

Enhancing Spatial web search with Semantic Web Technology and Metadata Visualisation

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by

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Abstract

The ability to discover information hosted by disparate data sources in an efficient manner is of great importance for quick and informed decision making in many disciplines, more so in the wake of natural disasters. Spatial Data Infrastructures (SDI) have created an open environment for sharing information over the web in a faster and more efficient way whereas geo-catalogue services play a pivotal role in the discovery and retrieval of the information offered by SDIs. However, current search mechanism which are based on keywords have proved inefficient as users face challenges in retrieving the right Geographic Information (GI) on the web. The problem is further exacerbated as more resources become available on the web.

Enriching service descriptions (metadata) with semantic descriptions has been seen as a solution to the challenges. This research explores ways of bringing together semantic web technologies and geographic standards so as to improve the search functionality in geo-catalogues. Ontologies being the cornerstone of the semantic web, capture relationships between concepts thus ensuring semantic interoperability in dynamic environments. This research describes strategies to support geo-catalogues with ontologies and semantic annotations in which resources are linked to their metadata and ontology concept.

Semantically enabled geo-catalogues make use of the underlying relationships though users still use keywords. The search space is increased in that all related concepts to the keyword are presented in an ontology visualizer allowing the user to navigate about the concepts. Ontology visualization is seen as an added advantage in that a user is helped in query formulate a better query by making use of the ontology concepts and their relationships as displayed in the ontology visualizer.

Keywords

geo-catalogue, service discovery, ontology, semantic annotation, ontology visualization

Dedication

To my husband, Simon
My children, Rejoice, Farai, Joyful and Chido
Thank you for bearing my absence and for the prayers and moral support.
God bless you all

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I thank the ALMIGHTY GOD for blessing me with life, this far He has taken me.

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List of Acronyms

CSW	Web Catalogue Services
DL	Description Logics
DBMS	Database Management System
DMU	Disaster Management Unit
ECHO	European Commission Humanitarian Aid Office
XML	eXtensible Markup Language
GML	Geographic Markup Language
GI	Geographic Information
GN	GeoNetwork
GSDI	Global Spatial Data Infrastructure
ebRIM	electronic business Registry Information Management
GN-ebRIM	GeoNetwork ebRIM
GIS	Geographic Information Systems
GWS	Geospatial Web Services
HTTP	Hypertext Transfer Protocol
ISO	International Standards Organisation
MSG	Meteosat Second Generation
NDMO	National Disaster Management Offices
OGC	Open GeoSpatial Consortium
OWS	OGC Web Services
SW	Semantic Web
SDI	Spatial Data Infrastructures
SAWSDL	Semantic Annotations for WSDL and XML Schema

SOAP	Simple Object Access Protocol
SOA	Service Oriented Architecture
SWP	Spatial Web Portals
UDDI	Universal Data Description and Integration
URI	Uniform Resource Identifier
URL	Uniform Resource Locator
WFS	Web Feature Service Interface Standard
WMS	Web Map Service Interface Standard
WMO	World Meteorological Organisation
WS	Web Services
WSA	Web Service Architectures
WSDL	Web Service Definition Language
OWL	Web Ontology Language

Chapter 1

Introduction

Growth in web technology has seen the emergence of the Semantic Web which has been envisioned to provide solutions to users of web resources, especially in the area of data and service discovery. Catalogue services play a pivotal role in data and service discovery. Interoperable systems have been put in place to overcome heterogeneity in information that is shared. The Open GeoSpatial Consortium (OGC) has taken a step to fully support interoperability through established protocols and interface specifications thereby offering support for the important task of discovery and retrieval of information that meets the user's needs. As of now many Spatial Data Infrastructures (SDI) exist which facilitate sharing of data over the web in distributed environments. However search and retrieval of data and services is difficult due to the vocabulary used in different SDI which lead to semantic heterogeneity problems when only simple keyword-based search is employed [KLK06a].

According to Global Spatial Data Infrastructure (GSDI)¹ SDI refers to relevant technologies, policies and people all collaborating to facilitate the availability of and access to spatial data[GSD04]. Disparate data sets existing with different organizations are networked through a central hub that allows interoperability of the data formats. Services and data from different SDI are registered in catalogue services, however accessing these remains a challenge to many users despite standards governing registration of services by SDI in geo-catalogues

1.1 Motivation and problem statement

In early warning information systems, GI play a pivotal role in effective planning and decision making. The information is made available by different SDI through catalogue services as data, maps and satellite images allowing users to discover them, however not much meaning is attached to them. It is left up to the user to make meaning of what is made available on the maps such that they may really never discover the functionality and usage of such information[Lem08]. Web service environments are increasingly being used to

¹GSDI: <http://www.gsdi.org/>

access, integrate and reuse GI, however the search and retrieval of useful spatial data and services remains a challenge to the user community due to the diversity in meaning of data and web services [Ege02]. It is not easy for a user to find the right service with the right functionality for his/her specific purpose [LdV04]. Catalogues exist that provide searchable repositories of information and services but mechanisms to support discovery and retrieval are insufficient [KL04].

Interoperability of platforms for discovery and accessing data/services have been upheld and supported by the OGC through established protocols and interface specifications such as Web Catalogue Services (CSW) thereby offering support for the important task of discovery and retrieval of information that meets the user's needs. Retrieval methods that are currently in use are typically limited to keyword search or sub-string matching only. The search methods only account for the syntax of the search terms without taking into account the underlying conceptualizations. Using these methods, the information required is poorly defined in the search and results often do not satisfy the user's needs. As a result users may often miss critical information when searching for spatial web services.

While geospatial catalogue services provide the capability for advertising and discovering shared data and services over the web, the search mechanism so far is achieved through static key word matching without full exploration of underlying semantics, such as hierarchical relationships among metadata entities [YDZ⁺06]. Data/service registration in CSW achieves syntactic interoperability which is vital when using key word searching, where retrieval is based on syntax matching. More has to be done to allow machines to be able to interpret meaning of terms used thus achieving semantic interoperability. This has resulted in the emergence of the semantic web.

The Semantic Web is an extension of the current world wide web(www), but it is based on the idea of exchanging information with explicit, formal and machine-accessible descriptions of meaning [SvH06] using such languages as eXtensible Markup Language (XML). In this case, documents and services are provided with well-defined meaning (semantics) and laid down in formal descriptions. Full implementation of the Semantic Web requires ontologies in which widespread availability of semantic annotations for existing and new documents on the Web have been made.

Ontologies play a pivotal role in making web content understandable and available for machine processing through the encoding of the meaning of concepts in a particular domain by detailing the relationship between the concepts [DH08]. Before publishing a resource in the web, it has to be annotated with descriptive metadata to make it accessible. Users are able to find the resource using search engines and evaluate if the discovered resource satisfies their current information needs. There is need to move from the conventional methods that leave users questing for better search mechanisms that return results meeting the user's needs. The user will not need to scan through the results to weed out those that are not relevant. In order to curb the users' frustrations, semantic web technologies can be explored and their potential augmented in geo-catalogue web services in order to enhance the discovery of data and ser-

vices. The ability to share information in a timely and contextually relevant manner is crucial to providing effective service delivery within the domain of disaster operations management.

A motivating scenario is when a user wants to find services providing information about *high rainfall, strong winds* and *direction of the system* during cyclone activity. Service providers have the information available through a geo-catalogue. The question that remains is *whether the meaning of direction, strong winds and high rainfall the user has in mind is the same as that one understood by the provider?*. Using *rainfall* as keyword in the search may not retrieve all required services in that it misses the services that use *precipitation* in the metadata. Ambiguities in these definitions results in too few resources or none being discovered (Section 4.5 and 5.3 discuss this in detail). The success of an early warning system in disaster management, amongst all, largely depends on finding and successfully integrating related information to make decisions in the face of disasters. The scenario just demonstrates how easy it is to lose out on information urgently required.

Providing solutions to the scenario mentioned above and many others calls for other options that make use of underlying hierarchical structures and relationships of concepts when searching for data/services using geo-catalogue services. One possible way to solve the problem is the use of ontologies to reveal the implicit and hidden knowledge. This research proposes strategies for integrating ontologies and semantic annotations into a geo-catalogue (GN) so as to improve search mechanism allowing users to retrieve the most relevant information when required.

1.2 Research Identification

The main objective of the research is to investigate how semantic web technology can support geo-catalogue services through semantic annotation.

1.2.1 Research sub-objectives

This main objective can be reached by defining the following sub-objectives:

1. To identify the possibilities and limitations of how current map content is presented through OGC catalogue services in client applications.
2. To review formalization techniques for better representation and semantic annotation of geographical metadata.
3. To develop an innovative method for integrating Semantic Web Services technology in existing geoweb catalogues for the purpose of enhancing the functionality and improving the hit-rate in service discovery

1.2.2 Research Questions

1. How is spatial web search typically done?

2. How can semantic annotations support the use of geo-catalogue services by data providers and consumers?
3. What kind of ontologies are suitable for annotation?
4. How can OGC catalogue services such as GeoNetwork be enhanced with ontological visualization and annotations?

1.2.3 Innovation aimed at

This research is aimed at developing a method for integrating Semantic Web technology in existing geo catalogues so as to allow intelligent search. The method will be incorporated in GeoNetwork for richer discovery of data and services.

1.2.4 Related Work

OGC has established and developed standards to allow interoperability of data formats shared by SDI and accessed through CSW. The OpenGIS Catalogue Services Interface Standard (CAT) supports the ability to publish and search collections of descriptive information (metadata) about geospatial data, services and related resources [OGC07b]. Providers of resources register service descriptions using their choice model. The hope has been to help users access the resources through client applications in an efficient way.

The WMS provides a simple Hypertext Transfer Protocol (HTTP) interface through which geo-registered map images from distributed geospatial databases can be requested. In the request, the user defines the layers of data required and area of interest. The response comes as a map image which can be displayed in a browser. There is room to combine datalayers from several SDIs in producing a single map. The interpretation of the map images lies with the user in every case, no semantic descriptions are made when registering the services in catalogue services. The OpenGIS Web Feature Service Interface Standard (WFS) defines an interface where requests for retrieving geographic features are made and the operations involved. In catalogues this information is registered as metadata elements. To complement OGC work are International Standards Organisation (ISO) standards which have established relationships within metadata elements and format for their registration.

ISO 19115:2003 defines the schema required for describing geographic information and services. It provides information about the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data. Though mostly used for digital data ISO 19115 is applicable even for maps. ISO 19139 was established to close the gap in ISO 19115, that of the formatting of the data through an XML schema. While all these standards have been developed and implemented, syntax matching in query and retrieval has been achieved, however semantic interoperability remains unaddressed in these standards.

Realizing the standards established by OGC and how they can be augmented with semantic web technologies for better service description and dis-

covery, W3C has come up with recommendations for Semantic Annotations for WSDL and XML Schema (SAWSDL). The specification defines how to annotate WSDL interfaces and operations with categorization information that can be used to publish a Web service in a registry. The annotations on schema types can be used during Web service discovery and composition [W3C07]. Some work has been done on including semantic metadata descriptions in catalogues such as GeoBrain.

GeoBrain ², is a multidisciplinary system aimed at mobilizing NASA data and information through Web Service and knowledge management technologies allow users to dynamically and collaboratively develop interoperable and Web-executable geospatial service chains. To efficiently classify, register, describe, discover and access geospatial information, a semantically enabled OGC Catalog Service for Web (CSW) was used.

Klien proposed an architecture for ontology based discovery and retrieval of geographic information[KL04]. The user is allowed to formulate a query for metadata and geodata. The architecture can be extended further to allow spatial and temporal reasoning and to allow nested queries to be executed. [BCP08] developed a new algorithm, Service Aggregation Matchmaking (SAM) for composition-oriented discovery of Web services. Its deployment has been stalled by the lack of descriptions of services.

In this research, we will study how search functionality works within GN, a geo catalogue its limitation in relation to OGC standards and how it can be improved using web technologies. The electronic business Registry Information Management (eBRIM) extension package is studied to tape on its capabilities to add an extra package in which tailor made products can be added. This will be the point of entry for integrating ontologies and semantic annotations into GN. Ontologies play an important role in service discovery by overcoming the limitations of agreements of textual specifications[LdV04].

1.3 Method Adopted

This research focuses on using semantic web technology and metadata visualization to improve search functionality for web services in geo-catalogues. In order to achieve this goal the following methodology was used.

1. Requirements analysis: In this phase of the research literature review was done to expose the concepts involved Service Oriented Architecture (SOA) take allowing discovery of GI. We investigated current implementations for data and service search and discovery and their limitations.
2. Design: This phase of the research focused on Use case design. The use case is that of severe weather events. Hurricanes (also termed cyclones or typhoons) are always accompanied with strong winds and heavy rainfall causing flooding and extensive damage to infrastructure (Chapter 4). In our use case an administrator working with Disaster Management Unit (DMU) is interested in finding information about cyclone activity.

²GeoBrain: <http://geobrain.laits.gmu.edu>

which caused damage to infrastructure. He wants to find rainfall stations which recorded highest rainfall amounts, associated wind speeds and cyclone track. These data give a situation awareness platform for which decisions can be made. The use case has two actors involved and was used to demonstrate the advantage of using semantic web technology in view of limitations of current search mechanism

In order to solve the problem we developed an ontology (MetOnto) using Meteorological terminology as agreed by World Meteorological Organisation (WMO) using the Protégé Ontology Editor and its plugins. Protégé uses the Web Ontology Language (OWL) and Pellet as a reasoner. We augmented the GN with ontology concepts and semantically annotated these to their resources through metadata descriptions. We also studied the functionality GeoNetwork eBRIM (GN-eBRIM), an extension of GN. We outlined the processes step by step in Section 4.5 and the conditions that have to be met to solve the problem. More discussion on tools used can be found in section 5.4.

3. **Implementation:** This part of the research is focused on solutions available to implement ontologies and semantic annotation in GeoNetwork. Attention was be paid to proposed changes on the user interface, visualization of ontologies where the concepts are part of the metadata descriptions. In the implementation the functions were realized following standards provided by the Open Geospatial Consortium and International Standards Organization so as to ensure an interoperable system within a distributed environment.

1.4 Thesis Structure

This thesis was structured as follows:

Chapter 1: introduces the research, in which the motivation, problem statement, objectives and research questions and method to be used are described.

Chapter 2: exposes key concepts involved in Service Oriented Architectures (SOA), principles used in OGC Web Services (OWS) and the importance of CSW in service discovery. We discussed current implementations used in web service discovery, and their limitations in relation to OWS architecture. GN and GN-eBRIM architectures are discussed to some level of detail and the potential of the extension package within GN-eBRIM

Chapter 3: discusses Semantic Web technologies, paying particular attention to ontology development and semantic annotations. Techniques for visualization of ontologies are described in detail.

Chapter 4: describes the use case development, and the method of solving the use case through the integration of ontologies and semantic annotation into GN and GN-ebRIM using OGC, ISO and W3C standards.

Chapter 5: describes functionality of a semantically enabled GN, and visualization of ontologies and their advantages while searching for resources in GN CSW.

Chapter 6: the results, conclusions from the research and recommendations for further research are discussed in this chapter.

Chapter 2

Web services and Discovery of GI

2.1 Introduction

Advances in information technology and computer applications has led to so much relevance and reliance on such systems in sharing information. Thousands of resources are being made available on the web for reuse in different formats. The desire to share this information in interoperable environments have seen the birth of SDIs. SDIs are being set up to overcome the challenges faced in efficient use and sharing of GI when using conventional Geographic Information Systems (GIS) among heterogenous users [KLK06a]. Data and services provided by different SDIs can be shared and exchanged through geo-catalogue. Spatial data and resources can now be exchanged over the web and geo-catalogues play an important role in the discovery of spatial web services. Standards and protocols have been developed to govern the use of geo-catalogue services by both service providers and users. Metadata are a key component in supporting discovery, evaluation and the use of GI. Indexed and searchable metadata provide a disciplined vocabulary against which intelligent geospatial search can be performed within or among SDI communities[GSD04]. In order to serve user communities with GIS datasets through catalogue services, SOA principles are used[AAF⁺06]

2.2 SOA Principles and Web services

The service oriented architecture (SOA) is a special kind of architecture which evolved in distributed computing developing initially from monolithic and tightly-coupled systems to loosely-couple systems in distributed environments. SOA separates services, which are the functionality that a system can provide, from the consumers of those services[MAS⁺03]. It presents an approach for building distributed systems that deliver application functionality as services to either end-user applications or other services[EAA⁺04]. SOA involve three type of actors, service providers, service consumers and service registries also called discovery agencies. The interaction within a SOA are illustrated in Figure 2.1 and the role of the actors are as described below.

