview

OGC and ISO TC/211 have done tremendous work in modeling geographic information by publishing abstract models (ISO 191xx) and implementation specifications for these models (GML, KML, etc. ), as well as application schemas (e.g. CityML). However there are no implementations of these abstract models using taxonomy languages (SKOS) and ontology languages such as RDF/S or OWL. This situation has created the emergence of ad-hoc working groups outside OGC to create ontologies for geospatial information (often redundant) such as W3C Geo, Ordnance Survey spatial relationships, Geonames ontology and taxonomies for feature types. These ontologies do not follow a comprehensive and coherent approach based on solid theoretical foundations. We envision that OGC could play a crucial and important role in formalizing and standardizing geospatial ontologies to enable the “Semantic Geoweb”. OGC has started to make steps in this direction by standardizing the query language for the Semantic Web, GeoSPARQL (extending SPARQL with geospatial functions), however this specification fails to provide a comprehensive set of ontologies to describe geospatial data, and also impose a specific ontology to be used for query language. GML has focused on the structure and syntax of geospatial data, enabling syntactic interoperability of geospatial data, but fails to capture the semantics of the models, including linking to semantic data from other domains.

A comprehensive unified and extensible semantic framework is needed to represent data and metadata to enable true cross-domain interoperability, provide a scalable architecture

to integrate heterogeneous geospatial data, and link to datasets from other domains (healthcare, law enforcement, public safety, etc.). Web standards (URI, HTTP) and Semantic Web standards (RDF, RDFS, OWL, SKOS, SPARQL, RIF, Linked Data API, etc.) provide the necessary foundation to enable this level of interoperability on the web. OGC can leverage these standards and develop a set of core ontologies for geospatial information, upon which Community Of Interests (COIs) can build and extend to facilitate the semantic interoperability of cross-domain heterogeneous geospatial information.

During the Testbed-10 effort, Image Matters has identified, designed and formalized a set of modular geospatial core and cross-domain ontologies in OWL (mereo-topology, spatial relations, locations, features, temporal ontologies, geometries, CRS, events, measures, etc.). These “ontology components” provide a core ontological foundation for geospatial information that is universally applicable to any domains. These core ontologies leverages some of existing standard abstract models (ISO 19xxx), but are modularized and adapted to better leverage the expressiveness of OWL and favor reusability. The resulting Geospatial Ontology can be used as a starting point for building the OGC ontological foundation for all common geospatial information that could be used across various domains (E&DM, Law Enforcement and Public Safety, Gazetteer, Hydrology, Aviation, etc).

## 6.2 What is an Ontology?

### 6.2.1 Definition

Ontologies provide a way to share the semantics of concepts in some area of interests. It is all about common understanding of essential concepts. A generally accepted short definition of ontology is given by Gruber (Gruber, 1993):

An **ontology** is an explicit specification of a conceptualization.

The term conceptualization is defined as follows:

A **conceptualization** is the combination of objects, concepts, and other entities that are assumed to exist in some area of interest and the relationships that hold among them. A conceptualization is an abstract, simplified view of the world that we wish to represent for some purpose.

### 6.2.2 Benefits of ontology

We can summarize the benefits of ontology as follows:

- It provides a common and shared understanding/definition about certain key concepts in the domain
- It offers the terms one can use when creating RDF documents in the domain.
- It provides a way to reuse domain knowledge



- It makes the domain assumptions explicit
- Together with ontology description languages (such as RDFS and OWL), it provides a way to encode knowledge and semantics such that the machine can understand
- It makes automatic large scale machine processing become possible

### 6.2.3 OWL

OWL stands for Web Ontology Language, and it is currently the most popular language to use when creating ontologies. OWL started as a research-based of the DAML+OIL Web Ontology Language. W3C created the Web Ontology Working Group in November 2001, and the first working drafts of the abstract syntax, reference and synopsis were published in July 2002. The OWL documents became a formal W3C Recommendation on 10 February 2004. The standardization has triggered the development of OWL ontologies in numerous areas of interests. For example, in the life science community, OWL is extensively used and has become a de-factor standard for ontology development and data exchange.

The numerous contexts in which OWL has been exercised have helped identifying deficiencies in expressiveness and usability in ontology editors. In response to the feedback from real-world users, it was decided that an incremental revision of OWL was needed. A new W3C OWL working group was officially formed in September 2007. On 27 October 2009, OWL 2 has become a W3C standard. OWL 1 is a subset of OWL 2, i.e. an ontology created by using OWL 1 will be recognized and understood by any application that can understand OWL2.

The W3C OWL 2 Primer has given a good definition of OWL:

*The W3C OWL 2 Web Ontology Language (OWL) is a Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things. OWL is a computational logic-based language such that knowledge expressed in OWL can be reasoned with by computer programs either to verify the consistency of that knowledge or to make implicit knowledge explicit.*

The geospatial ontologies defined by this testbed are using OWL 2 standard.

### 6.3 UML versus OWL modeling

Modeling ontologies is very different than modeling object oriented software artifacts. This section attempts to outline the differences and similarities between UML modeling and OWL modeling.

UML is a notation for modelling object oriented software artifacts. OWL is a notation for knowledge representation. These are two quite different problems so asking about expressivity differences is going to lead you into apples versus oranges comparison. In

particular thinking in object oriented terms when working with OWL or RDFS will almost always lead you astray.

To take an example, both OWL and UML have things called "classes" and those classes are related in some sort of hierarchy that you can depict via a diagram. However, they are not the same notion at all.

In UML a class is *software object*. You can create instances of a class and that creation process has a procedural semantics involving things like assigning values to attributes (aka slots, members). So procedural notions, such as a default value for an attribute which is resolved at construction time, is a simple well-defined thing in UML. Instance objects also have some associated storage so UML distinguishes between containment and association - things are that are stored in the object v. things that are outside the object. Instance objects have a runtime semantic so you can have notions of static values and mutable values.

None of that is true in RDFS or OWL or similar languages. In those cases a class is a *category*, it is a label given to a set of things in a domain. In OWL terms a class is simply the set of things which are members of that set. So RDFS/OWL has no notion of instantiating or constructing an instance and so no notion of default values for instance creation. If you have a resource and it meets the criteria for membership of the class then it is a member of that class; if you didn't already know that your resource was in that class then you can derive this information by reasoning. Asserting a property on a resource (or discovering such an assertion) can lead to you inferring that it is a member of further classes. Resources (in RDFS terms, Individuals in OWL terms) are not things with state, storage or runtime semantics. They are simply identifiers for things in your domain. Assertions about those resources can be made, found or derived but the resources themselves aren't objects with slots and so notions like static and public/private have no meaning here. This is not a limitation of OWL or RDFS so much as the fundamental nature of what you are modelling. OWL classes are like labels for concepts, UML classes are like templates that define a runtime object and its storage.

Despite all these differences there is however some connection between both modeling languages. Both UML and OWL are languages for modelling. They are modelling totally different things and so have different capabilities and a completely different approach to semantics but there are some structural similarities. MOF (Meta Object Facility) is the meta-modelling tool that underlay UML. It is a language in which you can express other modelling languages. So UML is specified in MOF. You can do the same for RDFS and OWL - that is, express their metamodels in MOF. This is what ODM (Ontology Definition Metamodel) provides which provides a profile for writing RDF and OWL within UML. It also includes mappings between UML and OWL as well as mappings amongst RDF, RDFS, Common Logic and Topic Maps.

This discussion should highlight why modeling ontologies cannot be done by simply converting (automatically or not) UML diagram to OWL. Ontologies are better designed from the ground-up but can be informed by concepts expressed in UML models.

## 6.4 Design Approach

This section outlines some the key principles used to design the geospatial core ontologies.