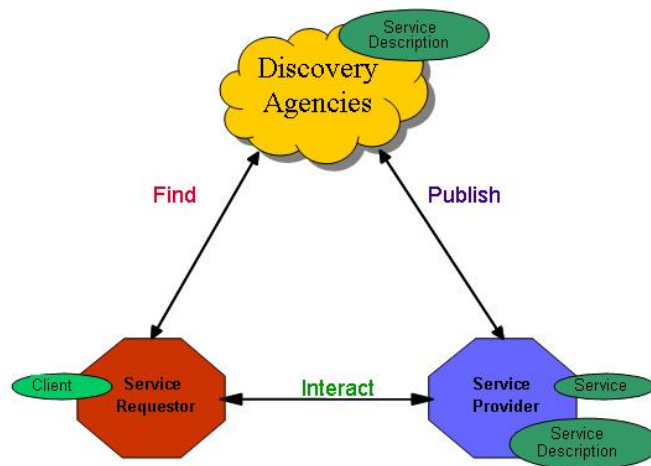


Figure 2.1: Service-Oriented Architecture: source (W3C02)

- **Service Provider**
A service provider creates service descriptions which are published in the registry. The provider also receives request messages from the consumer.
- **Service Consumer**
The service consumer requests for available services as given by the service descriptions in the registry. Once the consumer finds the required services, interactions with the provider are established in order to start using the services.
- **Discovery Agency**
The discovery agency/registry provides the service descriptions published by the service provider. The agency can be localised or distributed. After the services have been published, service requestors can search for services within the registry. The discovery agency plays the role of mediator/broker between service provider and service requestor.

An application takes advantage of web services through publication of service descriptions, finding and retrieval of service descriptions, and binding or

invoking of services based on the service description [W3C02]. Three operations involved in SOA are publish, find and bind (also known as interact as in Figure 2.1.

- **Publish:** The publish operation is used by service providers to register data and services to a directory (such as registry, catalogue or clearing-house). A service provider contacts the service directory to publish (or to unpublish in some cases) a service. A service provider typically publishes service metadata describing its capabilities and network address called the Uniform Resource Locator (URL).
- **Find:** The find operation is used by service consumers to discover specific service types or instances. Service consumers describe request for services from the registry and the registry responds by delivering the results that match the request. Service consumers typically use metadata published to find services of interest.
- **Bind/Interact:** used when a service consumer invokes a services. A service consumer uses service metadata provided by the registry to bind to a service provider. The service consumers can either use a proxy generator to generate the code that can bind to the service, or can use the service description to implement the binding before accessing that service.

2.2.1 Web Services Core Technologies

The three operations, in SOA (publish, find, bind) are used is Web Service Architectures (WSA).

“A Web Services (WS) is a software application identified by a URI¹ whose interface are binding and capable of being identified, described and discovered by XML artifacts and supports direct interaction with other software applications using XML based messages via Internet-based protocols.”

In [LdVA03], a web service is defined as *“a self describing, self contained application that can be published and invoked over the web. ”*

The web services architecture is composed of three functional components, which are transport, description and discovery. These are implemented using SOAP, WSDL and UDDI respectively.

- **SOAP**
The Simple Object Access Protocol (SOAP) is a lightweight, XML-based protocol for transfer of structured data and type information across a network in a stateless manner. Web services use SOAP for communication between WS registries, remote WSs and client applications.

¹Uniform Resource Identifier

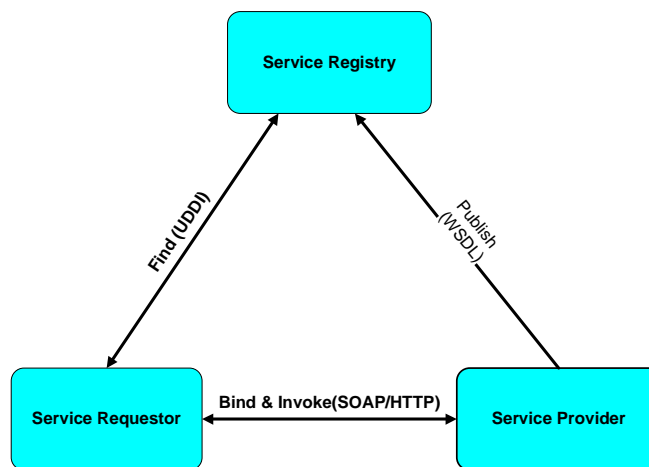


Figure 2.2: Interactions in a service-oriented architecture

- **WSDL**

The Web Service Definition Language (WSDL) is an XML based language used to describe WSs and how to locate them [CMRW07]. WSDL gives details of how communication with a remote WS is done. Using standard XML schema, it describes how to interpret the messages, how to contact the WS and the protocols to use. WSDL helps avoid the misinterpretation of data between client and services.

- **UDDI**

The Universal Data Description and Integration (UDDI) is the global look up for locating services. The standard provides an information repository and query service for WSs. UDDI is domain-independent standard method allowing publishing and discovering information about WS.

These technologies are consumed in the functional components of the WSA

2.2.2 The Web service architecture

Functional components existing within the WSA are transport, messaging, description and discovery. These are implemented using the core technologies described above. The **transport** protocol is responsible for transporting messages between network applications. The **messaging** protocol encodes messages in XML format so that they can be understood and SOAP is the standard format for exchanging WS data over HTTP. The **description** component defines the language used to describe a service and is handled by WSDL. The **discovery** component facilitates registration and discovery of service and is implemented using UDDI. UDDI therefore plays a pivotal role in registration and discovery of services in catalogue services. Figure 2.2 shows SOA and the interaction of the above mentioned technologies. If geospatial content is included in web services, the result is a Geospatial Web Services (GWS).

2.2.3 Geospatial Architecture and Services

Geospatial web service are web services with a spatial component that allows GIS functions to be performed. GWS technologies are used to manage, analyze and distribute spatial information [ZYD06]. The geospatial part of the architecture concentrate on supporting maps, and their visualization and features and their geometries. The web part supports the availability of distributed data, sharing of services and interoperability of technologies that allows data discovery. Data discovery functionality provides search and discovery to geospatial data and services. Data visualization provides visualization of images of the actual geospatial data and data Access component provides access to the actual geospatial data. Standardization of the architecture has been achieved through the ISO 19119 *Geographic Information - Services* which has been adopted as part of the OGC Abstract Specification, Topic 12 *OGC Architecture*.

Geospatial web services are used in web mapping in OWS. The OWS is used in the implementation of WMS. WMS produces maps of spatially referenced data dynamically from geographic information [OGC06]. A map portrays geographic information as a digital image file that can be displayed on a computer screen. The map is rendered in pictorial format such as GIF, PNG, JPEG and sometimes as Scalable Vector Graphics (SVG) but the map is not the data itself.

2.2.4 WMS operations

WMS supports three operations, **GetCapabilities** which returns service-level metadata, **GetMap** which returns a map with well defined geographic and dimensional parameters and **GetFeatureInfo** which returns information about particular features displayed on the map. All the operations are invoked through a web browser where requests take the form of URLs. The content of the URL is depended on the requested operation.

The **GetCapabilities** allows a user to retrieve service metadata which is returned as XML capabilities file. The file contains a description of WMS information content and the acceptable request parameters. The **GetCapabilities** Request helps a client discover the data layers that are supported by WMS and the projections. Clients are directed to particular WMS through catalogue services. Some of the WMS functionalities provided to clients through the **GetCapabilities** operation are:

- Interfaces which are supported by WMS
- Image formats that can be served among which are PNG, GIF and JPEG
- Available spatial reference systems for delivery of map data from the WMS
- One or more map layers made available from a particular WMS server.

The **GetMap** operation returns a map for a specific request. The URL invoked usually indicates what information (data layers) is to be displayed on the map, the geographical extend, the preferred coordinate reference system used

and width and height of output image. A composite map can be produced when results of two or more maps produced with the same geographic parameters and output size are accurately overlaid.

The self describing GetCapabilities operation provides capability representation thus improving interoperability, but does not cater for semantic interoperability since the semantics of the data are not included. To support catalogue searching, a list of keywords or keyword phrases describing the server hosting the WMS are included in metadata descriptions. The metadata fields to be filled by the provider include the coordinate reference system, lineage, usage, features displayed data quality among others. The meaning of displayed features is left to the user.

2.3 Catalogue Services

With data and services being hosted by a variety of SDI, effective service discovery therefore requires an extensive search system service across multiple domains. Catalogues support discovery, organization, and access to geographic information and thus help the user to find information that exists[PG06]. Each service provider has to register/publish the services they offer in the catalogue services by means of metadata descriptions. Catalogue services are required to support the discovery and binding to registered information resources within an information community. For data/services to be discovered efficiently, semantic heterogeneity has to be overcome and interoperable applications made available supporting both the provider and the consumers. To this end OGC has established standards for catalogue services through the Web Catalogue Services CSW [OGC07b].

2.3.1 Web Catalogue Services

The CSW forms the basis upon which standard geo-catalogues are being built. The CSW advertises application schemas for metadata, which handle descriptions conforming to metadata standards such as ISO 19115:2003 and supports XML encoding as per ISO 19139. ISO 19115 is an International Standard which defines the schema required for describing geographic information and services and specifies the identification, the extent, the quality, the spatial and temporal schema, spatial reference, and distribution of digital geographic data. ISO 19139 defines Geographic Metadata XML Schema implementation derived from ISO 19115. The CSW architecture is shown in Figure 2.3

In the CSW UDDI is used for registration and discovery of services by services providers and service consumers respectively. Queries are executed through the request-response model of the HTTP protocol as shown in the fig 2.3. The query send searches catalogued metadata and produces a result set containing references to all the resources that match the query. Some of the operations supported in the CSW are

1. DescribeRecord

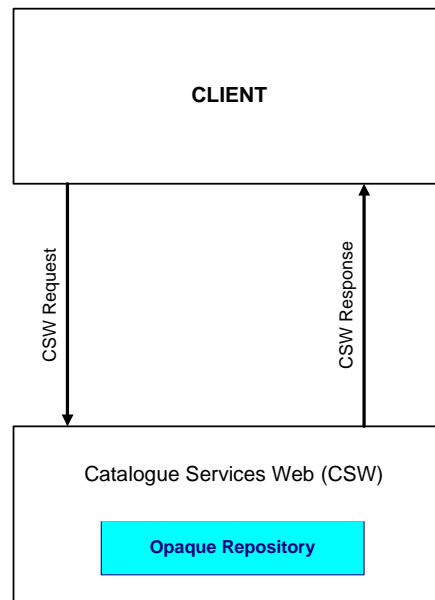


Figure 2.3: Architecture principles in CSW

2. GetRecords
3. GetDomain
4. GetRecordById

2.3.2 Geospatial Catalogues

Geospatial catalogues are catalogue services that publish metadata on GI while providing mechanism to access and retrieve such information. Metadata is used as the target for querying raster, vector and even tabular GI. The goal of a geospatial catalogue is to support a wide range of users in discovering relevant geographic information from heterogeneous and distributed repositories [LSdS06, BKAS05]. OGC catalogue service specifications and metadata standards are implemented in order to achieve interoperability. Queries in geocatalogues are achieved through two requests that are supported by HTTP, that is **GET** and **POST**. Resources published in geocatalogues often include maps [OGC06]

2.3.3 Metadata

Metadata, generally defined as data about data helps the user understand what the data are about and the processes that occurred in producing the data [ABDM05]. Metadata is available through catalogue services and plays a pivotal role because of its ability to manage, organize and provide information about geographic data. Service providers offer particular data access and geo-processing services, which are described by the metadata [BEH⁺03]. Metadata

standards, such as ISO 19115, ISO 19119, ISO 19139 and Content Standard for Digital Geospatial Metadata (published by FGDC) are the basis upon which metadata is registered in geo-catalogues. The catalogue used in this research GN supports the ISO 19115:2003, FGDC and Dublin Core for description of documents.

2.4 GeoNetwork

GeoNetwork is a spatial information management system based on OGC standards, which is useful for managing the spatially referenced resources. Its decentralization allows access to a variety spatial products from different providers through descriptive metadata. It allows sharing of information which may be used for decision support and aims at information consistency and quality and to improve the accessibility of GI along with associated information in a standard and consistent way [Geo07].

Main features of GeoNetwork include:

- Online editing of metadata
- Instant search on local and distributed geospatial catalogues
- Uploading and downloading of data and documents
- Online map layout generation
- Scheduled harvesting and synchronization of metadata between distributed catalogues

2.4.1 GeoNetwork Architecture

GeoNetwork is based on SOA concepts as described in Section 2.2 and Geospatial portal reference architecture [OGC04]. While the reference architecture supports four service classes which are portal services, catalog services, data services and portrayal services, GeoNetwork supports only the first three services. It is implemented both as registry information service where metadata is published by service providers and also as portal service providing access to other meta information systems and catalogue services. Figure 2.4 shows the Geospatial portal reference architecture on which GeoNetwork is based.

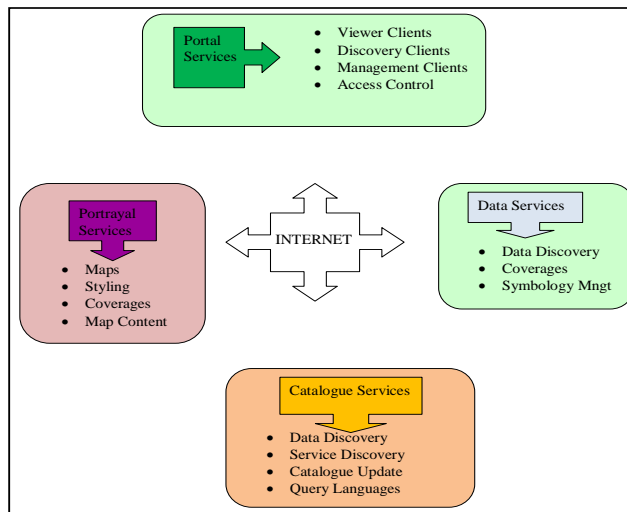


Figure 2.4: Geospatial Architecture: Basis for GeoNetwork Adopted from (OGC04)

2.4.2 Portal Services

The Portal Services provides access to the geospatial information as well as management and administration of the portal and users. Rules available govern the Authentication and Access Control which through controlled privileges regulate the access to reserved information and services. The Portal Platform contains an Advanced Metadata Editor Module for creating and editing ISO compliant metadata records for GI using ISO 19115 standards. A user interface available allows the user to display and navigate content retrieved from data services. Users can locate needed content through the discovery client using free text search criteria. Users are able to retrieve specific content if it stored with GN database.

2.4.3 Data Services

Data services provide access to spatial content stored in repositories and databases. Common encodings allow for data processing. The Data services can be distributed and do not need to be necessarily need to be resident on the portal. For resources to be accessible through data services, they are usually stored with URLs and Uniform Resource Identifier (URI)s. Feature services, coverage services and symbology management are included within the Data Services. The feature services is defined according OpenGIS Web Service Specification (WFS)

2.4.4 Catalogue Services

The main functionality of the Catalogue Services is to provide a mechanism for classification, registration, description, searching, maintaining and accessing information about resources on a network [OGC07b]. A metadata catalogue services is implemented with a facility to search for and retrieve information on spatial data made available by other catalogues. More specifically, the OGC

Web Catalog services Z39.50 protocol allow distributed search capabilities. The catalogue services for the web (CSW) test client within GeoNetwork support the same operations operations listed in Section 2.3.1

2.4.5 Technologies in GeoNetwork opensource

GeoNetwork opensource is platform independent application. It is based on Java for server pages, which provides an easy way for building a web application. GN uses a standardized interface for connection to database, where Mckoi is used for desktop environments and PostgreSQL or MySQL for large system environments. The metadata repository is maintained by the PostgreSQL database management System (DBMS). Java Easy Engine for Very Effective Systems (Jeeves) manages all HTML and XML requests and responses. Jeeves provides access to the database, multilingual support, service chaining and session management. The XML+XSLEngine which is the basis of Jeeves is a serverarchitecturewithmultipleaccessmodes supporting HTML and XML message formats. It allows separation of presentation layer from the business logic layer as illustrated in Figure 2.5

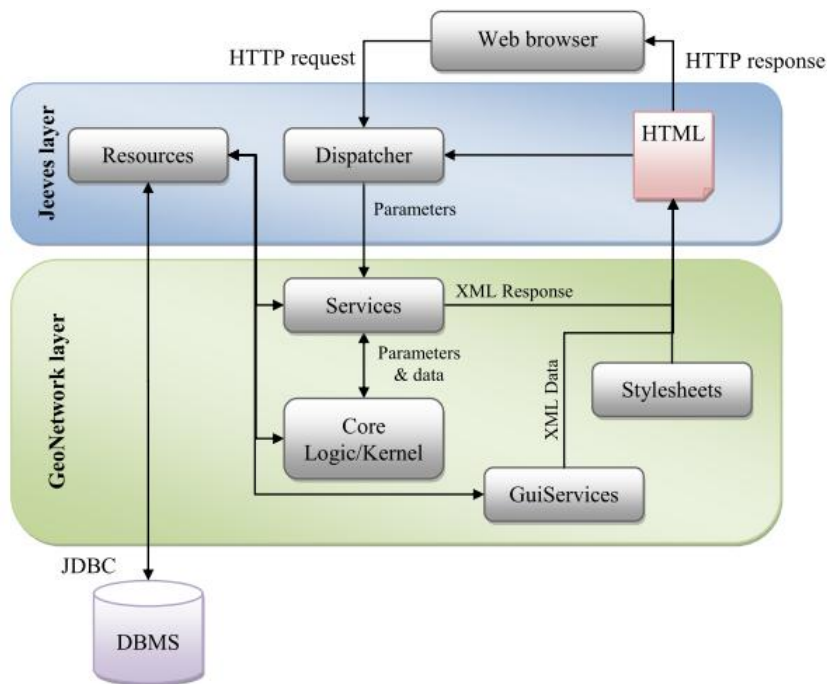


Figure 2.5: Significant technologies in GeoNetwork opensource: Adapted from (OH08)

Jeeves uses XML as internal data representation and XSL to producing HTML output. The Z39.50 catalogue allows access modes such as SOAP for search. All HTML requests are send in HTTP format and converted to XML with the GN layer. Responses are in HTML format. A request made on GN follows the request workflow as illustrated in Figure 2.6

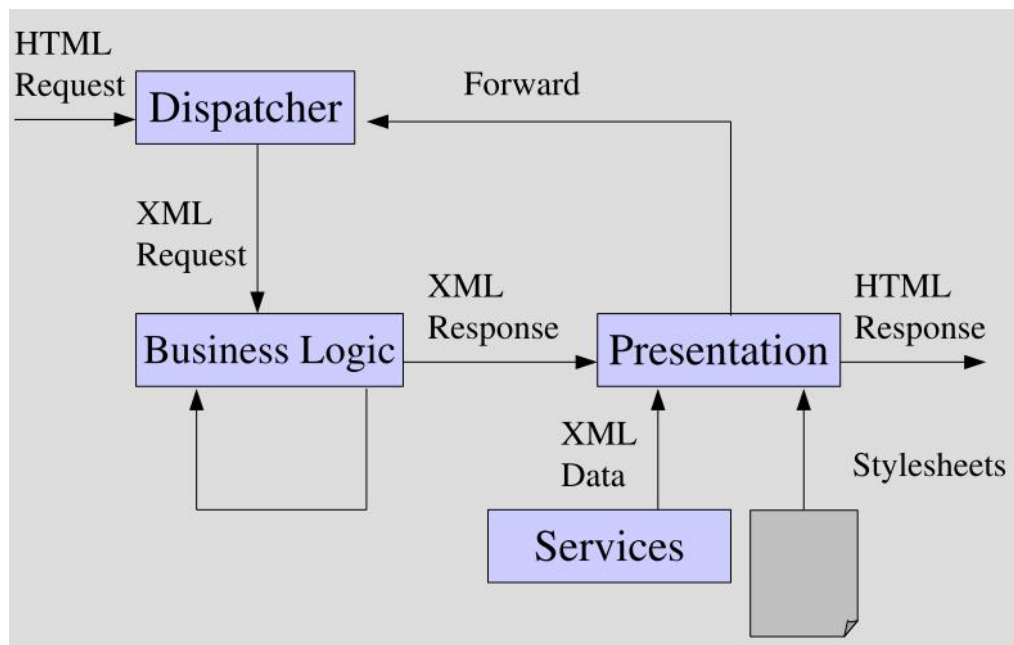


Figure 2.6: RequestWorkflow in GeoNetwork: Adapted from (Car09)

Within the request flow is the business logic unit that handles all the transformed request in XML format and accesses the DBMS within GN which is the repository for metadata. The business logic is split into two layers. The services layer receives requests and dispatches the outputs. The metadata and access manipulation allows for editing metadata according to its schema and stores it in XML form in the database. GN uses Lucene for indexing and searching of metadata. Search is done using keywords just like in other catalogues. The search is achieved through the use of the Z39.50. The interactions within the business logic are illustrated in Figure 2.7.

These components form the architecture of GN which has been implemented based on the OpenGIS CSW[OGC07b]. The technologies used by GN for interoperability and message query execution allow matching to be done based on syntactic structure. GN is capable of supporting other interfaces such as the CSW ebRIM.

2.5 GeoNetwork-ebRIM

GN-ebRIM is based on OGC specifications CSW-ebRIM Registry Service Part 1[OGC09a]. The ebRIM registry runs as a separate servlet that is loaded by GN application and is kept synchronized. Whenever metadata in ISO19115/19139 format is added or updated in GN database it is imported (upon transformation to ISO19139) to the ebRIM repository. Updating in the ebRIM repository also occurs instantly whenever a particular record is edited or deleted in GN. Indexing takes place simultaneously allowing faster searching. A geonetwork-client-ebRIM component resides in the geonetwork-legacy which ensures that

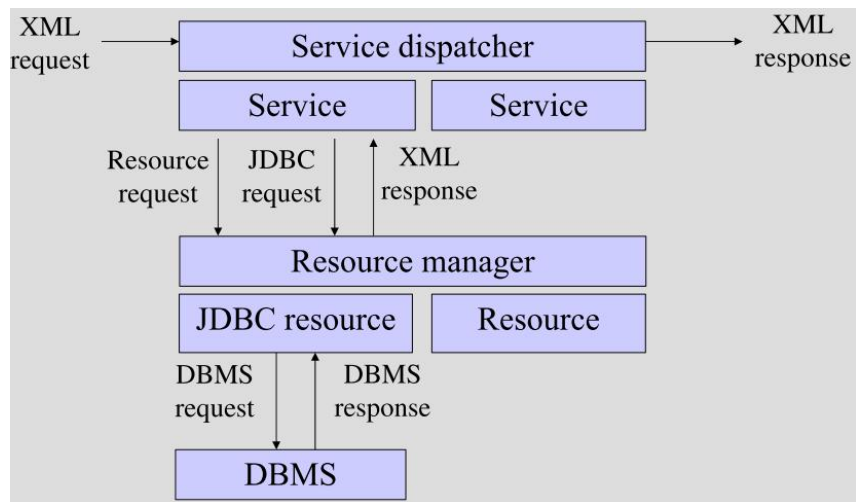


Figure 2.7: Business Logic in GeoNetwork: Adapted (Car09)

every change in the GN metadata catalogue is reflected in the ebRIM registry. The added component that allows operation of ebRIM within GN is shown in Figure 2.8

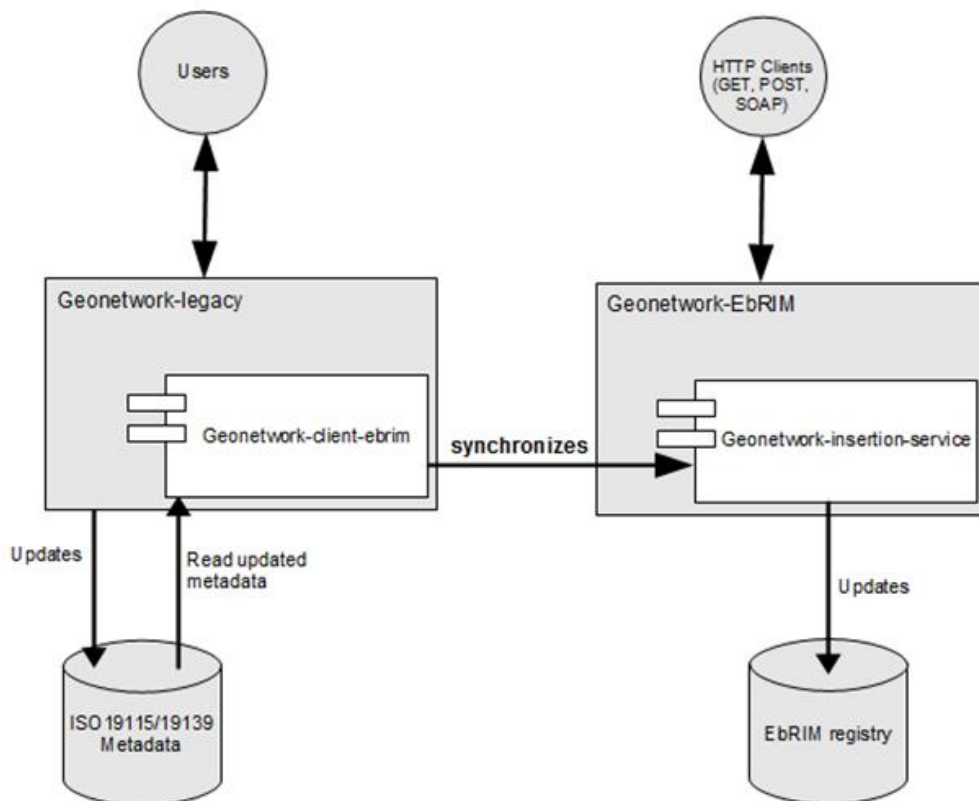


Figure 2.8: GeoNetwork integrated with ebRIM registry. Adapted from (TvIDG09)

The GeoNetwork ebRIM is the registry package providing the ebRIM protocol service. Within the architecture an extension class provides the OGC Filter parsing of incoming filters and allow conversion of filters into Lucene queries.

The architecture layer within GN-ebRIM is composed of four design artifacts, which are the web, service, persistence and domain layers. The web layer implements SOAP, sends and receives XML requests to the logical service layer. The logical service layer implements the CSW ebRIM operations. An ebRIM CSW client only searches and reads from GeoNetwork opensource. The persistence layer does all the CRUD (Create Read Update and Delete) operations to the database and the domain layer represents the semantical domain of the ebRIM application and contains all domain objects. The sequence diagram for inserting metadata into GN-ebRIM is given in section 4.5.

GN-ebRIM² has implemented the Basic Extension Package [OGC08] which concentrates on the provision of service-related information in support of geospatial applications. The implementation is capable of harnessing and validating XML documents that conform to the XSD and the implementation is loosely-coupled to the Persistence Layer for storage and retrieval. GN-ebRIM is seen as a solution to introducing to integrating ontologies and semantic annotations in GN.

Though the catalogue services within GeoNetwork is according to OGC's CSW, successful search highly depends on the quality of registered metadata records. The effectiveness of a catalogue query depends on the methods implemented for discovering relevant information in the registered metadata[LSdS06]. If enriched with semantic metadata and semantic annotations, the user is assisted in query formulation through the use of ontology concepts which they can visualize and navigate on if included in GN. Wherever semantically enhanced catalogues are used, there is significant improvement in information retrieval.

2.6 Limitations in Discovery of GI

Portrayal Services support visualization of GI in form of maps. These are made available to users through web services. In order to discover and retrieve information on maps, users metadata in catalogue services. Discovery of services registered in catalogues heavily depends on the expressiveness of the metadata and the users' ability to formulate good queries. Currently there is no prescribed way to search for information in catalogues though often times searching requires the some skill in formulation of a query which the user may not have. Search for services is done through the traditional means of using keywords. The catalogue analyzes the query, compares the given search criteria to the registered service descriptions and returns all matching records.

Even standard OGC-compatible catalog services retrieve information by syntax matching where specified search terms are matched against the metadata descriptions of the resources registered with the catalogue service [HSVV04]. This puts a limitation on the search functionality in geo-catalogues services.

²All information on GN-ebRIM has been obtained through personal contact with the developers. No documentation on the architecture is available for public consumption

With so much available in terms of web technologies, search for data and services is marred by a number of challenges. Current search mechanisms are based on key words only without taking advantage of underlying hierarchical structures that can improve the search mechanism. The limitations in the search functionality are as follows:

- The XML based standards like UDDI, WSDL, and SOAP allow syntactic interoperability of applications. However they are more focused on operational and syntactic details in order to implement and execute Web services. UDDI introduces keyword-based search and retrieval mechanism without any attempt to use underlying hierarchical relationships[YDZ⁺06]. Standards such as the Dublin Core describing the services do not allow relevance ranking, as such its possible to return more than necessary results.
- UDDI is domain-independent, and so it does not support domain-specific query capabilities particularly for domains such as GIS requiring spatial queries.
- The lack of machine-understandable semantics in the technical specifications and classification schemes used for retrieving services, prevent UDDI registries from supporting truly effective service discovery.
- Whilst WMS standards cater for technical aspects that allow integration of information, they ignore the semantic aspect, thus limiting scope of data sharing between providers and users.
- Formulation of queries is often left to the user who may have little or no knowledge and experience about the service or data they are looking for, so poor query formulation also results in poor results.

2.7 Conclusion

While online maps offer a lot of geospatial data sets meant to help user communities make informed decisions, search and retrieval of these resources remains a frustrating task. Though standards have been developed to overcome heterogeneities, making web applications interoperable, semantic interoperability has been realized. Standardized geo-catalogue services such as GN rely on syntax matching of key words and substrings, as a result users face the challenge of retrieving unwanted results or even non at all. Registration of services in geo-catalogues require consideration of semantic web technologies that assist in making meaning of resources available to users. Extensible and more expressive descriptions are required in geo-catalogues and GN-ebRIM can be of use through its Basic extension package. The use of semantic web technologies is seen as a part of the solution to overcoming limitations of current search mechanisms in geo-catalogues. In the next section we look at available semantic technologies for use in geo-catalogues.

Chapter 3

Semantic Web Technologies

3.1 Introduction

The Semantic Web is not a separate Web but an extension of the current one, in which information is given well-defined meaning, better enabling computers and people to work in cooperation[BLHL01]. The Semantic Web (SW), though not yet realized is aimed at enhancing web data with metadata, data processing techniques and processing methods that allow the meaning of such data to be machine readable and human understandable. The SW is *based on the idea of creating machine understandable data which can be used and shared*[MG03]. Standards like UDDI or WSDL form the basis for the working technology of the SW. Semantically rich data models are created using web languages such as the Resource Description Framework (RDF)[W3C04b] and the Web Ontology Language (OWL) [W3C04a]. The models consist of subjects and entities formed into a triple (subject-predicate-object). Subjects and objects are entities while predicates give the relationship between the entities. The SW relies a lot on ontologies that structure underlying data for the purpose of making it machine understandable allowing exchange of this data over the web. As given in [EFI⁺04], the SW heavily relies on ontological knowledge to achieve semantic interoperability and to represent resources based on concepts and meanings derived from their metadata.

Thousands of resources are being made available on the web for reuse in different formats. Spatial data and resources can now be exchanged over the web and geo-catalogues play an important role in the discovery of spatial web services as described in section 2.2.3 and metadata descriptions assist users in discovering available resources. With all these technologies in place users continuously struggle to get the right GI because of lack of meaning of resources. The vocabulary used is often understood by the provider leaving the user of the service in the dark. This can be overcome by using semantically defined metadata. By way of example, finding resources that publish information about severe weather events is not such an easy task for the user. He may choose to use *storm* as search keyword when the provider has registered the resource with the term *tropical cyclone*. Understanding the relationships between these terms and reasoning about them in catalogue services widens the search space. An ontology visualizer assists a user to navigate about concepts and their re-

relationships, giving a user a better perspective of concept to use in their query. Semantic annotations link resources to their metadata resources through the ontologies giving an added advantage in the search mechanism.

In Section 3.2 we discuss ontologies and methods for ontology visualization. In section 3.3 we describe semantic annotations, levels of semantic annotations and how they are utilized in catalogue services.

3.2 What is an Ontology?

No universally accepted definition of what an ontology is exists, but ontologies remain as one of the cornerstones of the SW. With the need to share information about a domain in an understandable way, ontologies set the platform for defining common vocabulary where machine-interpretable definitions of the basic concepts of the domain and their relationships are included. Ontologies are means to ensure semantic interoperability in dynamic environments. Their prevalent availability helps to solve semantic mismatches and is crucial for realizing the vision of seamlessly interacting services. Some common definitions of an ontology are given below.