### 6.4.1 *Minimal ontological commitment*

Our modular design of the ontologies follows the principle of making a *minimal ontological commitment* to the nature of concepts and of relationships between concepts. As explained by Thomas Gruber, an ontology should require the minimal ontological commitment sufficient to support the intended knowledge sharing activities. An ontology should make as few claims as possible about the world being modeled, allowing the parties committed to the ontology freedom to specialize and instantiate the ontology as needed (which is often called ontology *profile*).

Opting for such a minimal approach is made dramatically easier by the vocabulary extension mechanisms offered natively by Semantic Web technology. Applications that require more constrained behavior may define compatible extensions to OWL or SKOS. For example, modelers may coin sub-classes and sub-properties of OWL or SKOS properties, or associate those properties with specific formal axioms. By making a minimal ontological commitment, the ontologies can be applied and reused across multiple Communities of Interests (COIs), thus increasing the rate of wide-spread adoption.

### 6.4.2 *Modularization of ontologies*

Quoting Stuckenschmidt and Klein (Stuckenschmidt & Klein, 2004), “ontologies that contain thousands of concepts cannot be created and maintained by a single person”. Modularization helps designers manage complexity by reducing the size of the design problem (Stuckenschmidt, Parent, & Spaccapietra, 2009). We want designers design modules of a size that they can apprehend, and later either integrate these modules into a final repository or build the relationships among modules that support interoperability. This is a typical application of the divide-and-conquer principle.

Modularization also provides a way to keep performance of ontology services at an acceptable level. Performance concerns may be related to query processing techniques, reasoning engines and ontology modeling and visualization tools. Reasoners currently available are performing well on small-scale ontologies, with performance degrading rapidly as the size of the ontology increases. Keeping ontologies small is one way to avoid the performance loss, and modularization is a way to replace an ontology that tends to become oversized by smaller subsets. Modularization fulfills the performance goal if, whenever a query has to be evaluated or an inference to performed, this can be done by

looking at just few modules, rather than exploring the whole ontology (Stuckenschmidt et al., 2009).

#### 6.4.3 *Reusability of ontologies*

Reusability is a well-known goal in software engineering. Reuse is most naturally seen as an essential motivation for approaches aiming at building a broader, more generic repository from existing, more specialized repositories. However, it may also apply to the inverse approaches aiming at splitting an ontology into smaller modules. In this case, the decomposition criterion should be based on the expected reusability of a module, i.e. how well can a module fill the purpose of various applications. Reusability emphasize the need for rich mechanisms to describe module, in a way that maximizes the chances for modules to be understood, selected and used by other services and applications.

#### 6.4.4 *Understandability*

An obvious prerequisite to the ability to use ontology to understand its content. Whether the content is shown in visual or textual format, understanding is easier if the ontology is small (a module). Small ontologies are undoubtedly preferable if the user is a human being. Size, however is not the only criterion that influences understandability. The way it is structured contributes to improving or decreasing understandability.

### 6.5 OWS10 Geospatial Ontologies overview

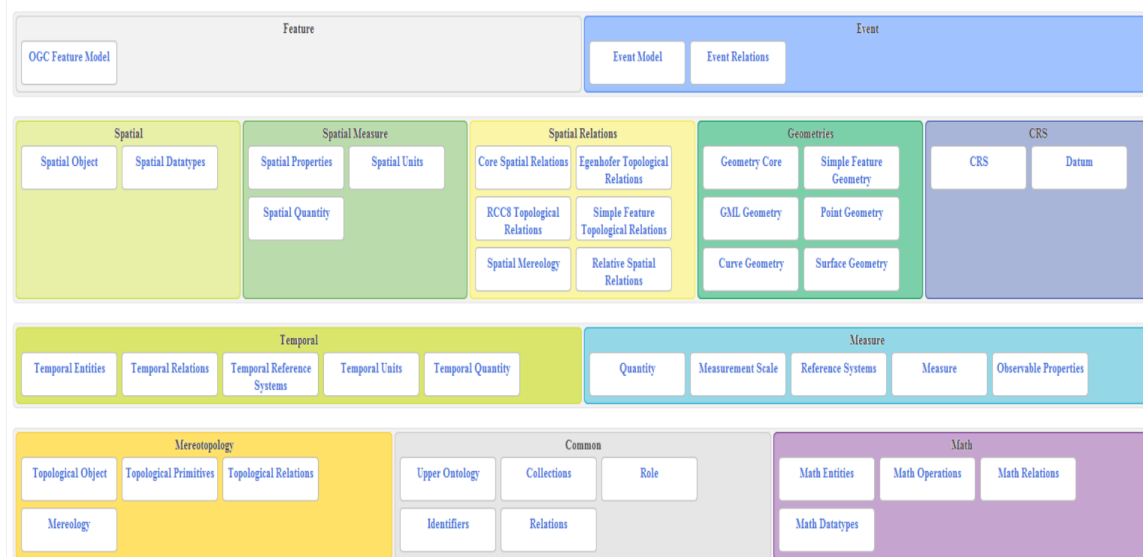
The ontologies are organized into set of microtheories. Microtheory is defined as follows:

**A microtheory** is a coherent and consistent set of facts, ontologies, and rules that describe a specific sub-domain.

The surrounding semantic context of a microtheory binds the microtheory to a well-formed, unified problem space. Microtheories partition the knowledge base into a coherent collection of concepts, facts, and rules pertaining to one limited realm of knowledge domain. Unlike a knowledge base, a microtheory must be free of contradictions. Microtheories can inherit from each other and are organized in a hierarchy, which also must be **consistent** (*free of contradictions*) between microtheories. This **microtheory consistency requirement** is extremely important in the application of ontologies to sophisticated machine reasoning, and is often the downfall of imprecisely crafted ontologies. Thus, the consistency requirement differentiates microtheories from more commonplace, but less rigorous ontologies that are little more than embellished taxonomies.

In the context of this work, each microtheory consists of a set of well-scoped ontology modules containing concepts and relationships that a reasoning engine can interpret against a body of knowledge. The rules are based on the semantic of the OWL 2. The following subsections give an overview of each microtheory starting from the most general to more specialized. For better readability, the documentation of these ontologies

is available online at <http://ows10.usersmarts.com/ows10/ontologies/>. This work defines the baseline for future modifications and refinements. The following figure provides an overview of the defined microtheories.



**Figure 1: Overview of the Testbed-10 OGC ontologies**

An example, defining the OGC feature model, is available in Annex A on page 36. The following figure illustrates the concept. It depicts the first page of the OGC Feature Model microtheory.

## OGC Feature Model Ontology

**IRI:**

<http://www.opengis.net/ont/spatial/feature>

**Creation Date:**

2013-10-22

**Authors:**

Stephane Fella - Image Matters LLC

**Imported Ontologies:**

<http://www.opengis.net/ont/spatial/object> ([visualise it](#))  
<http://www.opengis.net/ont/common/collections> ([visualise it](#))  
<http://www.opengis.net/ont/spatial/geometry> ([visualise it](#))  
<http://www.w3.org/2004/02/skos/core> ([visualise it](#))

**Other visualisation:**

[Ontology source](#)  
[LODE Ontology Browser](#)

---

### Abstract

Ontology for OGC Feature Model

This ontology is available at <http://www.opengis.net/ont/spatial/feature> , and uses the default namespace prefix **feature**

### Table of Content

1. [Introduction](#)
2. [Classes](#)
3. [Object Properties](#)
4. [Namespace Declarations](#)

### Introduction

The starting point for modeling of geographic information is the geographic feature. A feature is an abstraction of a real world phenomenon. A geographic feature is a feature associated with a location relative to the Earth. A digital representation of the real world can be thought of as a set of features. A feature has a spatial domain, a temporal domain, or a spatial/temporal domain as one of its attributes. Features are usually managed in groups as feature collections. The terms feature and object are often used synonymously. The terms feature, feature collection and coverage are defined in line with OpenGIS.