An ontology is an explicit specification of a conceptualization [Gru95].

An ontology is a set of knowledge terms, including the vocabulary, the semantic interconnections, and some simple rules of inference and logic for some particular topic [Hen01].

The term conceptualization is defined as *an abstract, simplified view of the world, which needs to be represented for some purpose [KHL⁺07]*. The conceptualization is based on objects, concepts, and other entities which are presumed to exist in some area of interest, and the relationships that hold among them. The concepts and constraints used in ontologies are stated explicitly.

Currently OWL is used for authoring ontological statements and was developed as a follow up to RDF and RDFs. OWL allows reasoning about concepts and goes beyond previously used RDF constructs in that it adds more vocabulary for describing classes, their properties and the relationships between classes. The W3C¹, has defined OWL in three sublanguages, OWL-Lite, OWL-DL and OWL-Full which define the expressiveness of each sublanguage [DHK07].

¹OWL: <http://www.w3.org/TR/owl-features/>

OWL-Lite is the syntactically simplest sub-language which supports users requiring only a classification hierarchy and simple constraints.

OWL-DL is much more expressive than OWL-Lite and supports users who would want maximum expressiveness but retaining completeness. It is based on Description Logics and subject to automatic reasoning. It is therefore possible to automatically compute the classification hierarchy, which is also called inferred hierarchy while checking for inconsistencies.

OWL-Full is the most expressive OWL sub-language and is meant for users who would want maximum expressiveness and the syntactic freedom of RDF but with no computational guarantee. As a result it is not possible to perform automated reasoning on OWL-Full ontologies.

In view of the capabilities of each of the sublanguages above, ontologies referred to in this document are modeled using OWL-DL. RDF statements are used within OWL statements as given in the example below. The extract comes from the MetOnto developed in full in Section 4.3.1

```
<owl:Ontology rdf:about="SevereWeatherEvents"/>
<owl:Class rdf:ID="number">
<rdfs:subClassOf>
<owl:Class rdf:ID="TropicalDepression"/>
</rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:ID="Threat">
<rdfs:subClassOf>
<owl:Class rdf:ID="SWEvent"/>
</rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:ID="Cyclone">
```

3.2.1 Components of an Ontology

An OWL ontology consists on classes, properties and individuals [DHK07]. Individuals also known as instances, represent objects in the domain of interest. Properties represent binary relations between individuals. They link two individual together for example, considering the ontology used in this research the property *hasObservation* links the subclass *Observation* to the class *Cyclone*. OWL classes are sets that contain individuals. The classes form concrete representation of concepts (Section 4.3).

3.2.2 Kinds of Ontologies

Ontologies differ in their degree of formality and Uschold[UG96] defines four levels of formality.

- Highly informal where concepts are expressed in loose natural language

- Semi-informal where concepts are expressed in a restricted and structured form of natural language. Reduced ambiguity increases clarity of concepts
- Semi-formal where concepts are expressed in an artificial formally defined language such as RDF, OWL and other
- Rigorously formal in which concepts are well defined with formal semantics, theorems and proof of properties

Wherever ontologies are referred in this document, they are of the formal kind.

3.2.3 Ontologies as knowledge Representation

An ontology together with a set of individual instances of classes constitutes a knowledge base. In the context of metadata, the terms used are specified with constraints on their interpretation in relation to other terms used in the metadata description. The concepts in an ontology are formally described using a knowledge representation language. Tasks such as searching, discovering relationships among concepts are only possible when the ontology has been represented in a way that allows manipulation by machines. Description Logics (DL) is a family of languages that describe knowledge in terms of concepts and restrictions on roles [KLK06b].

DL form the foundation for knowledge representation languages such as RDF and OWL and therefore the structured knowledge they present can be accessed and reasoned about. DL has a terminological part which deals with definition of concepts and an assertional part (ABox) which asserts facts about individuals (instances).

3.2.4 Ontology Development

Ontology development has several phases of which conceptualization is the first one. In the conceptualization, terms and concepts for the application domain are decided. The domain chosen for our case is that of **severe weather**. These are converted into knowledge representations by explicitly defining the concepts and specifying properties of objects and individuals occurring within the domain. The full ontology is given in Section 4.3

Ontology development is an iterative process. Currently there are no laid down rules or standards for ontology development, however any practical development should include the following [NM01]

- Defining the concepts in the ontology. Concepts are also known as classes in the ontology,
- Arranging the classes in a taxonomic (subclasssuperclass) hierarchy, also called “*is-a*” hierarchy.
- Defining properties of classes (known as roles in Description Logics) and describing allowed values for these properties.

- Creating a knowledge base by defining individuals, which are the instances of the classes, by filling in the values for their properties and restrictions.

3.2.5 Taxonomies

Hierarchical classification of objects is referred to as a taxonomy. The taxonomy defines classes of objects and their relationships forming a tree like structure. The relationships are inherited down the hierarchy. Ontologies in like manner are like taxonomies in that they classify concepts and their relationships but in a more structured manner, thus give a higher level of abstraction. The development of the ontology in this research was based on keywords used in severe weather advisories. Having developed ontologies, their visualization assists the user in having better understanding of related concepts.

3.2.6 Ontology Visualization

Visualization is the graphical presentation of information, with the goal of providing the viewer with an understanding of the information contents. GI is often presented on maps as data layers superimposed on each other. The role of the map is to provide the user with a quick understanding of the available content [FSvH04] as well as providing a way of quickly accessing individual data. In the same manner ontology visualization is meant to give a user an overview of concepts and their relationships. Any ontology visualization method should be flexible enough to meet the needs of different users.

The use of ontologies in the geospatial domain has resulted in the need for effective ontology visualizations for the purpose of design and browsing in the search for information. Through ontology visualization interesting information about the data relationships can be extracted which would otherwise not be possible when using textual information alone. Effective visual interfaces enable users to observe, manipulate, search, navigate, explore, filter, discover, understand, and interact with data far more rapidly and far more effectively to discover hidden patterns [NKKP07]. Visualization is the key for having better understanding of the data that is contained by ontologies. Users can visually follow a concept identifying its nearest neighbours for any interesting related concepts. Visualization of ontologies can be likened to car navigation systems in which a user have options either to have an overview or display the details.

Visualization of ontologies is not an easy task [KHL⁺07], since its not only about the hierarchy of concepts but also includes the role relationships among concepts and their instances. For any method to be considered good for the visualization of an ontology, it has to support the presentation of ontology ingredients which are classes, relations, instances, and properties [KTH⁺06]. The efficiency of the method is seen in its ability to support user tasks. Users are interested in different levels of detail and in this section we outline the methods available for ontology visualization and their capabilities.

- **Indented list:** Ontology visualization tools such as Protégé and their techniques offer a tree view visualization of ontologies which looks much like Windows Explorer. The taxonomy as dictated by the *is-a* inheritance

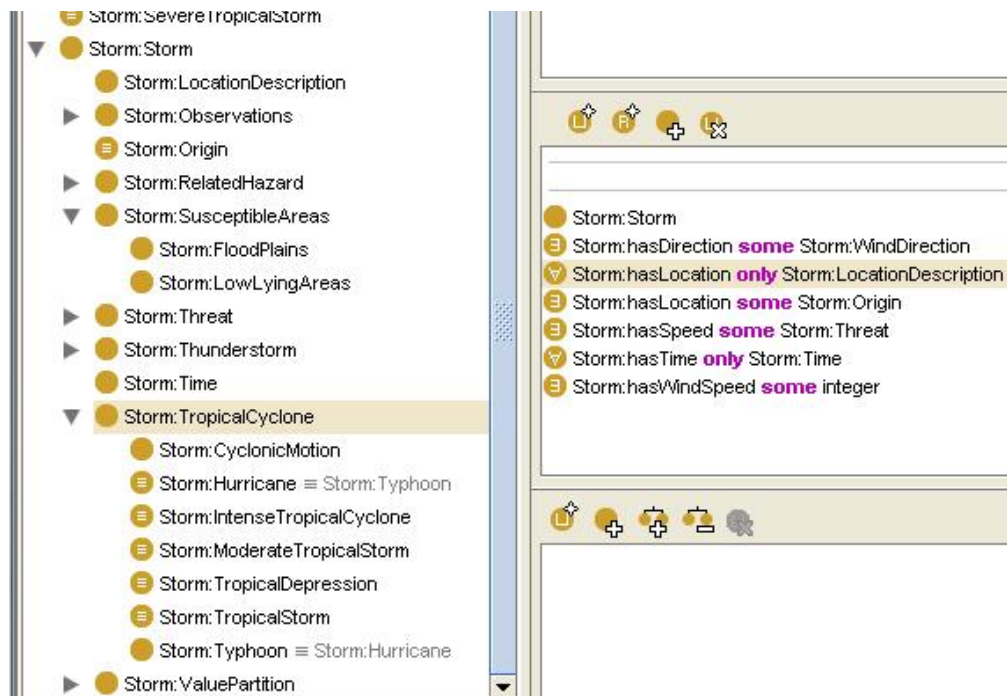


Figure 3.1: The MetOnto is represented in the Protégé Ontology Editor

relationship is presented as a tree. The classes form nodes in an indented, expandable and retractable tree [KHL⁺07]. Instances are often displayed in a separate window. Child classes appear under their parent classes but indented to the right, Properties are always displayed in a separate window. The indented list offers a simple implementation and representation of ontologies in a manner which is quite familiar to the user. The top-down layout of a tree browser allows for a systematic exploration of the whole ontology making the task of locating a specific class or instance or identifying the children or instances of a class easier than in most of the other visualizations. The indented list allows direct access to the contents of the classes [RB03]. Figure 3.1 shows an example of ontologies displayed in a tree view.

- **Nodelink and tree:** In this technique, ontologies are represented as sets of interconnected nodes. Their taxonomy is presented in a top-down or right to left layout. The presentation allows expansion and retraction of nodes and their subtrees. The ontology is viewed as a 2D graph with the capability of displaying the properties, inheritances as well as relations. Tree-like node link diagrams are most effective when representing an overview of the hierarchy but only when dealing with small ontologies. Visualization of large ontologies, involving several elements is not well handled with this technique. Ontoviz, a plugin found in Protégé uses this technique and Figure 3.2 shows an example of such a visualization.
- **Zoomable:** For this type of visualization, all lower level nodes in the hi-

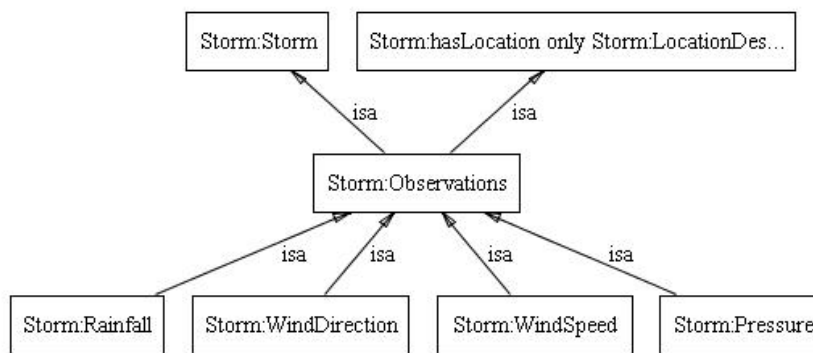


Figure 3.2: MetOnto displayed in Nodelink and tree view

erarchy are nested inside their parents but having small size compared to their parents. The user is able to zoom-in to the child node allowing it to be enlarged whilst being made the current view level. Jambalaya a Protégé plugin has such capabilities. These zoomable interfaces are effective where there is need to browse and locate specific nodes. However they do not offer an effective overview of the hierarchical structure and they do not support the user in forming a mental image of the hierarchy [RB03]. In Figure 3.3 zooming shows the current view of the metOnto as *tropical cyclone* and the related concepts around it.

- **Space-filling:** Space filling techniques use the whole screen space by subdividing the space available for each node among its children, where the subdivision will correspond to a property of the node assigned to it such as size, number of contained nodes, and others. Space filling techniques have been successful at visualizing trees that have property values at the leaf (instance) node level, which is the case in ontological structures [PGB02]. The techniques allow for colour and size coding of properties at instance level. Techniques are mostly affective when the user is mostly concerned about leaf nodes and their properties.
- **Focus + context or distortion:** This method combines context and focus where the central node is on focus and the rest of the nodes are presented around it. The outer nodes are reduced in size and can even reach a point where they become invisible. A variable radius of visibility is employed in a hyperbolic equation which limits the size of the graph in manageable steps. A user has to focus on a node in order to expand it. The method gives a user options to expand, retract and hide nodes by double clicking on the nodes. Focus + context techniques are very good at providing global overviews, displaying many nodes at once. The method can be used to focus on certain nodes for the purpose of viewing related nodes and locating specific instances. However, the method cannot represent the ontology in a hierarchical manner making it difficult to distinguish parent from child nodes. Clutter is unavoidable whenever role relations are made visible.

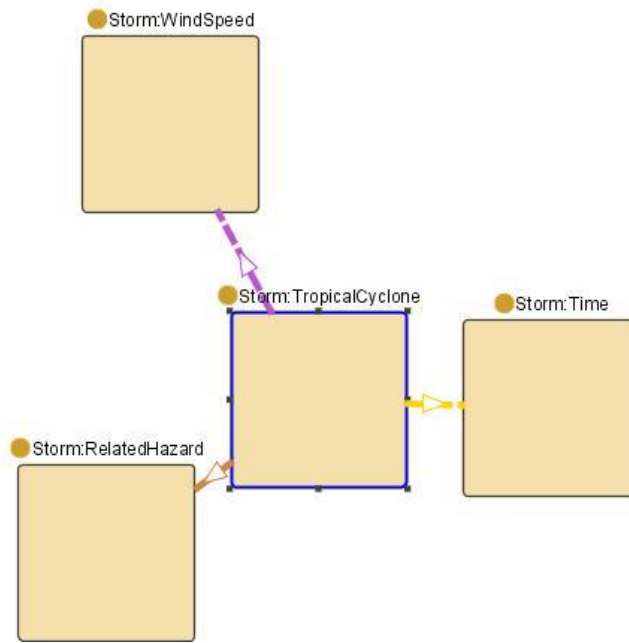


Figure 3.3: MetOnto concepts in Zoomable view

Figure 3.4 illustrates how an concepts are represented using this technique.

While several ontology visualization methods and techniques are available, each one of them has its own advantages and shortcomings. The type of visualization employed in geo-catalogues largely depends on the nature of the size of the ontology, and the tasks that have to be supported with the visualization. It is important to have an ontology visualizer that combines the capability of displaying hierarchies whilst allowing other functions such as zooming to be done. It should be flexible enough to allow varied views of ontologies depending on user's needs at a particular time as well as allowing concept querying. The tools used in creating the visualizations are explained in Section 5.4. Once the ontology has been developed and a visualizer identified, to help user tasks in geo-catalogues the ontology concepts have to be linked to their metadata resources through a process called semantic annotation.

3.3 Semantic Annotations

The world wide web hosts a vast collection of resources, including geoinformation, held by standards which tell us how to locate the resources. XML based standards like UDDI, WSDL, and SOAP allow interoperability of applications, however they are more focused on operational and syntactic details in order to implement and execute Web services.

Resources available on the web might be textual information, maps, multi-spectral images, some vector data such as OGC Web Feature Service and others.

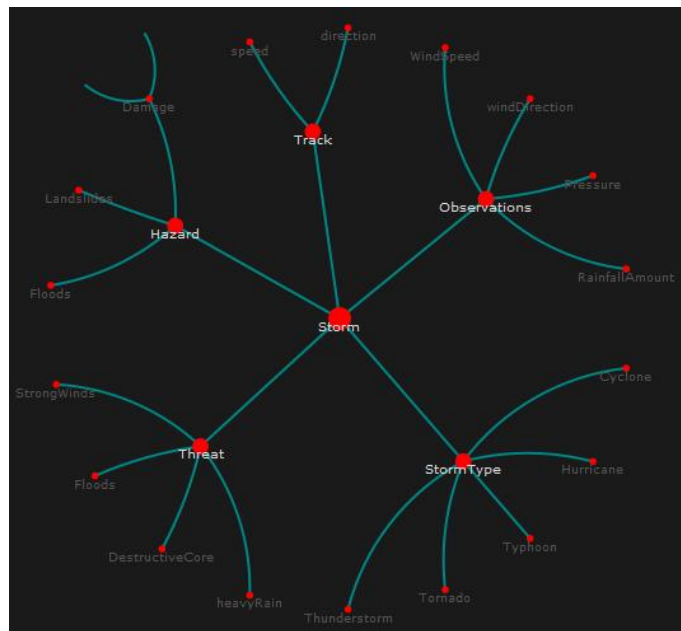


Figure 3.4: MetOnto represented in Focus+ Context view

Lack of proper descriptions of the resources, results in limited use, usually only by those who have expert knowledge about the resources. By way of example, an application can potentially load and visualize data on a map, but the user may not have the slightest idea on how to read and interpret the map. Quite often the interpretation is left to the user. Another motivating scenario is where a user wants to find a web service that takes *weather station code* as input and gives the output as *susceptibility to cyclone induced floods*. Such a search will return only a percentage of web services having this information available. This only shows that whilst resources might be available through the web, users often face the challenge of finding the resources besides the ability to evaluate if the available information meets their needs. For these resources to be more useful to users, they have to be annotated with descriptive metadata. Annotations formally identify resources through the use of concepts and the relationships among them [MM09].

Semantic annotations are to tag ontology class instance data and map it into ontology classes [GC06] and according to Kiryakov, semantic annotation is a specific metadata generation and usage schema, aiming to enable new information access methods and to extend the existing ones [KPT⁺04]. A semantic annotation is the additional information that identifies or defines a concept contained in a semantic model in order to just describe that part of the model. Semantic annotations, also known as explicit identifiers of concepts enable users to formulate flexible search queries for geospatial data.

Semantic annotations are increasingly playing an important role in the world of metadata to deal with semantic heterogeneities between information systems. The process of semantic annotation is based on geospatial evidences as it considers the spatial component. The annotation process takes advantage

of standards provided by OGC such as Geographic Markup Language (GML) though the annotation schema itself uses FGDC's geospatial metadata standards [OGC09b].

3.3.1 Why use Semantic Annotations

Relating queries to conceptualized domain knowledge using semantic annotations enables reasoning to expand the user queries, which in turn increases the number of relevant records in the repository that return a more precise result. Semantic annotations help address challenges that the users often face when searching for information on the web in the following ways.

- Application specific knowledge used within a small community is made available to the user. The use, for example, of "*windgusts*" leaves the user without any clue of what this exactly refers to. Providing semantic descriptions gives the user more understanding that helps their interpretation of such services/data.
- Users often face challenges arising from hierarchical problems of given ontologies. The provider of a service might prefer to use more specific terms like "*tropical depression*" whilst the user knows only about "*storms*". To help the user, tropical depression is modeled as a subconcept of domain concept storm, otherwise searching using "*storm*" does not return all services providing information about storms.
- Semantic annotations address the issue of a multilingual user community of geospatial resources. If concepts modeled at the domain level are allowed to support semantic annotation in different languages, it makes it possible for a user to still search for resources despite a different language being used.

Requirements that have to be met in the development of semantic annotations are discussed in Section 4.3.2

3.3.2 Levels of Semantic Annotations

Semantic annotations establish a link between a geospatial resource, its metadata and the ontology [OGC09b]. Within OWS, three different levels of semantic annotations are envisaged. These three levels differ in their capabilities because of different reasoning capabilities. Figure 3.5 shows the three levels at which semantic annotation can be done, that is service metadata, data model and data entities.

1. **Service Metadata:** Metadata sections such as keywords are semantically enriched so as to make the meaning a reality. Keywords that are registered in the metadata offer limited information about the services/data. To give them more meaning, the keywords are linked directly to the concepts in the domain ontology by adding pointers to the URIs. Another option would be to use the metadata field proposed as Service Content

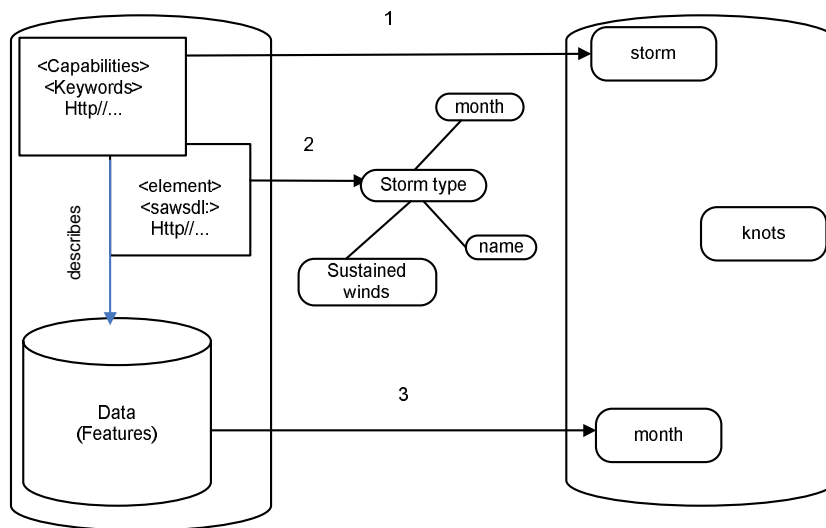


Figure 3.5: Levels of Semantic Annotation

Metadata in WS-Common [OGC07a]. No specifications exist for the type of metadata to be added to this field so we take advantage of this to add domain concepts to this field where each concept is identified by its URI. The example given below refers to metadata annotation for WMS where keywords come from the MetOnto herein referred.

```
<WMS_Capabilities version="1.3.0">
<Service>
<Name>WMS</Name>
  <Title> Severe Weather Situation Awareness </Title>
  <KeywordList>
<Keyword vocabulary=http://www.semanticweb.org/
ontologies/2009/11/Storm.ow#>Cyclone
</Keyword>
<Keyword vocabulary=http://www.semanticweb.org/
ontologies/2009/11/Storm.owl#>Observations
</Keyword>
  </KeywordList>
```

Adding URIs results in clutter, therefore the need for an ontology visualizer which allows the user to see the concepts and their relationships at the domain level. Ontology visualizers are discussed in detail in Section 3.2.6 and further on in Section 4.3

- Data Model:** Within this level, semantic annotations focus on associating feature type and feature attributes to concepts in the resource ontology. Reasoning on the data model level is made possible through the direct link of data schema to the resource ontology. An additional attribute such as an identifier (URI) established the association between the concepts which

are in the XML schema and the resource ontology. A geo-catalogue is able to retrieve the linked resource ontology and inference is made between user's request and the semantic descriptions of the service made available.

3. **Data Entities:** Semantic annotations can also be done at attribute level. In OWS, GML features and feature attributes are entities which are annotated at this level [OGC09b]. Individual entities are annotated either with domain concepts or with individuals on the domain level. The individual entities are tightly coupled to domain concepts. This comes at a cost where high volumes of entities are involved though flexible in terms of annotation of features.

Data model and data entities semantic annotations are of more use where spatial reasoning is required. W3C recommended the use of the Semantic Annotations for WSDL SAWSDL. Two additional attributes enable the mapping between the language used to model ontologies and the original data schema [W3C07]. The two attributes, the *liftingSchemaMapping* and *loweringSchemaMapping* point to XSLT documents allowing automatic transformation between schemas provided ontologies are XML-based. This is achieved through the addition of modelReference attribute to XML element type definitions.

3.3.3 Mechanisms for Semantic Annotations

Semantic annotation task can be done in three ways, manually, semi-automatically or automatically. In manual annotation the burden lies with user, who has to find the right ontology. Manual annotation is tedious and quite often error-prone given large ontologies with thousands of concepts and millions of instances involved. In semi-automatic annotation task, algorithms of how the annotation is done are provided, and there is little human intervention in the process. Quality is maintained in the process. The automatic way doesn't require any human intervention.

3.4 Conclusion

Semantic web technologies strive to achieve semantic interoperability and can be used to improve search capability of catalogue services. Until now search and retrieval of resources has been done using traditional means of matching without making use of semantic description. Ontologies and semantic annotations can be used to improve the search space in geo-catalogues. Ontologies define a common vocabulary allowing the sharing of information provided by different SDI nodes. Semantic annotation on the other hand provide a link between a geospatial resource, its metadata and ontology and a catalogue service can retrieve results of a request by inferencing to the ontology made available to it. The level of annotation chosen depends on the goal and the user requirements.

Visualization of ontologies aids users to manipulate, search, navigate, explore, filter, discover, understand, and interact with services/data far more easily and thus helping them in formulating queries by use of linked ontology

concepts. Several methods and techniques for ontology visualization exist and whichever method is chosen should be flexible meeting needs of a variety of users, experts and non experts. The next chapter presents a case study involving in which ontologie and annotaions are employed in the process of finding data/services from distributed environments.

Chapter 4

Use Case: Severe Weather Information for Situation Awareness

4.1 Introduction

The disaster and emergency response relies heavily on effective information sharing structures such as SDIs for the purposes of disseminating early warning information. Data/services offered by key players has to require meaningful definitions for ease access, retrieval and interpretation by users.

Currently, information sharing in the disaster mitigation sector is difficult to coordinate due to the need to address the organizational issues as well as technical issues involved in search and retrieval on data [CDJS04]. While geoinformation might be made available through catalogue services, the meaning attached to it is most significant for users to be able to evaluate its usefulness. Even simple notifications for the disaster, incident, crisis, and emergency require significant coordination of semantic definitions, messaging technologies, and standardization processes [Ian06]. Catalogue services provide a platform through which resources can be found provided such information is registered in geo-catalogue services. Addition of semantic descriptions in a standard geo-catalogue is believed to significantly improve the search for information in distributed environments.

GN Opensource is one such catalogue which allows sharing and discovery of resources in distributed environments. The details of GN are provided in Section 2.4. It allows sharing of information which maybe used for decision support. Users are able to locate resources from different nodes. We propose strategies for implementing ontologies and semantic annotations in GN. We chose the weather domain from which we developed the application ontology. The ontology is used for semantic annotations, by linking metadata descriptions to their resources.

The situation modeled in this research (use case) forms the basis for proof of concept. Though a bunch of operations may be involved but only a fragment have been extracted in the development of the ontology and semantic annota-

tions required to solve the use case at hand. The use case outlines a known context of application of ontologies and semantic annotations but does not limit the concepts used to this domain.

In this chapter we discuss details of the use case in Section 4.2 and the requirements of the method are defined in Section 4.3. In section 4.4 we present the use cases and sequence for registering services in GN. Section 4.5 discusses the semantic annotation of the MetOnto for consumption by the search queries.

4.2 Use case Identification

Severe Weather Information for Situation Awareness within the confines of disaster management is selected as a use case illustrating ways in which semantic web technologies can be made use of for decision support systems. Across the globe, the European Commission Humanitarian Aid Office (ECHO) is promoting disaster preparedness as part of an overall Commission on Disaster Prevention and Preparedness approach to reduce vulnerability and exposure of people to risks and disasters as well as the economic costs of such disasters. Many projects undertaken so far have created avenues for the sharing of knowledge and experiences among non-government organizations (NGOs) and National Disaster Management Offices (NDMO). ECHO also creates awareness amongst NGOs and NDMO partners for the need to network at the national level to improve coordination and facilitate the sharing of information part of which is geoinformation.

In Zimbabwe hydro-meteorological related disasters come in different magnitudes requiring early warning information. The Meteorological Services together with the Department of Hydrology, play a pivotal role in making sure weather information is relayed to the relevant authorities in time for the purposes of early warning. Cyclone induced floods may result in loss of property, loss of lives and extensive damage to infrastructure. In this regard the Disaster Management Unit (DMU) was initiated to create a platform where stakeholders share information and get updates of threatening situations so as to have an effective emergency preparedness and response on ground.

Domain knowledge is required to understand the types of severe weather events as well as the associated hazards. On the other hand, specific information about an area under threat is necessary to allow quick decision making and timely response to avert disaster. Dissemination of early warning information requires clear and explicit information generated from severe weather advisories. One way to share and discover the information is through use of geo-catalogues, giving access to users, and sometimes real time information is required. Quite often the information may be available on the web but not so easy to find due to poor definition of queries by the user, vocabulary used which is unknown to the user and differences in knowledge background between the user and Meteorological service provider.

The ontology for the use case herein referred is described in full in Section 4.3. The application ontology is not limited to the terms herein referred. GN is used as a portal to access services of the Meteorological Agency and the Infor-

mation for situation awareness.

A motivating scenario is that of an administrator working with DMU who wants to find the location of a cyclone, its track, damaging winds and areas of heavy rainfall. Heavy rainfall causes flooding of low lying areas and early warning information will help in making decisions such as evacuation. Besides he would also want assess damage within 20km of the track of the cyclone. The administrator uses GN to access the information. The role played by each part (service provider and user) are given in Section 4.4. First the requirements for the use case are discussed.

4.3 Requirements Analysis

The requirements is based on user's perspective while searching for geospatial resources through a catalogue services. In the use case we described the different actors who are GI providers and users. Data and services are made available together with their semantic descriptions and semantic annotations. In order to improve the search functionality, the elements of the application are detailed below.

Requirements definition clarifies what the application should fulfill.

- The user interface should provide functionalities to search and retrieve data and/or services. Queries are done through free text search. Visualization of ontologies should be possible and flexible on the amount of detail viewed depending on user needs.
- It should allow for two actors, the service provider and the user. The user in the use case is the administrator, while the service provider is the Meteorological stations forming the Meteorological Agency.

Service providers should be able able to publish data and/or services and their metadata. Users should be able to to search for and retrieve geospatial data and services from the catalogue services.

Guidelines for sharing and dissemination of information will be availed. Metadata should be created according to metadata standards, and service providers should adhere to the guidelines when publishing the data/services and semantic metadata descriptions.

4.3.1 Concepts of the MetOntology (MetOnto)

The application ontology for the use case was created basing on terminology used in forecasting of severe weather events and as agreed by the WMO. The major concepts captured here are:

- Storm
- StormType
- StormLocation
- Prediction

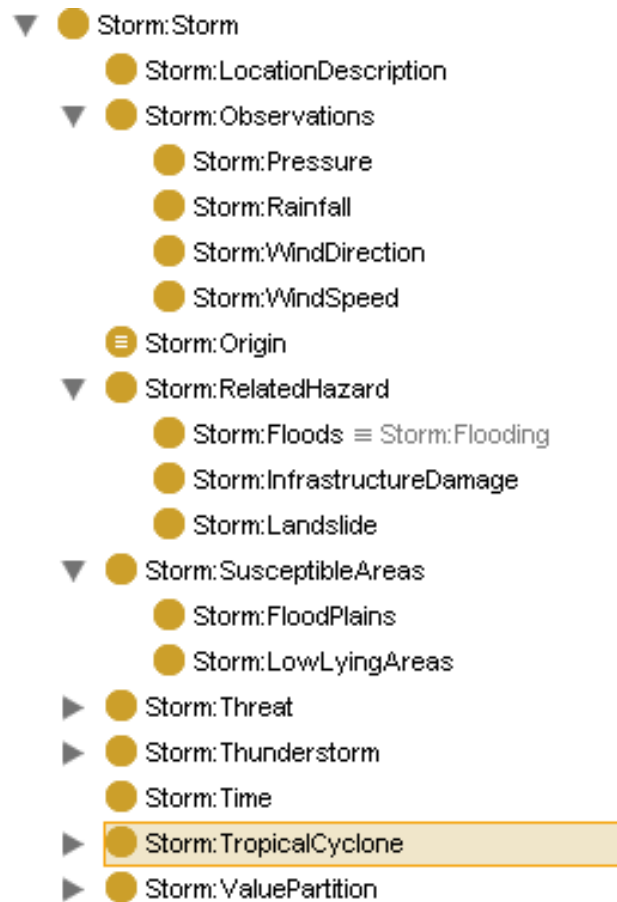


Figure 4.1: MetOnto Concept overview

- RelatedHazards
- Observations
- Origin
- Threat

An iterative process was used to develop the MetOnto as described in Section 3.4.5. An overview of the MetOnto ontology developed is shown, in part, in Figure 4.1. Sometimes users want to have an overview of an ontology and the Protégé ontology editor is capable of providing an overview of the concepts.