**Figure 2: Microtheory excerpt****6.5.1 Common Microtheory**

The Common Microtheory is composed of ontology modules that are reusable across all other ontologies (not only geospatial). It consists of the following modules:

- Upper ontology
- Collections
- Identifier
- Relations
- Role

These ontologies have been influenced by BFO, DOLCE, SUMO, and ODP (ontologydesignpatterns.org).

**6.5.2 Mereotopology Microtheory**

Mereotopology is a first-order theory, embodying mereological and topological concepts, of the relations among wholes, parts, parts of parts, and the boundaries between parts [Wikipedia]. Barry Smith, Anthony Cohn and his coauthors Smith and Varzi (Smith, 1996; Varzi, 1996) alone and with others, have all shown that mereotopology can be useful in formal ontology and computer science, by formalizing relations such as contact, connection, boundaries, interiors, holes, and so on. Mereotopology has been most useful as a tool for qualitative spatial-temporal reasoning, with constraint calculi such as the Region Connection Calculus (RCC). We consider this microtheory as foundational for building any geospatial ontologies.

The Mereotopology Microtheory is composed of ontology modules related to topological and mereological concepts and relations. We consider this microtheory as foundational for building any geospatial ontologies.

The initial version consists of the following modules:

- Topological Objects
- Topological Relations
- Topological Primitives
- Mereology

**6.5.3 Temporal Microtheory**

The Temporal Microtheory is composed of ontologies related to temporal concepts and relations. The initial version consists of following group of ontologies:

- Temporal Entities composed of temporal objects and regions such as time instant and time interval,

- Temporal topological relations among temporal entities,
- Temporal reference systems,
- Temporal units and quantities (duration, frequency,..).

The microtheory has been influenced by a number of ontologies and models (OWL-Time, ISO 19108, CNTRO 2.0, BFO, SWRL Temporal, NASA SWEET).

#### **6.5.4 *Spatial Microtheory***

The Spatial Microtheory is composed of ontologies related to spatial concepts and relations. The initial version consists of following modules:

- Spatial entities composed of spatial objects inhering spatial qualities and spatial regions.
- Spatial relationships (RCC8, Egenhofer, simple features topological relationships, relative relationships).
- Geometries (Core geometry, GML geometries, Simple Feature Geometry).
- CRS and Datum
- Place
- Spatial properties, quantities and units
- Spatial Mereology

Some of the ontology modules (geometries, spatial relationships) are the results of modularization of GeoSPARQL ontology and links to GeoSPARQL specification are encoded in the ontology when applicable.

#### **6.5.5 *Measures microtheory***

The Measures Microtheory is composed of ontologies related to measurements of qualities or quantities. The initial version consists of the following modules:

- Measure
- Measurement Scale
- Reference Systems
- Quantity
- Observable Properties

The microtheory has been influenced by a number of ontologies and models (QUDT, OGC O&M, NASA SWEET, EngMath, MUO, OBO UO). The quantity ontology extensively leverages little-known but elegant OWL 2 technique called *punning*, which consists of a class playing the role of a class and an instance of a metaclass at the same time. By using this technique, dimensionality of quantity are kept coherent. This microtheory is used to define spatial and temporal measures.



### 6.5.6 *Event microtheory*

The event microtheory is composed of ontology modules related to event concepts and relations. It is using the spatial and temporal microtheory to describe time and place of events. The initial version is composed of the following modules:

- Event Object
- Event relations

The microtheory has been influenced by a number of ontologies and models (DOLCE, Event Ontology, F-Model, Simple Event Model). This microtheory was used to describe an ontology for modeling Incident in the context of Emergency and Disaster Management (E&DM).

### 6.5.7 *Feature microtheory*

The feature microtheory is used to model OGC Feature Model. It defines the concepts of Feature and FeatureCollection and is derived from the Spatial Object ontology. This ontology expresses geospatial concepts using OGC Feature terminology.

## 6.6 **Deployment information**

The ontologies have been deployed at the following endpoint:

<http://ows10.usersmarts.com/ows10/ontologies/>. The homepage shows the different microtheories with their respective modules. When accessing a module, an ontology documentation is generated automatically from the source ontology. All the ontologies have been licensed under [Creative Commons 3.0 Attribution 3.0 United States](#). Source ontology can be accessed in RDF/XML or Turtle format from the documentation page.

## 6.7 **Next Steps**

The core geospatial ontologies have been result of eight years of Research and Development at Image Matters in the domain of geospatial semantic. Image Matters decided to release these ontologies for the broad community seeking to facilitate semantic interoperability between systems using geospatial information. The intent is to *bootstrap* the Geospatial Semantic Web, by providing an initial candidate geospatial ontologies for standardization. We think a joint effort between OGC and W3C would be the right venue to bring this work to maturation and standardization due to their expertise both in geospatial domain and semantic web respectively.

### 6.7.1 *Path to standardization*

Some of the work occurring at ISO TC 211 to convert ISO TC 191xxx models to OWL could be leveraged, by improving some of the microtheories that are not fully completed (Coordinate Reference System for example). However we strongly caution of the use of an automatic conversion from UML model to OWL , as pointed out in the previous section discussing the difference between UML modeling and OWL modeling. We believe that careful manually crafted ontologies, consistent with other microtheories will provide better results.

To favor the adoption of the geospatial ontologies, improve the robustness and completeness of the microtheories, we suggest for the next testbed exercising the ontologies by converting existing geospatial data into geospatial knowledge, creating catalogs for unit of measures, CRSs and feature types (for gazetteers). The ontologies can also be exercised by creating ontologies for more specialized domain that leverage the core geospatial ontologies, as it was done for this testbed for E&DM. The result of these activities should lead to identifying best practices and provides a rich set of examples how geospatial ontologies could be used for different vertical communities and be queried using open linked data standards and protocols (Linked Data Platform, GeoSPARQL).

### **6.7.2 GeoSPARQL 2.0**

Based on feedback from the OGC Geospatial Semantic WG and lessons learned from Testbed-10, there is a need to modularize and simplify GeoSPARQL specification. The Testbed-10 geospatial ontologies address many of these aspects (for example modularization of spatial relations), and could be used as a starting point. GeoSPARQL provides a geospatial extension of SPARQL by defining geospatial function extensions and data types (in the same way Spatial SQL extends SQL). GeoSPARQL could be simplified by clearly defining geospatial functions using SPARQL Service Description vocabulary standard and the geospatial datatypes (WKT Literal and GML Literal). The query language should be independent of the ontology describing geospatial concepts (the same way Spatial SQL is independent of relational models). We believe that this simplification and modularization of the specification will foster the adoption of the specification to a larger community.

There is also a need to describe the capabilities of GeoSPARQL. These descriptions provide a mechanism by which a client or end user can discover information about the SPARQL service such as supported extension functions and details about the available geospatial dataset, supported CRSs, inferences supported. There are a number of standards that already exists to describe SPARQL endpoint such as the W3C SPARQL 1.1 Service Description, VoiD and DCAT. These standards will be adapted to accommodate description of GeoSPARQL endpoints, by defining profiles and best practices. The next testbed should demonstrate the feasibility and robustness of the approach by implementing the specifications.

We believe that this simplification and modularization of the specification will foster the adoption of the specification to a larger community.