Besides having a general view of the concepts involved in an ontology, users sometimes want to see more detail concerning the ontology. The MetOnto concepts were further developed according to superclass-subclass relationship, for example the class *Observations* consists of subclasses *rainfall*, *windspeed*, *direction* and others. The *subClass* *windDirection* has instances *North*, *Northeast*, *East*, *Southeast*, *South*, *Southwest*, *West* and *Northwest*. Part of the MetOnto

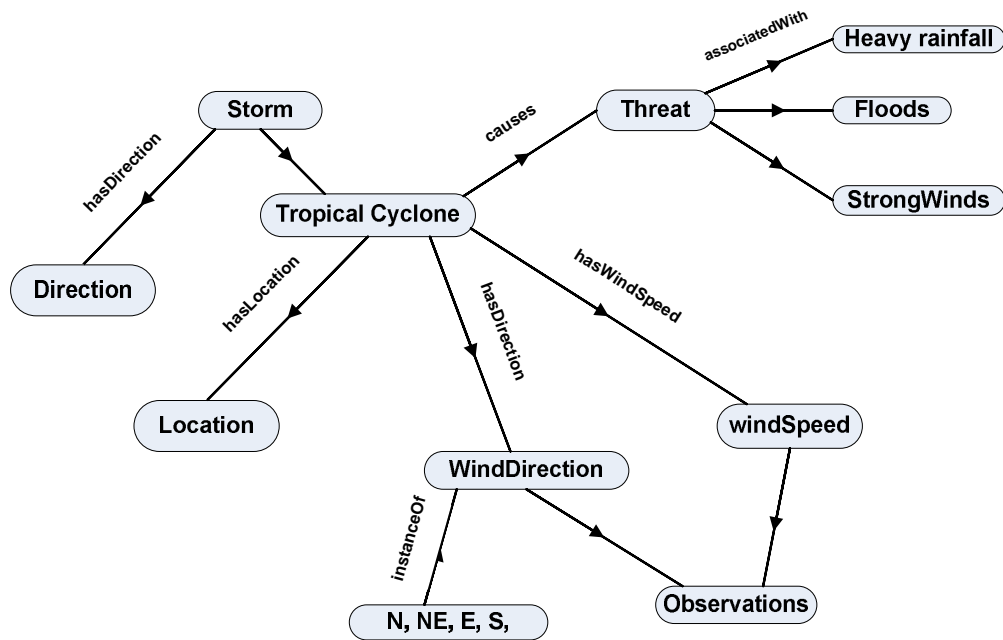


Figure 4.2: MetOnto: Detailed view

with some level of detail is shown in Figure 4.2. By way of example we give details of the subclass *Tropical Cyclone*, its relationships with other subclasses and instances. This kind of visualization is made available in Geonetwork when required as shown in Section 5.3. Part of the OWL code for the MetOnto is given in Appendix A.

4.3.2 Development of Semantic Annotations

In the development of semantic annotations, the following requirements were considered.

- Semantic annotations should be defined by domain experts during modeling of ontologies.
- Users should be able to understand the semantic information they deal with.
- The semantic annotations should be derived from appropriate domain ontologies

In developing semantic annotation questions regarding to what objects, and actions on the domain ontologies they refer to were addressed.

4.4 System Architecture

The proposed application is based on a SOA approach where services, interoperability and loose coupling are the main technical concepts. Interoperabil-

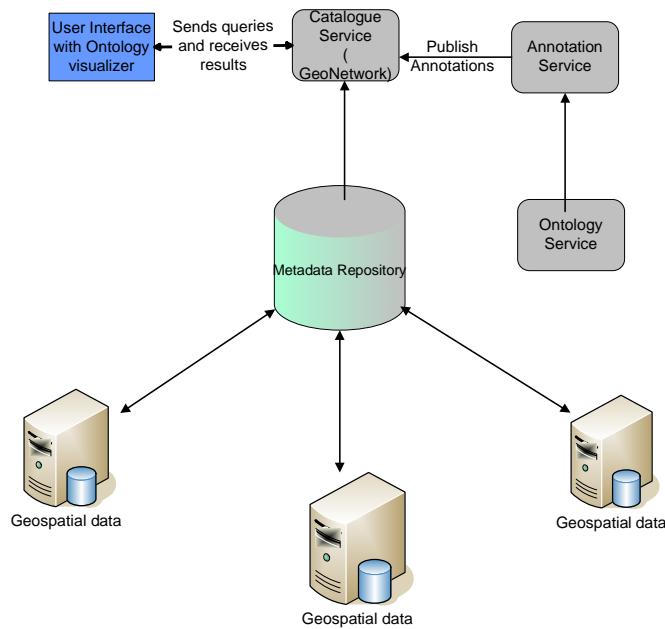


Figure 4.3: Integrating Ontologies into GeoNetwork

ity allows for a functional distributed environment for the services and loose-coupling reduces dependencies. We adopt the GN architecture however with additional components. An ontology service and annotation service form part of the proposed new GN CSW as a first solution. The second option looks at an additional catalogue services (ebRIM) on top of the GN. The user interface will include an ontology visualizer. Figure 4.3 and Figure 4.4 illustrate the proposal of how semantic web technologies can be integrated into GeoNetwork and GeoNetwork-ebRIM respectively.

4.4.1 Semantically enabled GeoNetwork

The functions of the annotation service and the ontology service are as described below.

- The ontology service allows the development of ontologies as outlined in Section 4.3.1. The ontology concepts are used in the process of developing semantic annotations.
- The annotation service’s goal is to link the ontology concepts to metadata descriptions which refer to different kinds of geospatial data. These might be graphs, maps or images. The annotation method employed in the development of semantic annotations should be as uniform as possible considering all kinds of content, but flexible enough to allow exploitation of the semantics of each content [AF07].

Within the annotation services, annotation procedures are defined for the different kinds of geospatial datasources and the level of semantic an-

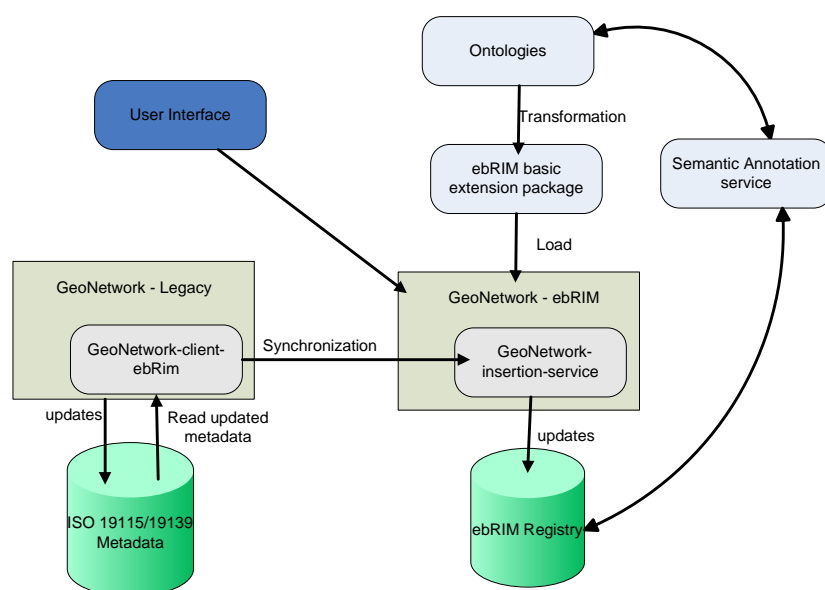


Figure 4.4: Integrating Ontologies into GN-ebRIM

notation being used as discussed in Section 3.3.2. For the purpose of this research we used level 1, semantic annotation of metadata. The procedure is stored as a workflow. Each workflow consists of annotation schema to be used, the ontology concepts describing the data and the steps on execution and storage of generated annotations. The schema are metadata fields that will be used in the annotation process. Once the annotations are generated and linked to ontology concepts they are published and stored separately. Storage of semantic annotations in current GN is not possible because OWL format is not compatible with GN.

4.4.2 System architecture in GN-ebRIM

In this section we look at how to integrate ontologies and semantic annotations in GN-ebRIM. Details about the functionality of GN-ebRIM are explained in Section 3.3. The basic extension package within the ebRIM architecture allows for customization of the CSW such that additions can be done. Such additions allow new additional types of extrinsic objects and external links, associations that link registry objects and classification schemes or classification nodes. We take advantage of this extension package to include ontologies in the CSW-ebRIM profile thus capturing semantics of concepts and at the same time enhancing the search functionality within the geo catalogue service. Figure 4.4 below shows the architecture of semantically enhanced GN-ebRIM catalogue services.

After developing the ontologies they are transformed into a format acceptable within ebRIM registries. All elements relating to ontologies are identified and transformed into ebRIM using XSLT so as to map them in the basic extension package taking. As such classes, subclasses and their relationships have

Table 4.1: OWL elements in ebRIM registries

OWL	ebRIM term
ontology	ClassificationSchema
class	ClassificationNode
subClassOf	subClassOf
property	association
range	sourceobject
domain	targetObject
annotation	Classification

to be explicitly defined. Table 4.1 shows some of the terminology in OWL constructs and element to which they are mapped in the ebRIM registry.

A transformation code identifies the parentClass, the Association, the source object being mapped and the target class to which it goes in ebRim registries.

```

<xsl:variable name="parentClassName" select="..
  /rdfs:subClassOf/owl:Class/@rdf:ID" />
<xsl:if test="string($parentClassName)">
<xsl:variable name="parentClassID" select=
"concat('urn:owl:severe-weather:ebRim:ObjectType:',
  $parentClassName)" />
<xsl:variable name="subClassAssociationID" select=
"concat('urn:owl:def:ebRIM-AssociationType:IsSubClassOf-', $ID, '-',
  $parentClassName)" />
<rim:Association id="{ $subClassAssociationID}"
sourceObject="{ $ID}"
associationType="{ $isSubClassOfAssociationType}"
targetObject="{ $parentClassID}" />
</xsl:if>

```

The mapping code given above was used to transform the MetOnto developed for the use case of this study. subClass *Windspeed* is treated as the source and the class *Observation* as the target class to which it should be registered under ClassificationNode *SevereWeatherEvent* and the ClassificationScheme being *SevereWeather* and the result of the transformation is given below.

```

<rim:Association id="urn:owl:def:ebRIM-AssociationType:
IsSubClassOf-windSpeed-Observations" sourceObject="windSpeed"
  associationType="urn:owl:def:ebRIM-AssociationType:IsSubClassOf"
  targetObject="urn:owl:severe-weather:ebRim:ObjectType:Observations"/>

<rim:ClassificationNode code="Observations" objectType=
"urn:owl:severe-weather:ebRim:ObjectType:Observations"
lid="urn:owl:severe-weather:ebRim:ObjectType:Observations"

```

```
id="urn:owl:severe-weather:ebRIM:ObjectType:Observations"  
parent="urn:owl:def:ebRIM-ClassificationScheme:SevereWeather">
```

Semantic descriptions of metadata content are linked to the ontologies in the annotation service. In this case each ontology has a metadata description, indicating its URI, creation date and associated keywords and these form the annotation schema within the annotation service. In GN-ebRIM the semantic annotations can be stored in the ebRIM repository, which is not possible in GN

4.5 Use Case Development

In the use case GN is used for accessing information for Severe Weather Information for Situation Awareness

Description

The use case selected in for Disaster Management Unit, which is a national body overseeing all disaster issues and making frantic efforts to educate people on how to mitigate the impact of hazards that affect their day to day living. This is in tandem with the efforts being made by ECHO in promoting disaster preparedness as part of an overall Commission to Disaster Prevention and Preparedness approach to reduce vulnerability and exposure of people to risks and disasters while reducing the economic costs of such disasters. Many projects undertaken so far have created avenues for the sharing of knowledge and experiences among non-government organizations (NGOs) and national disaster management offices NDMO. ECHO also creates awareness amongst NGO and NDMO partners for the need to network at the national level to improve coordination and facilitate the sharing of information part of which is geoinformation. Much of this background information has already been given in Section 4.2.

A holistic approach is required when dealing with geohazards. While the Meteorological Agency is the main service giving realtime information, satellite images are being provided every 15mins from Meteosat Second Generation (MSG) with derived products such as wind speeds, rainfall estimate. The Hydrology Department provide flooding information and they measure rainfall runoff. The services/data are available in a geo-catalogue. Availability of geospatial information is quite crucial in hazard prone areas as agencies have to locate regions affected for them to be able to respond to situations and to undertake infrastructure reconstruction in the aftermath of a disaster. The DMU in collaboration with Meteorological agency has to facilitate the sharing of the information with its stakeholder agencies and disseminate it to grassroots levels. Quite often the information may be available on the web but not so easily accessible due to the way the information has been constrained and poor search mechanisms currently in use. The user needs to know which data and services are available and how to access them.

The best way of sharing the information is to use state of the art technology, such as Spatial Web Portals (SWP). SWP are often used as search engines by the user communities in order to find geo-web resources and geoinformation.

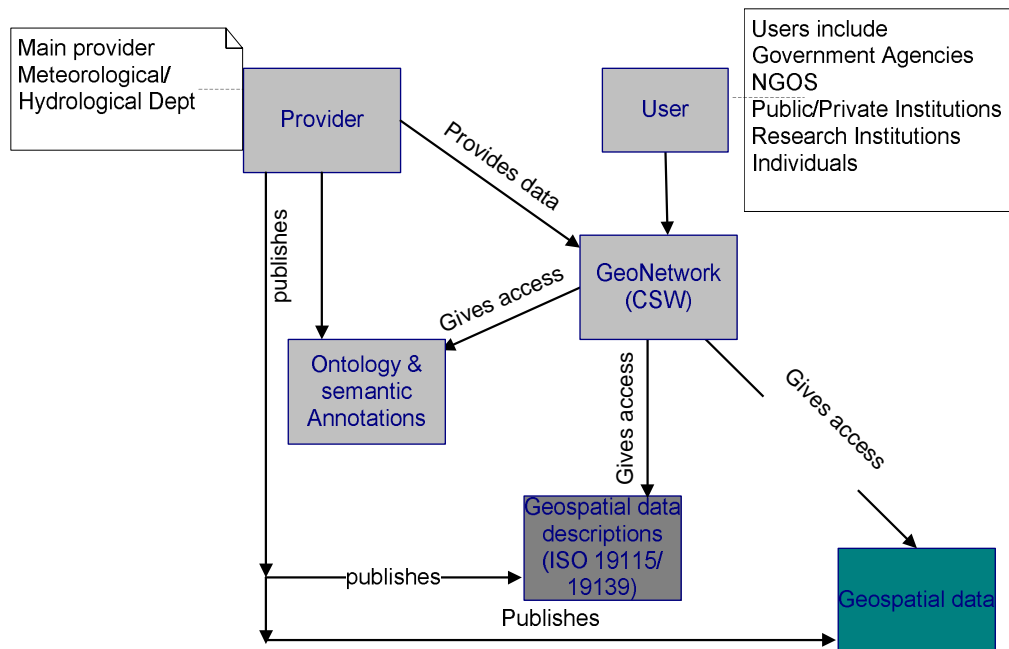


Figure 4.5: Publishing Data in GeoNetwork

Users can have access to the metadata to services available through the SWP. The user can also refer to the meaning (semantics) of concepts (ontologies) and semantic annotations used to check if it meets their needs.

Current search mechanisms have been based on key words only without using the semantics and hierarchical nature of concepts. The research shows a way of improving search mechanism in a distributed environment through the use of ontologies and semantic annotations. They are the basis on which datasets and services are described in this research.

GN is used as the state of art technology for the discovery of data and web services. Users should be able to search for geo data and services provided by the Meteorological Agency and other stakeholder institutions. They should be able to access the metadata thus assessing if the data are usable. Besides, the user can refer to the concepts and semantic annotations to search for the data and services with high precision. Below we describe the processes from registering services/data in GN Catalogue service to retrieval of services/data.

Publish Data

In our use case the major provider of the required services is the Meteorological/Hydrological Agency. How data is registered and published in GN and GN-eBRIM is detailed below. The use case diagram below shows how the provider make their data and services available within the GN. In Figure 4.5 services/data are registered, however the service provider has to link the metadata to concepts in the MetOnto ontology.