## **7 Incident ontology for E&DM**

### **7.1 Overview**

Incident management plays a crucial role in many application domains including Homeland Security, Law Enforcement and Public Safety (LEAPS), Emergency and Disaster Management (E&DM). An Incident Management System (IMS) needs to facilitate rapid, agile and effective engagement of first responders at national, state and

local jurisdictional levels to respond to emergency incidents that may pose an immediate security threat to human life and/or the flow of commerce. The current systems face the following challenges:

- Analysts and operators need to quickly triage, fuse, connect dots, detect patterns, infer insights, and make sense of the flow of incident information to get an unambiguous Common Operational Picture
- Need to integrate and interpret incidents, observations, mutual aid requests, alerts, etc. generated across a multi-agency, multi-jurisdictional spectrum
- Limited interoperability between agencies due to different protocols, taxonomies, models and representations (stovepipes are still there!)

The current data-centric approach mainly based on syntactic and structural approach imposes a huge cognitive burden on the user to make sense of the large volume and varieties of information.

Data model standardization relies upon homogeneous data description and organization. This imposes strict adherence to a standard that is defined at the syntactic-schematic level, whereupon it's harder to achieve consensus and less flexible. Modelers struggle between producing simpler models for which it is easier to gain consensus, but harder to achieve desired business reality, versus those seeking richer models that are closer to reality but have unwanted complexity.

Data-centric approaches increase the chance for multiple interpretations and misinterpretations of data. Data interpretation requires knowledge of its semantics (e.g., meanings, significance, relevance, etc.) and surrounding context. Data-centric approaches are unable to capture these semantics and context, which are in turn required for automated fusion, analytics, and reasoning.

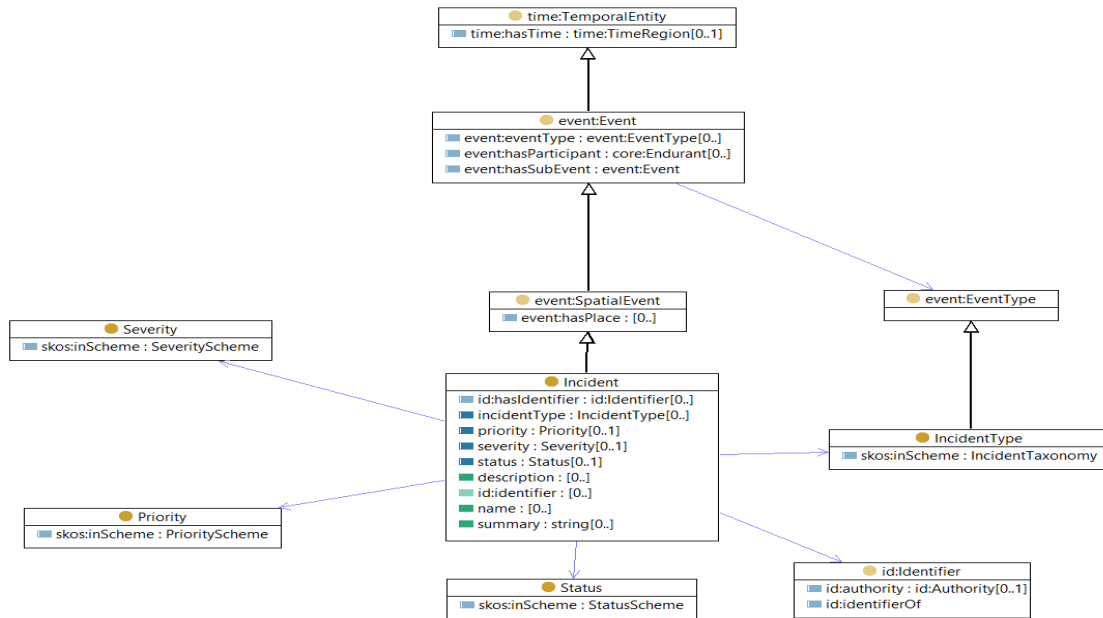
To address these challenges, we adopted a knowledge-centric approach. The knowledge-based approach employs a standards-based formal, sharable framework (RDF, OWL, SPARQL) that provides a conceptual domain model to accommodate various business needs. Decentralized model extensions can be accommodated without adversely affecting existing information infrastructure.

## 7.2 Core incident ontology overview

For Testbed-10 testbed, we investigated the definition of a core ontology for representing incident information used by IMS. The goal of this ontology is to provide a semantic model for Incident Management systems that could be adapted across multiples domains and jurisdictions to enable interoperability of incident management systems between these domains. The Incident ontology attempts to capture the minimal set of concepts and properties that are truly cross-domain. Using the built-in extensibility and multilingual mechanisms of Ontology Web Language (OWL) and Simple Knowledge Organization System (SKOS), the Incident ontology can be adapted to build specific profiles for Military and Civilian IMS while still being interoperable because they are based on the

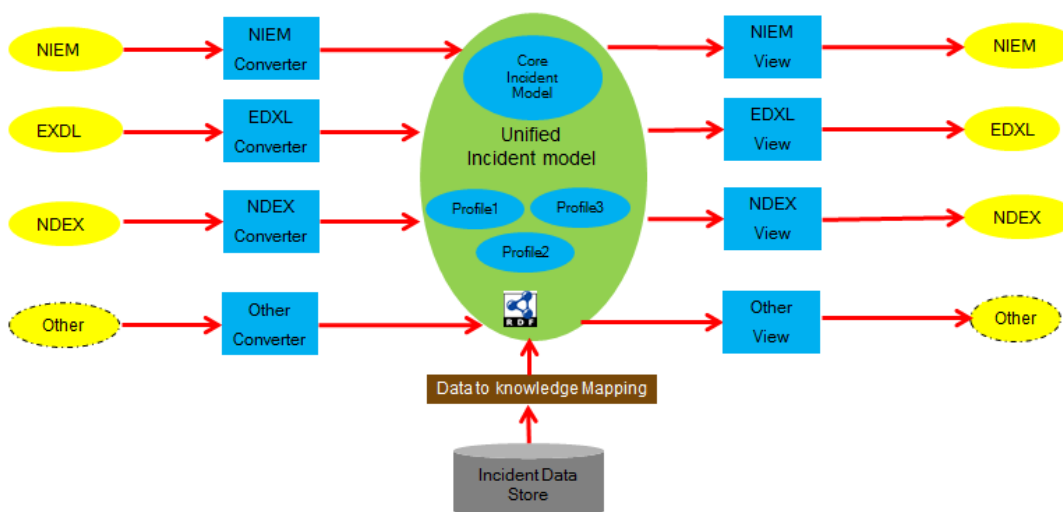
same core concepts. Our Incident ontology is built-on a set of core ontologies (spatial, temporal, identifier, event, SKOS) to provide a coherent model for geospatial reasoning on incidents.

The figure 3 gives an overview of the Incident Ontology Model. Incidents are based on the Event ontology defined in the Core Geospatial Ontologies.



**Figure 3: Core incident ontology model**

The core Incident Model can be extended using the built-in mechanism in OWL to add specific information used within an application domain or jurisdiction, thus becoming specialized profile of the core Incident model. Existing standards based on syntactic and schematic standards (NIEM, EDXL, NDEX,...) can be integrated in Semantic Incident Management Systems by the use of adapters converting the standard to an RDF representation using the different incident profiles. The benefit of this approach is to provide a unified semantic representation of incidents that can integrate different systems without breaking incompatibilities. The knowledge-based model allows machines to interpret information without ambiguities, perform triaging, reasoning and fusion of information. The system will assist the user by reducing the cognitive burden to make sense of the information. The common knowledge-based representation of the incidents can be used to convert back the information to existing data-centric standard. The semantic layer introduces a layer of ‘smartness’ in the existing IMS that can adapt easily to future change in the model.



**Figure 4: Semantic layer with adapters to the core incident model and derived profiles**

There are a number of data-centric standards that are used in existing standards such as NIEM, NDEX, CAP, EDXL, that are applicable to the same approach. We suggest investigating a semantic encoding of these standards for future testbeds. The Abu Dhabi Police LEAPS Models provide the richest model for the LEAPS domain, and we strongly suggest using these models as future baseline for developing a semantic model for LEAPS.

### 7.3 Controlled vocabulary in the emergency and disaster management domain

There are a number of controlled vocabularies used in IMS systems (incident types, severities, statuses, priorities, alert types, etc). In the incident ontology, these vocabularies are captured as taxonomies using the Simple Knowledge Organization System (SKOS) ontology. SKOS provides a model for expressing the basic structure and content of concept schemes such as thesauri, classification schemes, subject heading lists, taxonomies, folksonomies, and other similar types of controlled vocabulary. As an application of the Resource Description Framework (RDF), SKOS allows concepts to be composed and published on the World Wide Web, linked with data on the Web and integrated into other concept schemes using semantic mapping constructs.

In basic SKOS, conceptual resources (concepts) are identified with URIs, labeled with strings in one or more natural languages, documented with various note types, semantically related to each other in informal hierarchies and association networks, and aggregated into concept schemes.

An advanced SKOS adds the following features:

- 1) conceptual resources can be mapped across concept schemes and grouped into labeled or ordered collections

2) relationships can be specified between concept labels.

The two most important entities in the SKOS ontology are *skos:ConceptScheme* and *skos:Concept*. In order to distinguish the type of schemes (Incident Type Scheme, Severity Scheme, etc), we introduce in our Incident ontology subclasses of *ConceptScheme* and *Concept*. Some of the benefits of using SKOS are its multilingual support, its extensibility mechanism and interoperable way to share taxonomies based on Linked Data Standards. It also provides vocabularies for mapping concepts between different taxonomies (*skos:exactMatch*, *skos:narrowerMatch*, ...), enabling semantic mediation on taxonomies.

These controlled vocabularies are defined outside the Incident ontology, so it could accommodate multiple domains (military, civilian, cyberspace ...), be controlled by authoritative standard bodies and sharable with other systems. Typically these controlled vocabularies takes the form of *code lists* or *taxonomies* (with broader, narrower terms), which can be both be accommodated by SKOS.

In our Incident ontology, we define the following intrinsic qualities for Incident: **incidentType**, **severity**, **priority** and **status**. The values of these properties are typically defined in controlled vocabularies based on the Simple Knowledge Organization System (SKOS) ontology.

In order to support triaging of incidents by systems and end-users, incidents are typically classified using well-known *controlled taxonomies* defining incident categories. To accommodate these requirements, our ontology leverage the SKOS ontology by introducing a subclass of *skos:Concept* named *IncidentType*.

As an example of Incident Type taxonomies, we use the Homeland Security Working Group (HSWG) taxonomies to encode in SKOS

**Table 1: HSWG Incident taxonomy encoded using incident ontology and SKOS**

```

:HSIncidentTaxonomy
  rdf:type incident:IncidentTaxonomy ;
  dct:creator "Stephane Fella - Image Matters LLC"^^xsd:string ;
  dct:description "Taxonomy of incident defined by the Homeland Security Working Group.
Source: http://www.fgdc.gov/HSWG/ref_pages/Incidents_ref.htm"^^xsd:string ;
  dct:created "2013-10-30"^^xsd:string ;
  dct:source "http://www.fgdc.gov/HSWG/ref_pages/Incidents_ref.htm"^^xsd:string ;
  rdfs:label "Homeland Security Incident taxonomy"^^xsd:string ;
  skos:hasTopConcept :AirIncident ;
  skos:hasTopConcept :CivilDisturbanceIncident ;
  skos:hasTopConcept :CriminalActivityIncident ;
  skos:hasTopConcept :FireIncident ;
  skos:hasTopConcept :HazardousMaterialIncident ;

```

```

skos:hasTopConcept :MarineIncident ;
skos:hasTopConcept :RailIncident ;
skos:hasTopConcept :VehicleIncident ;
skos:prefLabel "Homeland Security Incident taxonomy"^^xsd:string ;

HazardousMaterialIncident
rdf:type incident:IncidentTheme ;
rdfs:label "Hazardous material incident"^^xsd:string ;
skos:definition "Unintentional release of hazardous material(s)."^^xsd:string ;
skos:narrower :ChemicalAgents ;
skos:narrower :CorrosiveMaterial ;
skos:narrower :Explosive ;
skos:narrower :FlammableGas ;
skos:narrower :FlammableLiquid ;
skos:narrower :FlammableSolid ;
skos:narrower :HazardousWhenWet ;
skos:narrower :NonFlammableGas ;
skos:narrower :OrganicPeroxides ;
skos:narrower :Oxidizers ;
skos:narrower :RadioactiveMaterial ;
skos:narrower :SpontaneouslyCombustible ;
skos:narrower :ToxicAndInfectious ;
skos:narrower :ToxicGas ;
skos:prefLabel "Hazardous material incident"^^xsd:string ;

:HazardousWhenWet
rdf:type incident:IncidentType ;
rdfs:label "Hazardous when wet"^^xsd:string ;
skos:definition "Uncontrolled or potentially dangerous presence of a material that, by
contact with water, is liable to become spontaneously flammable or to give off flammable or
toxic gas at a rate greater than 1 L per kilogram of the material, per hour."^^xsd:string ;
skos:inScheme :HSIncidentTaxonomy ;
skos:prefLabel "Hazardous when wet"^^xsd:string ;

```

## 8 Emergency and Disaster Management Symbology

### 8.1 Introduction

A plethora of symbols and symbol schemes exist, but extremely few standardized sets can be found despite the big number of initiatives targeting exactly such a standardized set. Lots of those initiatives date back to the first decade 2000-2009 and have failed to become widely accepted and applied mapping symbol standards.

The initial goal of Testbed-10 was to identify the standard model for symbology for the Emergency and Disaster Management community. The model, formalized in an ontology, should describe the translation between different local, federal or international sources

with the homeland security symbology (found at: [www.fgdc.gov/HSWG/index.html](http://www.fgdc.gov/HSWG/index.html)) as the basis for the standard model.

A number of symbology mapping initiatives have reported progress on standardizing symbologies within their country or administrative or organizational boundaries, such as the

- Canadian Emergency Management Symbology (EMS) (<http://emsymbology.org/EMS/index.html>, currently not available);
- United Nations Office of Coordination on Humanitarian Affairs (UN-OCHA), which has created a set of 500 freely available humanitarian icons to help relief workers present emergency and crisis-related information quickly and simply (<http://reliefweb.int/report/world/world-humanitarian-and-country-icons-2012>);
- Portuguese Disaster Response Map Symbols (DRMS) project, an effort to create a standard set of symbols that may aid disaster managers and responders to create efficient maps (<http://www.rpec-cert.info>);
- Australasian All-Hazards Symbology, developed by the Intergovernmental Committee on Surveying and Mapping (ICSM) and the Victoria-based company Spatial Vision (<http://www.spatialvision.com.au/index.php/sectors/government/426-australasian-all-hazards-symbology-project.html>);
- The European INDIGO project Emergency 2D/3D Symbology Reference (<http://indigo.diginext.fr/EN/index.html>);
- World Meteorological Organization (WMO) Intergovernmental Oceanographic Commission efforts on map symbol standardization.

After recognizing the importance of sharing spatial information during emergency situations, the Federal Geographic Data Committee Homeland Security Working Group (FGDC HSWG) was asked to develop a set of standard symbols to be used by emergency personnel during a disaster event. The Emergency and Hazard Management Mapping Standard Point Symbology was submitted to, and accepted by, the American National Standards Institute (ANSI) in 2006 as “ANSI 415-2006 INCITS Homeland Security Map Symbol Standard” (Akella, 2009).