Within GN, metadata is published according to ISO 19115 and 19139 standards. The provider has to do more than provide data/service descriptions. First

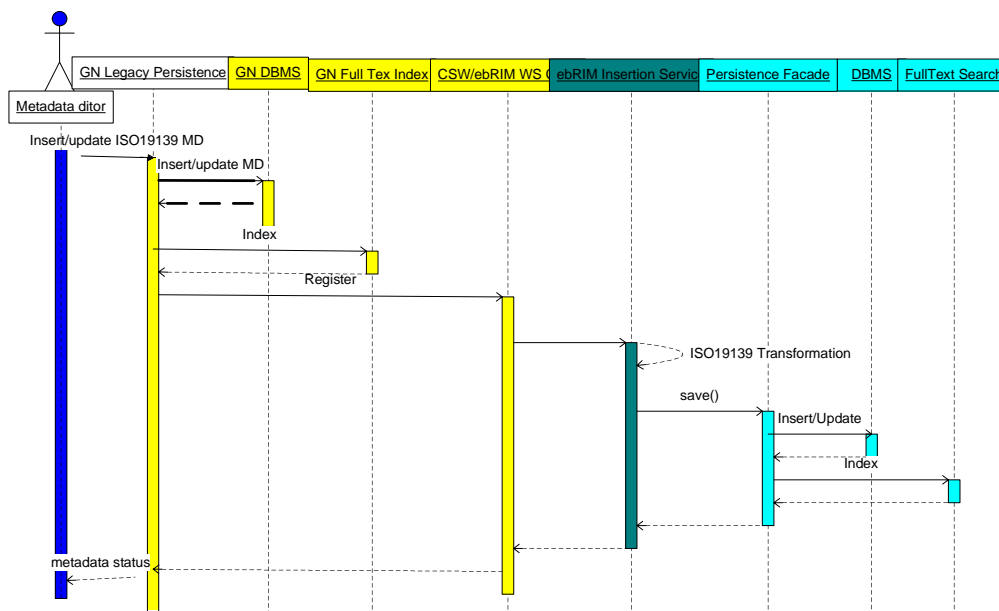


Figure 4.6: Metadata Registration in GeoNetwork-ebRIM

they have to decide on which data should be available for the external user community. Next they have to create metadata descriptions for their data/services as well as the ontology concepts. The provider also have to define annotation procedures for the different geospatial data they have which are stored as workflows for further reuse. Each ontology has a metadata description, indicating its URI, creation date and associated keywords and these form the annotation schema within the annotation service. Each annotation workflow depends on the content and should be understood by the users. The annotations are stored separately but in a manner that they can be referenced to every time a query is executed.

In GN-ebRIM the procedure for registering and publishing resources is the same as for GN, however there are additions. The metadata besides being updated in the GeoNetwork it is automatically synchronized and updated in the ebRIM repository according to ISO 19139 standards as already discussed in Section 2.5. GN-ebRIM has its own database and acts as a catalogue services on top of the general GN. Ontologies and semantic annotations are added to the database management service (DBMS) through the basic extension package after being mapped to ebRIM registries as explained in Section 4.4.2. The sequence of adding metadata in GN-ebRIM are given in the sequence diagram in Figure 4.6

The actors involved at this stage are shown in the Table 4.2. The proper setup of this stage is quite crucial for the system to work well and especially to meet the needs of the users. Functional roles of the provider should be explicitly defined and guidelines made available on publishing data/services

Table 4.2: Top Level use case

Actor	Top Level Use cases
User and provider	Meteorological/Hydrological Network
	other institutions forming the SDI network

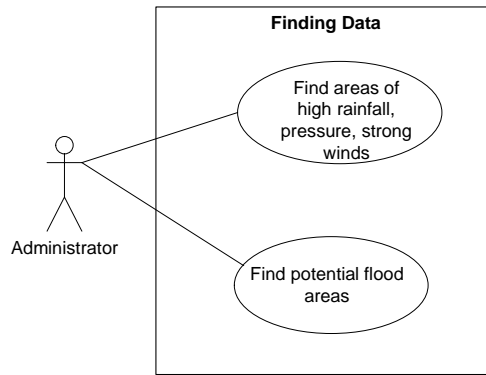


Figure 4.7: Use cases for the Case Study

Search Data/Services

The user, in this case the administrator has to know which data/services are available to solve the problem at hand. In order to find the data available the administrator searches in GN portal service. The search mechanism though keyword based, however it makes reference underlying concepts (ontologies), their relationships and semantic annotations. Semantic annotation has been done at Metadata level. Figure 4.7 gives an illustration of the use case in the search for data/services.

The user first has to search for all records which meet the search criteria, by a query that executes as a GetRecords query. Having returned the result, the user can send a GetRecordsById query to get data for the resources returned in the first query. The user wants to find stations with highest rainfall and windspeeds, and from there find potentially flooded areas. The actors involved are as given in Table 4.3

The user sends a query to the GN CSW using a keyword such as *rainfall*. Within the catalogue services the query searches within the data/service descriptions (metadata) and reference is made to the semantic annotation repository. The sequence of searching data in GN in Figure 4.8

In GN-ebRIM the search query goes through several steps. The request, like in GN is send in XML format to the ebRIM CSW then through the filter search engine compliant with OGC filters. The query is then send to the Database Management System (DBMS) in which ontologies and semantic annotations are kept. So the query references to the meanings of semantic descriptions and

Table 4.3: Sub level use cases

Actor	Sub level Use cases
Provider	Publish Data/Services, Metadata, Ontologies and Semantic Annotations
User/provider	Search data/Services, reference to ontologies and semantic annotations
User/provider	Retrieve and evaluate data/services for fitness for purpose

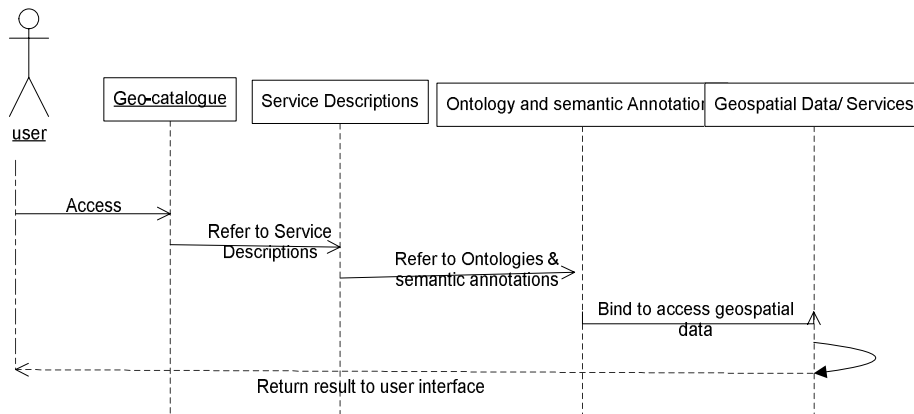


Figure 4.8: Sequence diagram - Search Data/Services

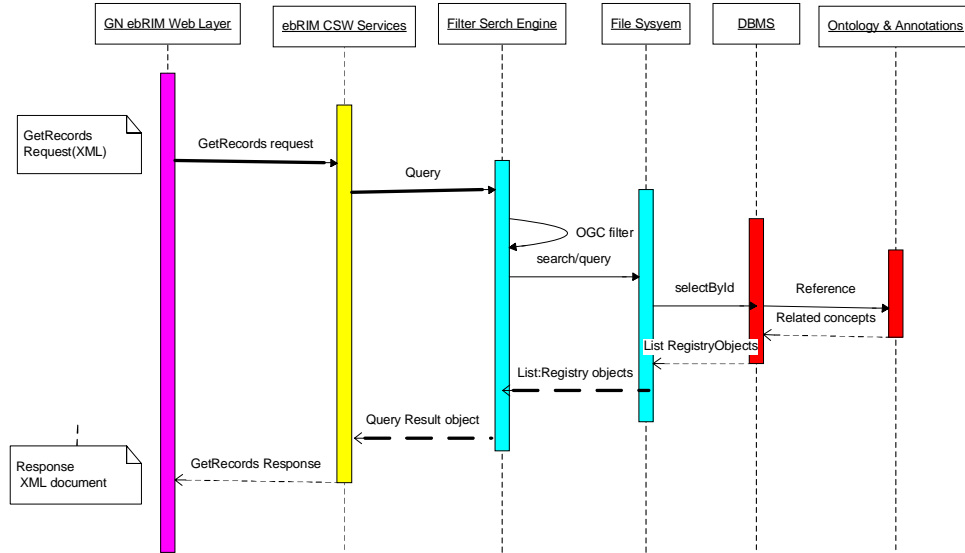


Figure 4.9: Sequence diagram - Query execution: Search Data/Services in GNebrIM

the results with related concepts are returned. The result is returned to the user as a another XML document. Having evaluated the results, a user can then send another query which allows for retrieval of actual records, send as GetrecordsById. Figure 4.9 shows the sequence of the steps which the query goes through until a response is given

Retrieve Data/Services

When the user locates the data/service he requires, he retrieves them. He has to select the data/service, visualize and evaluate the data for fitness for the purpose for which it is required. Figure 4.10 shows the use case diagram with an illustration of how retrieval of data/services is done.

Use case example: Finding Location of stations with within 20km of cyclone track and flooded areas

Situation awareness plays an important part in decision making in view of severe weather events. An administrator wants to find potential worst affected areas following a recent cyclone activity. Information from the Meteorological/Hydrological Dept says that areas within the periphery of the cyclone are the ones most affected but not always the center of the cyclone.

The determination of the track of a cyclone, requires knowledge of where the eye (core of cyclone) is. Locating these areas will require data that is on images together with observation data. Locations of lowest pressure form the core of the cyclone while the periphery is characterized by heavy rain and strong winds. The track is then identified as a line string however with a buffer of 20km around it. These data sets have to be available within the catalogue

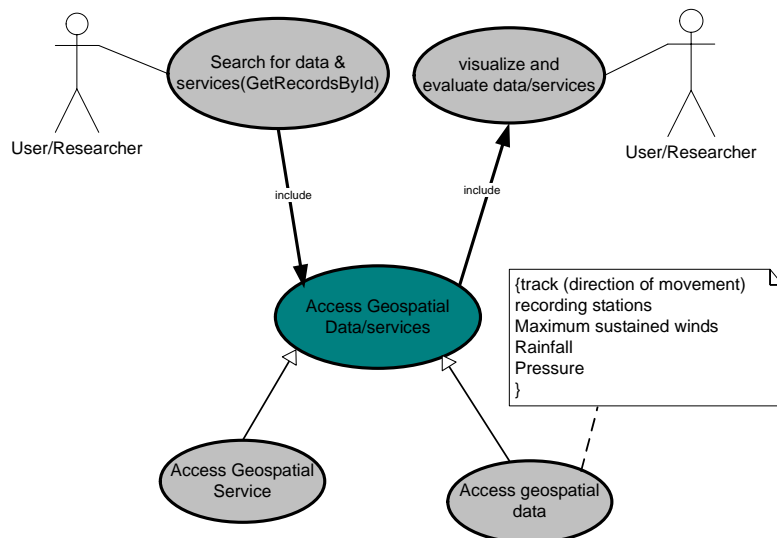


Figure 4.10: Sub-level use case diagrams for retrieving data/services

service as well as information on threshold what strong winds are. Potential areas to be flooded are low lying areas and flood plains. However constraints have to be made available defining these areas and linking them to heavy rainfall. Other potential areas would be those downstream of where heavy rainfall is experienced. Different spatial data sets are required for this information to be available to the administrator. The ontology used in this use case is not exhaustive to cover all the areas of interest but if ontologies from the other nodes within the network are made available in the catalogue services, during the semantic annotation process, the workflows modeled allow the annotation schema to be filled with the right ontology concepts from other themes. Other themes like those from hydrology, topography could also be included. Spatial reasoners have to be used to find all areas within 20km of the track of the cyclone.

In order to obtain the data, the administrator use GN and does a free text search query to obtain all required result. The activity diagram for the use cases is as shown in Figure 4.11. The service provider, has registered the services and linked the concepts using metadata as follows.

```

<WMS_Capabilities version="1.3.0">
<Service>
<Name>WMS</Name>
  <Title> Severe Weather Situation Awareness </Title>
  <KeywordList>
<Keyword vocabulary=http://www.semanticweb.org/
ontologies/2009/11/Storm.ow#>Stormtype
<Keyword vocabulary=http://www.semanticweb.org/
ontologies/2009/11/Storm.ow#>TropicalCyclone
</Keyword>
    
```

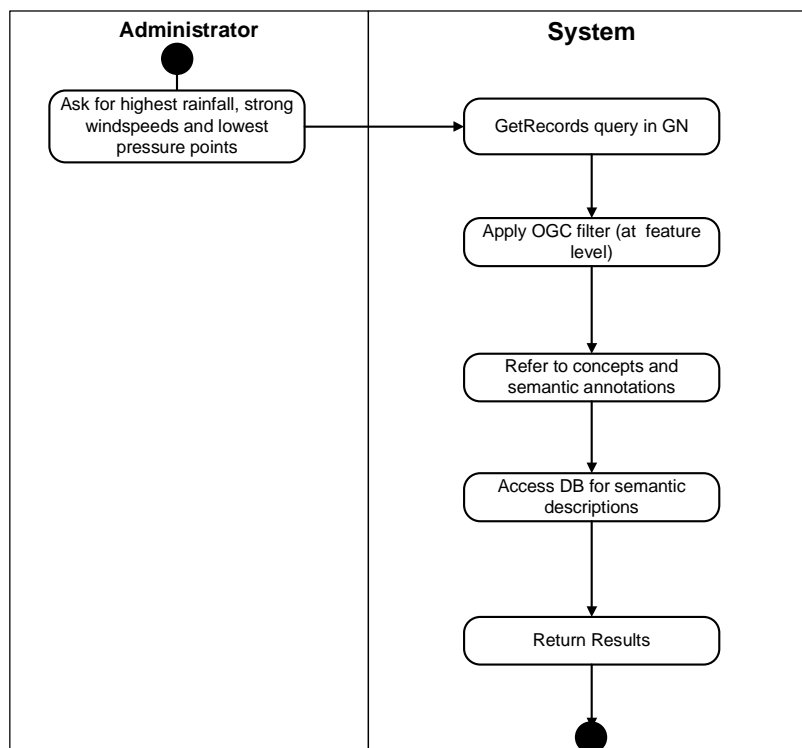


Figure 4.11: Activity diagram for the use case FindLocations

```

<Keyword vocabulary=http://www.semanticweb.org/
  ontologies/2009/11/Storm.owl#>Observations
<Keyword vocabulary=http://www.semanticweb.org/
  ontologies/2009/11/Storm.owl#>Prediction
<Keyword vocabulary=http://www.semanticweb.org/
  ontologies/2009/11/Storm.owl#>Threat
</Keyword>
  </KeywordList>
  
```

Observations has subClasses *rainfall*, *windspeed* and others. The administrator has no idea that rainfall is not registered anywhere in the metadata but GN is able to retrieve the records for rainfall because of the semantic registration by the provider. Windspeed and pressure are also subsumed in the class observations. The administrator can search using a keyword such as *rainfall* or *windspeed*. The relationship to **Observations** is represented in an ontology visualizer. In Section 5.2 and 5.3 we discuss the results.

To satisfy all the needs of the administrator, a nested query has to be formulated. Metadata for services from the Hydrology Dept has been available in GN and the ontology defining low lying areas and flood plains is integrated with the MetOnto. However in this research the Hydrology ontology is assumed to already exist and integrated with the MetOnto.

Step 1: Find records

The administrator searches for all stations with low pressure. The aim of this kind of query is to provide specific data per station. Since its data following a cyclone event, points give the track of the cyclone. Other station location should fall within 20km of lowest pressure point stations.

Step 2: Applying filter

In order to get locations within 20km the query send should be consistent with the Web Feature Service (WFS). These features will have been semantically annotated using feature type schema as outlined in section 3.3.2. To find all locations within 20km of a point requires some spatial reasoning and OGC Filters have to be used. An OGC filter is applied to the request as follows.

```
{<Filter>
  <DWithin>
    <PropertyName>Geometry</PropertyName>
    <gml:Point>
      <gml:coordinates>(StationCoordinates)</gml:coordinates>
    </gml:Point>
    <Distance units='km'>20</Distance>
  </DWithin>
</Filter>}
```

In a truly semantic system, a feature ontology is formed in OWL allowing for easy integration with the knowledge base [KHD05]. This allows the building of a filter for a feature request as OWL instance data and is represented as follows. Such kind of queries can be done in GN-ebRIM given the basic extension package that allows tailored products according to user needs.

```
{<filter:DWithin rdf:ID=featuresWithinRadius">
  <filter:propertyName rdf:resource="&gml;#location" />
  <filter:measuredFromGeometry
    rdf:resource="#StationCoordinates" />
  <filter:distance>
    <units:Miles>
      <units:value>20</units:value>
    </units:km>
  </filter:distance>
</filter:DWithin>
<gml:Point rdf:ID="StationCoordinates">

</gml:Point> }
```

Step 3: Reference to Semantic annotations

Semantic annotations provide more meaning to high rainfall and strong winds definition. The hierarchy has the concepts, *stationlocation* and *observations*. Instances of windspeed, rainfall and pressure provide the data required. Thresh-

olds defined for these concepts are part of the workflow in the semantic annotation services for annotating these ontology concepts to their metadata resources. More on the application functionality is given in Chapter 5.