For a number of reasons, the standard has so far not been widely adopted across the full range of DHC missions (Robinson, Roth, & MacEachren, 2010). The key problem is that it is generally extremely difficult to create a map symbol standard across organizations or missions (Bianchetti et al., 2012; Robinson, Roth, Blanford, Pezanowski, & MacEachren, 2012; Robinson et al., 2010). Robinson et al. (Robinson et al., 2010) interviewed fourteen mapmakers and users from a wide range of Department of Homeland Security missions to identify the main challenges and barriers to use a symbology standard. It turned out that most missions use in-house symbols that are better reflecting the specific needs of that mission. External symbologies are considered overly complex and ambiguous or use a symbol design that does not fit mission specific needs or format constraints. Usually, in-house symbols are created in an ad-hoc procedure, not following any standardized



methodology and evolve over time as user and mission requirements call for changes. Thus, compared to external standards, in-house symbologies are more agile and easier to modify and adapt to latest needs.

## 8.2 Semiology of Maps

“The semiotics of maps, a subfield of cartosemiotics, is the sign-theoretic study of maps” (Schlichtmann, 2009), with map symbolism being the “core subject of the semiotics of maps”. The other subjects include sign processes (basically the process from production a sign to its reception and the sign employment in cartographic communication), contexts (of sign processes), marginal notes (e.g. legends), and peripheral signification (e.g. allowing to draw further inferences about other context factors). For further information about map symbolism, please be referred to Schlichtmann’s overview of the semiotics of maps, which includes a very interesting discussion about the complexity of map symbolism (Schlichtmann, 2009).

## 8.3 Symbol Types

To understand the complexity of building a standard mapping symbol ontology for the disaster and emergency management domain, it is important to discuss the different types of symbols. There is general agreement in literature that symbols can be divided into three categories at least (MacEachren, 1995):

- **Geometric symbols**, sometimes referred to as abstract symbols (e.g. circles, squares, or diamonds), which are often further categorized into point, line, and polygon symbols. Those symbols often need a legend with additional information, as their meaning is not easily conveyed.
- **Pictorial symbols** are also known as image-related or representational symbols, are “similar in appearance to their referent”.
- **Associative symbols**, can be regarded as “emblems” which represent the referent through some analogous relation of parts of other commonly recognized symbols in combination.

In addition to those three categories that are prevalent in literature, there is a fourth, less developed category. This category includes symbols that are associative in nature, but refer to an event that is less commonly known or for which a no common picturization exist, for example a bio-hazard.

## 8.4 Symbol Comprehension

It is necessary to understand symbol comprehension and to define testing algorithms to evaluate the congruency of intended meaning of a symbol (by the map producers) and received meaning of a symbol (by map consumers). ISO 9186-1:2007 specifies methods for testing the comprehensibility of graphical symbols and ISO 9186-2:2008 specifies a method for testing the perceptual quality of graphical symbols (ISO, 2008, 2014). ISO 3864 stipulates a desired level of correctness of 67%, while the American National Standards Institute’s (ANSI Z.535.3) counterpart is 85% (ISO, 2012; Mayhorn, Wogalter, & Bell, 2004).

#### **8.4.1 Theory of Affordances and Other Cognitive Factors**

Gibson developed an interactionist view of perception and action that focused on information that is available in the environment (Greeno, 1994). His relational theory of affordances provides interesting insights into what affects our comprehension of symbols. The theory offers an explanation for how people perceive things they see in relation to their earlier frames of reference. According to Gibson, people perceive objects in terms of what they can offer or afford. Hartson in response to Norman defines and uses four complementary types of affordance in the context of interaction design and evaluation: cognitive affordance, physical affordance, sensory affordance, and functional affordance (Hartson, 2003; Norman, 1999). The cognitive affordance is of particular interest in the context of map symbol design and perception. It is a “design feature that helps, aids, supports, facilitates, or enables thinking and/or knowing about something”. Thus, clear and precise symbols could be a cognitive affordance enabling crisis managers to understand the meaning of the symbol. Functional affordance addresses potential actions taken by map symbol readers in response to the symbol.

Other research has shown that both knowledge and display design go hand in hand to increase understanding of map symbols. According to Langefors Infologic Equation, the understanding of a map symbol does not only depend on the symbol itself, but on the individual’s prior knowledge (Porathe & Sivertun, 2002). This aspect makes the symbol design process and similarly any symbol set transformation or comparison even more complex, as the various levels of knowledge and symbol familiarity need to be considered (Garlandini & Fabrikant, 2009; Hegarty, Canham, & Fabrikant, 2010).

#### **8.4.2 Culture and Gender**

Any symbol set should strive for cultural and gender independence in order to mitigate potential misunderstandings. Nevertheless, as recent research has underpinned, culturally neutral symbols are rather elusive (Chan, Han, Ng, & Park, 2009). The importance of this feature heavily depends on the cultural background of the target communities and might be less important in the disaster and emergency management domain.

#### **8.4.3 Sensory Issues and Differences**

A number of factors affect symbol interpretation that go beyond the general aspects of affordances as discussed before. Roughly 10% of the global population is expected to be color blind (Hägglund, 2008), which heavily affects color nuances perception and red/green or blue/yellow differentiation. Hägglund cites a number of general recommendations that can be made:

- Black, white, yellow and blue are most readily seen by all, even color blind;
- Red is typically used for warning but red is dull for the color blind; bright yellow is preferable to red but may still be mistaken for green by the color blind;
- Never red and green in the same symbol;
- Colors and patterns together decrease clarity; black and white patterns more differentiable;

- Color differences difficult to perceive when several colors in close proximity in limited spaces

Currently, no symbol set implements all of the recommendations given above, as they limit expressiveness and richness of the symbols if applied all together.

In addition to color blindness related aspects, there are other sensory aspects that may or may not be addressed in symbol sets, such as change blindness, foveal vs. peripheral attention and effects of speed of change and multiple inputs in exposure to map graphics (Ambler & Finklea, 1975; Fish, Goldsberry, & Battersby, 2011; Harrower, 2001). Drawing on the work of Simons and Rensink (2005), American geographers Fish, Goldsberry and Battersby note the importance of the change blindness “phenomenon whereby individuals fail to notice change that occurs in a visual stimulus”. Over a decade of research in this area reveals that human beings consistently overestimate their ability to detect substantial changes in visual graphics used for example in digital maps (Fish et al., 2011).

### 8.5 FGDC HSWG Symbol Set


The US Federal Geographic Data Committee Homeland Security Working Group (FGDC HSWG) symbology set, standardized by the American National Standards Institute (ANSI), divides symbols into four categories:

- **Incidents:** cause of action or source of disaster;
- **Natural events:** phenomenon created by naturally occurring conditions;
- **Infrastructure:** basic facilities, services and installations needed for the functioning of a community;
- **Operations:** capabilities or resources available during or implemented due to an emergency.

Borders and patterns around these shapes are used to visually classify the symbols into their respective groups. The FGDC HSWG Emergency Management Symbology is designed in black and white. There are concerns regarding the accuracy of the Symbology library, the limited reference to point symbols, the large amount of detail in the indications of status levels, a very low level of adoption of the FGDC symbology library, and the absence of evaluation with regard to cultural independence and generalizability. Nevertheless, we used it in this testbed and partially encoded it using the Incident ontology and SKOS.

### 8.6 Symbology ontology

For this testbed, we limited the symbology to icon representation, as it is a common representation used by E&DM community, but also because the timeframe for this testbed was too short to explore other symbol representation (line, area symbology) and rules of encoding. We used the Homeland Security Working Group Symbology Reference for Incidents and Natural Events as a starting point to develop a semantic model to represent symbology. The symbols were encoded in TrueType font files. The following figure shows symbology for natural events.

Homeland Security Working Group  
 Symbology Reference

Home Page | Symbology Background | Incidents | Natural Events | Operations | Infrastructures | Damage/Operational | Sample Maps | Download Symbols | Evaluation Results | FAQ

### Natural Events Symbology Reference

(Version 2.20, Released September 14, 2005)

Natural Events - Phenomenon found in or created by naturally occurring conditions.  
 Use this page to cross-reference the Natural Events symbols with their definitions.  
 Changed or new symbols are marked by an asterisk (\*) and have a light yellow or green background, respectively.  
[Printable list of changes](#)

Symbol Types	Symbol Image	Key Stroke	Symbol Terms and Definitions
1.) Natural Events Background Symbol (Background)		I	Natural Events Background Symbol (Background) - The background fill shape for the Natural Events symbol.
2.) Natural Events Frame Symbol (Frame)		#	Natural Events Frame Symbol (Frame) - The frame shape for the Natural Events symbol (unused).
3.) Geologic (Theme)			
4.) After Shock (GeologicFeature)		A	After Shock (Geologic) - An earthquake that follows a larger earthquake and originates at or near the latter's focus. (Source: Dictionary of Geological Terms, 3rd Ed.)
*5.) Avalanche (GeologicFeature)		B	Avalanche (Geologic) - A large mass of snow, ice, soil, or rock, or mixtures of these materials, falling, sliding, or flowing very rapidly under the force of gravity. (Source: Dictionary of Geological Terms, 3rd Ed.)
6.) Earth Quake Epicenter (GeologicFeature)		C	Earth Quake Epicenter (Geologic) - The point on the earth's surface directly above the focus of an earthquake. (Source: Dictionary of Geological Terms, 3rd Ed.)
7.) Landslide (GeologicFeature)		D	Landslide (Geologic) - A general term for a wide variety of processes and landforms involving the down slope movement under the force of gravity of masses of soil and rock material. (Source: Dictionary of Geological Terms, 3rd Ed.)
8.) Subsidence (GeologicFeature)		E	Subsidence (Geologic) - Sinking or downward settling of the earth's surface. (Source: Dictionary of Geological Terms, 3rd Ed.)
9.) Volcanic Eruption (GeologicFeature)		F	Volcanic Eruption (Geologic) - The ejection of volcanic materials (lava, pyroclasts, and volcanic gases) from a vent or fissure in the Earth's crust. (Source: Dictionary of Geological Terms, 3rd Ed.)
10.) Volcanic Threat (GeologicFeature)		G	Volcanic Threat (Geologic) - A vent or fissure in the Earth's crust where volcanic eruption is believed to be imminent. (Source: logical extension of "Volcanic Eruption")
11.) Hydro-Meteorological (Theme)			
12.) Drizzle (Hydro-MeteorologicFeature)		H	Drizzle (Hydro-Meteorologic) - Some time called mist. Very small, numerous, and uniformly dispersed water droplets that appear to float while following air currents. Unlike fog droplets, drizzle fall to the ground.
13.) Drought		T	Drought (Hydro-Meteorologic) - A period of abnormally dry weather sufficiently prolonged for the lack of water to cause a serious hydrologic imbalance across the affected area. Drought severity depends upon the degree of moisture deficiency, the duration, and (to a lesser extent) the size of the affected area.

Figure 5: Homeland security symbology for natural events

The core symbol ontology is very simple. The core concept is **PointSymbol**. It has a **symbolName**, an associated **font** and **denotes** a concept (Natural Event, Incident concepts, etc.). The **denotes** property provides the bridge between the symbol representation and the concept it represents. By using semantic mapping between concepts, it is possible to associate multiple symbols to one concept or vice-versa and perform semantic mediation of symbology

The following example represents a symbol for a VolcanicEruption event and its font definition.

Table 2: VolcanicEruption event encoded in ontology

```

:VolcanicEruptionSymbol
  rdf:type symbol:PointSymbol ;
  symbol:denotes natural-events:VolcanicEruption ;
  symbol:font <tty:ERS_v2_Natural_Events#0x46> ;
  symbol:symbolName "Volcanic Eruption" ;
  rdfs:label "Volcanic Eruption" .

<tty:ERS_v2_Natural_Events#0x46>
  rdf:type symbol:Font ;
  symbol:fontCode "0x46" ;
  symbol:fontFamily :ERS_v2_Natural_Events ;
  rdfs:label "Natural Event Symbol 0x46"
    
```

## 8.7 Datasets investigated

The testbed was mainly focused on developing a core generic model that could be applicable to a number of domains managing incidents. Due to the fact that we didn't have real datasets to work with, a number of open source datasets were investigated and mapped to the Incident ontology.

- 911 Seattle Police dataset
- OpenFEMA summaries
- Worldwide Incident Tracking System

The datasets investigated were however not rich enough to perform a relevant scenario that demonstrate the semantic incident management. We would recommend using some real dataset used by LEAPS or E&DM for the next testbed.

## 8.8 Recommendations

Due to the complexity of symbol sets, the difficulties to map between sets of different background, culture, tradition, and context, and the heterogeneous symbol comprehension factors, establishing a new model based on the FGDC baseline model cannot be achieved in a single test bed. Instead, we recommend for future test beds to do a direct comparison of two real data sets of neighboring administrative units or of a single administrative unit and the FGDC baseline in close cooperation with the symbol set users and producers. This approach needs to be combined with OGC base ontology development activities as recommended in the previous chapter.

In addition, we recommend building a set of core domain ontologies for the law enforcement and public safety as well as the emergency and disaster management domain.

As it is important to accommodate jurisdiction-specific and mission-specific profile requirements, it is necessary to identify *key points of interoperability* in a given service oriented architecture. As an example, the next test bed might investigate Abu Dhabi Police's (ADP) SoS architecture, defining the required interoperable service APIs and models, as well as the roadmap for achieving a prioritized implementation of these key interfaces and models. The Abu Dhabi Police have submitted a comprehensive set of domain models to OGC for Law Enforcement and Public Safety (LEAPS). These models can be used to derive a set of foundational ontologies that serve as the basis for interoperability throughout ADP's system of systems LEAPS domain. The purpose of this task is to formalize and semantically-ground ADP's LEAPS domain models as ontologies. These ontologies will be built upon OGC's Geospatial Ontology, and they will define the minimum-essential core set of concepts, properties and relationships for the LEAPS community.

The LEAPS ontologies must be designed to accommodate any jurisdiction/mission profile specific information (taxonomies, specialized concepts and relationships), using the built-in extension mechanisms of OWL. The ontologies will be exercised by building "ontology profiles", mapping existing ADP data to the new domain ontologies, and accessing these data through GeoSPARQL endpoints (as highly interoperable and useful LEAPS Linked Data).

The testbed should demonstrate the feasibility and robustness of the resulting LEAPS Ontology and candidate specifications by testing one or more implementations.

**Expected outcome:** (1) A set of core ontologies for the LEAPS domain. (2) Prototype applications and services to test and demonstrate profiles of the LEAPS Ontology, employing existing LEAPS data and using GeoSPARQL services to access these data.

**Benefits:** Demonstrates the benefits of semantically-enabled LEAPS data and services in terms of enhanced cross-domain data integration, search and discovery, and service interoperability. Pinpoints and tests minimum-essential required building blocks for LEAPS interoperability. Accelerates the path to common, coherent LEAPS Linked Data exchange. The roadmap will provide an agile, incremental, prioritized approach to the implementation of the *key points of interoperability* for LEAPS and E&DM SoS.

## 9 Hydro Model Interoperability

The Hydro demonstration thread worked on using HY\_Feature hydrological model as a mediation model to integrate heterogeneous hydrological models. Two models were tested. They are the National Hydro Network (NHN) of Canada and the National Hydrography Dataset Plus (NHDPlus or NHD+) of USA. Semantic mappings were tested to achieve hydro data and model conversion and integration among HY\_Feature, NHN, and NHD+. The test on semantic mappings focused on flow path linear feature. The ontologies for all three models and their conversion models were built using OWL with Protégé editor. The knowledge store is published through a generic SPARQL engine. The examples were documented in the ER in the five use cases - (1) mapping hydrographic features from NHD+ to HY\_Feature, (2) mapping hydrographic features from NHN to HY\_Feature, (3) hydrographic mapping between NHD+ and NHN, (4) finding upstream service (flow path feature tracing and model conversion), and (5) heterogeneous hydrological model integration (across borders of US and Canada).

The Hydro engineering report is available at [https://portal.opengeospatial.org/files/?artifact\\_id=57121](https://portal.opengeospatial.org/files/?artifact_id=57121).

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## **Annex A**

### **OGC Ontologies**

The OGC ontologies are documented online at <http://ows10.usersmarts.com/ows10/ontologies/#>. The following excerpt illustrates this documentation.

## OGC Feature Model Ontology

**IRI:**

<http://www.opengis.net/ont/spatial/feature>

**Creation Date:**

2013-10-22

**Authors:**

Stephane Fella - Image Matters LLC

**Imported Ontologies:**

<http://www.opengis.net/ont/spatial/object> ([visualise it](#))  
<http://www.opengis.net/ont/common/collections> ([visualise it](#))  
<http://www.opengis.net/ont/spatial/geometry> ([visualise it](#))  
<http://www.w3.org/2004/02/skos/core> ([visualise it](#))

**Other visualisation:**

[Ontology source](#)  
[LODE Ontology Browser](#)

---

### Abstract

Ontology for OGC Feature Model

This ontology is available at <http://www.opengis.net/ont/spatial/feature> , and uses the default namespace prefix **feature**

### Table of Content

1. [Introduction](#)
2. [Classes](#)
3. [Object Properties](#)
4. [Namespace Declarations](#)

### Introduction

The starting point for modeling of geographic information is the geographic feature. A feature is an abstraction of a real world phenomenon. A geographic feature is a feature associated with a location relative to the Earth. A digital representation of the real world can be thought of as a set of features. A feature has a spatial domain, a temporal domain, or a spatial/temporal domain as one of its attributes. Features are usually managed in groups as feature collections. The terms feature and object are often used synonymously. The terms feature, feature collection and coverage are defined in line with OpenGIS.



## Classes

[Feature](#) [FeatureCollection](#) [FeatureType](#) [GeographicFeature](#)

### Feature <sup>c</sup>

[back to ToC or Class ToC](#)

**IRI:**<http://www.opengis.net/ont/spatial/feature#Feature>

**Label:**

Feature

**Description:**

The starting point for modeling of geographic information. Abstraction of a real world phenomenon. "A digital representation of a real world entity or an abstraction of the real world. It has a spatial domain, a temporal domain, or a spatial/temporal domain as one of its attributes. Features are usually managed in groups as feature collections. The terms feature and object are often used synonymously. The terms feature, feature collection and coverage are defined in line with OpenGIS.

**has super-classes**

[object:SpatialObject](#) <sup>c</sup>

**Property Restrictions**

[featureType](#) <sup>op</sup> **min** 0

[geom:hasGeometry](#) **min** 0

### Feature collection <sup>c</sup>

[back to ToC or Class ToC](#)

**IRI:**<http://www.opengis.net/ont/spatial/feature#FeatureCollection>

**Label:**

Feature collection

**Description:**

**has super-classes**

[collections:Collection](#) <sup>c</sup> , [Feature](#) <sup>c</sup> , [object:SpatialObject](#) <sup>c</sup>

**Property Restrictions**

[featureType](#) <sup>op</sup> **min** 0

[collections:member](#) **only** [Feature](#) <sup>c</sup>

[geom:hasGeometry](#) **min** 0

### Feature type <sup>c</sup>

[back to ToC or Class ToC](#)

**IRI:**<http://www.opengis.net/ont/spatial/feature#FeatureType>

**Label:**

Feature type

**Description:**

Concept used to categorize a feature. This concept is used with the property [featureType](#) when soft-typing categorization of [Feature](#) can be used

<p><b>has super-classes</b>  <a href="#">skos:Concept</a><sup>c</sup></p>
<p><b>Geographic feature</b> <sup>c</sup> <span style="float: right;">back to <a href="#">ToC</a> or <a href="#">Class ToC</a></span></p> <hr/> <p><b>IRI:</b> <a href="http://www.opengis.net/ont/spatial/feature#GeographicFeature">http://www.opengis.net/ont/spatial/feature#GeographicFeature</a></p> <p><b>Label:</b>          Geographic feature</p> <p><b>Description:</b>          A geographic feature is a feature associated with a location relative to the Earth.</p> <p><b>has super-classes</b>  <a href="#">Feature</a><sup>c</sup>, <a href="#">object:SpatialObject</a><sup>c</sup></p> <p><b>Property Restrictions</b>  <a href="#">featureType</a><sup>op</sup> <b>min</b> 0  <a href="#">geom:hasGeometry</a> <b>min</b> 0</p>

## Object Properties

<p><a href="#">featureMember</a>   <a href="#">featureType</a></p>
<p><b>featureMember</b><sup>op</sup> <span style="float: right;">back to <a href="#">ToC</a> or <a href="#">Object Property ToC</a></span></p> <hr/> <p><b>IRI:</b> <a href="http://www.opengis.net/ont/spatial/feature#featureMember">http://www.opengis.net/ont/spatial/feature#featureMember</a>&gt;</p> <p><b>Label:</b>          feature member</p> <p><b>Description:</b>          Convenience property to link a Feature to a FeatureCollection</p> <hr/> <p><b>Characteristics</b>  <a href="#">owl:ObjectProperty</a></p> <p><b>has super-properties</b>  <a href="#">collections:member</a></p> <p><b>has domain</b>  <a href="#">FeatureCollection</a><sup>c</sup></p> <p><b>has range</b>  <a href="#">Feature</a><sup>c</sup></p>
<p><b>featureType</b><sup>op</sup> <span style="float: right;">back to <a href="#">ToC</a> or <a href="#">Object Property ToC</a></span></p> <hr/> <p><b>IRI:</b> <a href="http://www.opengis.net/ont/spatial/feature#featureType">http://www.opengis.net/ont/spatial/feature#featureType</a>&gt;</p> <p><b>Label:</b>          feature type</p>



<b>Description:</b> <hr/> <b>Characteristics</b> <i>owl:ObjectProperty</i> <b>has domain</b> <i>Feature</i> <sup>c</sup> <b>has range</b> <i>FeatureType</i> <sup>c</sup>
---

## Namespace Declarations

[back to ToC](#)

### **default namespace**

<http://www.opengis.net/ont/spatial/feature>

### **dc**

<http://purl.org/dc/elements/1.1/>

### **spatial**

<http://www.opengis.net/ont/spatial#>

### **vann**

<http://purl.org/vocab/vann/>

### **geom**

<http://www.opengis.net/ont/spatial/geometry#>

### **object**

<http://www.opengis.net/ont/spatial/object#>

### **rdfs**

<http://www.w3.org/2000/01/rdf-schema#>

### **dct**

<http://purl.org/dc/terms/>

### **xsd**

<http://www.w3.org/2001/XMLSchema#>

### **owl**

<http://www.w3.org/2002/07/owl#>

### **rdf**

<http://www.w3.org/1999/02/22-rdf-syntax-ns#>

### **skos**

<http://www.w3.org/2004/02/skos/core#>

### **collections**

<http://www.opengis.net/ont/common/collections#>

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