Step 4: Access Database

The data is available in database (PostgreSQL), and can be accessed through a geoserver.

Step 5: Return Results

The query returns results meeting the criteria. The user interface allows display of linked concepts and their properties if required, as well as map content of retrieved data. More information on the user interface is given in section 5.3

In the CSW eBRIM a Filter.xsd schema is defined in which a declaration of conceptRefType is made to explicitly reference the concept using the ontology URI and concept name. In the schema an operator *ClassifiedAs* is used to match records which are subject to classification. The operator used in CSW queries helps in discovering semantically annotated resources at data model. An example of usage of *classifiesAs* operator is as given below.

```
<csw:GetRecords xmlns:csw="http://www.opengis.net/cat/csw"

  <csw:Query typeName="ExtrinsicObject">
    <csw:ElementName>/ExtrinsicObject</csw:ElementName>
    <csw:Constraint version="1.0.0"><ogc:Filter>
      <ogc:classifiedAs>
        <ogc:PropertyName>/ExtrinsicObject</ogc:PropertyName>
        <ogc:Literal>
          http://www.semanticweb.org/
          ontologies/2009/11/Storm.ow#windspeed
        </ogc:Literal>
      </ogc:classifiedAs>
    </ogc:Filter>
  </csw:Constraint>
</csw:Query>
</csw:GetRecords>
```

The complete solution to the administrator's needs requires nested query handling within GN.

1. Identify a station with low pressure where low pressure is < 990mb.
2. Identifying stations where rainfall is high (> 50mm) and wind speed is high (> 47km/hr)
3. Computing the distance between the two stations

Defining thresholds addresses the ambiguities that arise in definitions of low and high if left to the user. This process is iterative. Spatial reasoning would

Algorithm 1: *Potentially damaged hard hit areas*

```
if Pressure < 990mb then  
  Retrieve StationID1  
  if Rainfall > 50mm AND WindSpeed > 47km/hr then  
    Retrieve StationID2  
  end if  
  calculate distance between StaionID1 AND StationID2  
end if
```

require some geometric computation to fulfill the requirement of *within 20km*. This whole process is given in the algorithm below.

As user needs become complex, methods that address the complexity are required. The tools used in the development of the ontology allow reasoning about terminologies and axioms and not spatial reasoning.

Chapter 5

Implementing Ontologies in GeoNetwork

The implementation of ontologies in GeoNetwork is through the additional components as illustrated in Figure 4.3. A SOA approach was adopted to allow interoperability in a distributed environment. Though the focus in the research was on the Meteorological Agency, other players are involved in the DMU such as Hydrology Dept, National Early Warning Unit, Sub-Aqua among others. This chapter discusses the implementation of semantic web technologies in GeoNetwork. In Section 5.1, the function of the annotation services is discussed with some level of detail. Section 5.1 details the processes within the annotation service. In Section 5.2 we explain the outlook of the proposed new user interface. In Section 5.3 visualization of results in the proposed new GeoNetwork is given and compared to the current one. In Section 5.4 we discuss the tools used in the research and Section 5.5 gives the summary to the chapter.

5.1 Components of the Annotation Service

The ontology service and annotation service form extra components in the semantically enabled GeoNetwork environment. The ontology service creates an environment for developing ontologies, in this case application and feature ontologies. The semantic annotation service links different kinds of geospatial data, which could be maps or satellite images to their metadata. Figure 5.1 shows the processes happening within the annotation service.

The semantic annotation is composed of metadata labels and annotation content. The metadata labels include fields such as description, keywords, period, location, pressure pattern and type of cyclone information. The ontology terms to be used in the annotation are specified and the content to be annotated is known. Provenance data such as the coordinates of location under consideration and originator of information. The pressure pattern is obtained for the location is obtained and other stations with similar pattern are obtained. The labels in the schema are filled with ontology terms and these terms fields are given a semantic description.

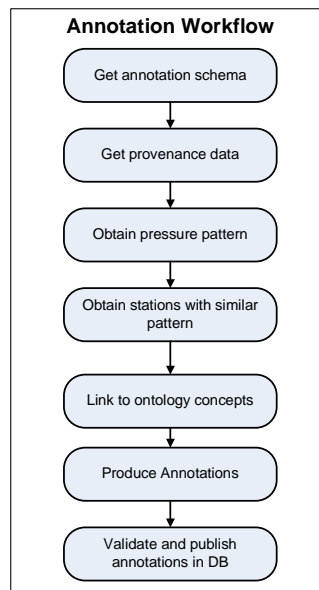


Figure 5.1: Workflow to annotate stations with low pressure

The metadata labels are originally in natural language but the use of ontology terms guarantee uniqueness when each field is associated with a concept that semantically represent their content [MdSM09]. The URL of the ontology used in the annotation was fed into the system where the system extracts the URI of all concepts in the ontology. The URIs are used to fill the annotation fields defined in the schema. The URI of all the chosen concepts and the associated annotated fields are saved in the DB.

Metadata following ISO 19115 standards is compatible with XML. Thus semantic annotations which are RDF/XML are stored in the same DB. Querying this data is achieved by use of XPath or XQuery statements and retrieval is possible through use of the Document Object Model (DOM) trees. DOM gives a standard way of manipulating XML documents which are presented in a tree-like structure.

5.2 User Interface

The GN use interface provides an abstract interface which support the discovery and access of geospatial information. The user interface has been implemented in such a way that the user sends query to the GN CSW using free text search. The proposed ontology visualizer enables the hierarchy of the related concepts to be displayed such that the search *rainfall* returns part of detailed view in Figure 4.2. This allows the user to navigate about the concepts and find a suitable search term.



Figure 5.2: Search by keyword in GN

5.3 Search and Visualization of the results in GN

To locate all stations recording rainfall, the first guess of the administrator would be to use the keyword *rainfall*. The query is executed and through keyword matching results are returned. The result is as shown in Figure 5.2

The current version of GN sends and receives in HTTP format. The search for rainfall yielded the result in 5.2 but the administrator has difficulties of getting results where rainfall is not directly mentioned in the metadata. A node that uses precipitation which is an equivalent of rainfall in its metadata is missed in the search.

The administrator wants to find out the direction of the cyclone for the purposes of evacuation. He types *cyclone direction*, but though this information is available, he returns nil results as shown in Figure 5.3

The results display the frustration users face when looking for web services in catalogues when they have to try different keywords to get the desired results. In the ontology environment though search is by keywords, the presence of semantic annotations assists the user in query formulation and results are therefore obtained much easier than in an environment where information is not semantically defined. The administrator still uses *rainfall* in his search query. Rainfall is subsumed by Observations. Since *observations* has been annotated in the metadata, through inference, it is possible to return the right information.

The ontology visualizer displays the hierarchy of concepts related to rainfall. The administrator is able to navigate about the hierarchy. Even if he had used precipitation in the search query, he would still get results, because precipitation is subsumed by rainfall. He is able to get direction of the cyclone from the semantic annotation done and the hierarchy helps him distinguish between *wind direction* and *storm track*. A search for *direction* would normally

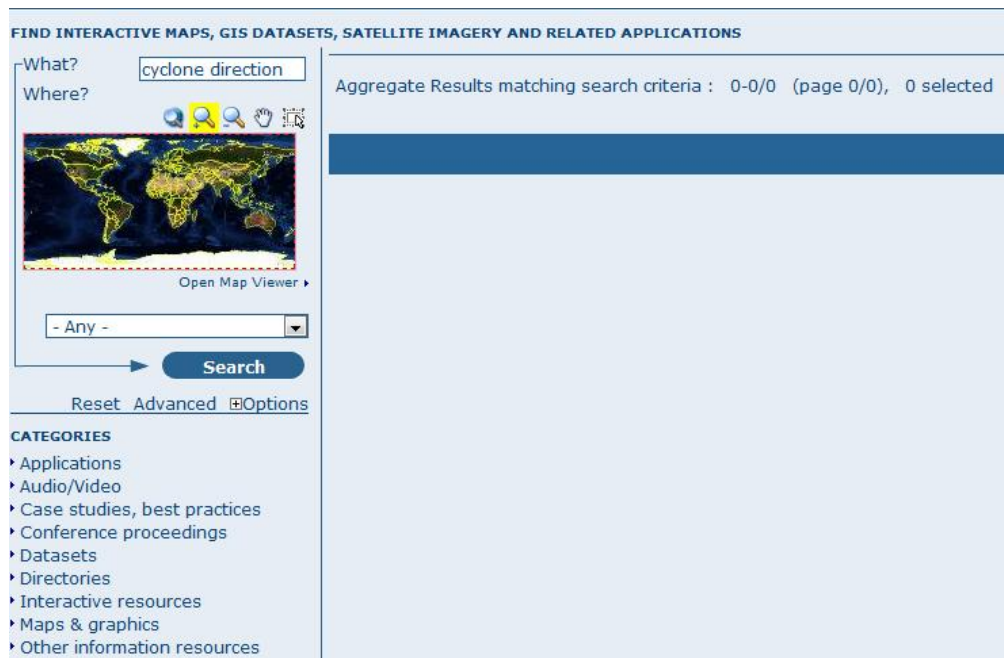


Figure 5.3: Search yields no matches

yield no results because the service provider makes no mention of this word in their metadata registration. In the semantic annotation environment, the result returns all related concepts displayed in the visualizer. Navigating about the concepts helps the user formulate a better query, since the result will give insight into which direction the administrator is interested in *winddirection* or *stormdirection*. Figure 5.4 shows the hierarchy of concepts displayed in GN

The method of ontology visualization depends on the amount of detail required by the user, level of annotation and storage capability of the geo-catalogue. In section 3.2.6 different ontology visualizations techniques are given in detail. Any visualization method chosen should be flexible enough to allow a general overview or detailed view of concepts.

Three ways of potentially introducing ontologies and semantic annotations in GN were identified as follows.

1. *Linking keywords to concepts in XML file*: This utilizes the `getCapabilities` document.
2. *Ontologies stored in a geoserver*: The ontology is stored separately and a link is provided on the GN interface. A user can click on the link to access a static structure of the ontology. So far tools for developing ontologies do not allow import on ontologies into GN. An ontology browser can be given as link within GN, where the administrator can browse through the list of classes, subclasses and relationships (properties) instead of leaving it to the user to think of one keyword after the other. A click on the link on GN interface produces the ontology browser as shown in Figure 5.5.

The screenshot shows a search interface for 'rainfall' in GeoNetwork. The search results include a metadata entry for 'RECENT CYCLONE ACTIVITY' with an abstract and keywords. Below the search results is an 'Ontology Visualizer' showing a network of concepts. The concepts are: Storm, Observations, WindDirection, Rainfall, Windspeed, Pressure, Location, Stormtrack, and PrecipitationLevel. The relationships are: Storm hasDirection direction; Storm hasObservations Observations; Observations isAnObservation Rainfall; Observations isAnObservation Windspeed; Observations isAnObservation Pressure; Observations isAnObservation PrecipitationLevel; Location annotationlink Stormtrack; Stormtrack annotationlink Pressure; WindDirection annotationlink Stormtrack; WindDirection annotationlink Storm; WindDirection annotationlink Observations; Pressure annotationlink Stormtrack; Pressure annotationlink Observations; Rainfall annotationlink Observations; Windspeed annotationlink Observations; PrecipitationLevel annotationlink Rainfall.

Figure 5.4: Proposed Semantic Search in GN

The screenshot shows an 'Ontology Browser' interface. On the left, there is a 'Contents' section with a list of items: SevereWeather, All Resources, All Classes (24), All Object Properties (11), All Data Properties (1), and All Individuals (3). Below this is a list of 'All Classes (25)' including Thing, Buildings, CyclonicMotion, Damage, DestructiveCore, Flooding, Floods, HighRainfall, Hurricane, Landslide, Lightning, Origin, Pipelines, Roads, Storm, StrongWinds, Threat, Thunder, ThunderStorm, Tide, and TropicalCyclone. The main area displays details for the 'Class: HighRainfall' with the URI <http://www.owl-ontologies.com/SevereWeather.owl#HighRainfall>. It shows an 'Asserted Class Hierarchy' where HighRainfall is a subclass of Threat, which is a subclass of Storm, which is a subclass of Thing. It also lists 'Superclasses (2)' as Threat and 'Usage (2)' with examples like 'Hurricane ? associatedWith some (Floods and HighRainfall and StrongWinds)'.

Figure 5.5: Ontology Browser

3. *Ontologies as Extension Package in ebRIM*: Ontologies can be stored directly into GN-ebRIM through the basic extension, so far viewed as the best option. Ontologies and Semantic annotations are stored directly in the ebRIM repository.

The tools used in this research as are discussed in brief in the following section.

5.4 Tools and techniques used

This section discusses the tools used in this thesis for ontology development.

Protégé: is a free and open source ontology editor which is java based. It allows for OWL-based ontology modeling and inferencing as well as to edit OWL files and databases. Being extensible with several, Protégé OWL plugin is one of them [KFNM04]. Visualization and reasoning is possible using the plugin. RDF(S), OWL Lite and OWL DL are supported in the OWL plugin as well as aprts of OWL Full. In this thesis, Protégé 3.4.1 was most used together with its visualization plugins, OWLViz, Ontoviz, Jamabalaya, and OWLDoc for production of the concept browser. Java script libraries were also used for creating some visualizers such as the hypertree.

5.4.1 OWLViz, Ontoviz plugins and Jambalaya

Both plugins allow visualization of ontologies. Classes, individuals and properties can be visualized using this plugins. One can actually visualize a particular class and its individuals (also called instances). Both plugins were used in this research. An example of visualization of ontologies using Ontoviz is shown in fig 3.7. OWLViz provides a treeview of the hierarchy of concepts . Nodes represent concepts with restricted concepts appearing as coloured nodes. The two plugins give a visualization of whole ontology and class properties. Jambalaya is another OWL plugin for visualization and fig 3.8 shows display of concepts in Jambalaya.

5.4.2 Pellet Reasoner

When modeling ontologies, Protégé has a function for reasoning on the ontology. One can classify the taxonomy, check for consistency and compute inferred types. All these were used in the thesis in building the MetOnto for sever weather events. Checking consistency returns concepts which have modeled unsatisfactorily. Classifying a taxonomy checks for the unsatisfied concepts as well as subsumption relationships between concepts. Inferred concepts are obtained after executing the *compute inferred type*

5.4.3 OWLDoc plugin

OWLDoc plugin is a Protégé plugin that allows generation of a concept browser in HTML format. For each class, a hierarchy of subclasses is given together with

the subproperties. Each class is also hyperlinked to other concepts to which it is related. An example of a n OWLDOc is given in figure 5.5.

5.4.4 Java Script Libraries

Some java script libraries were used to to develop the hypertree¹ and ontology visualization in Figure 3.4, also ontology browser² and Neon ToolKit³

5.5 Conclusion

The mock results demonstrate that limitations of traditional search mechanisms can be overcome by bringing together geographic standards and semantic web technologies. Visualization of the concept hierarchy assists the user in query formulation and semantic annotation allows discovery of the right information. Even non-experts are able to discover the resources they require through the semantically enabled GN. The method assists service providers to register their services in a manner that they can be discovered. While reasoning about concepts has been dealt with tools used for ontology development, spatial reasoning is still an open issue. Current geo-catalogues such as GNare not able to handle queries such as *within*, *adjacent* and others in as much as they would be handled within databases. GN-ebRIM is proposed a solution allows complex queries as it has a better option of integrating with ontologies and semantic annotations.

¹JIT: <http://thejit.org/>

²JOWL: <http://jowl.ontologyonline.org/>

³NeOn: <http://neon-toolkit.org/wiki>

Chapter 6

Discussion, conclusion and recommendations

6.1 Introduction

Spatial Data infrastructures have created an open environment for sharing resources through the web, yet users have continued to face challenges in discovering the resources due to the inefficient search methods, vocabulary used and poor query formulation. The standards developed such as for metadata registration, have helped overcome syntactic heterogeneities and thus search is limited to keyword match. To overcome this problem, focus has shifted toward the semantic web where information is well defined. In this research we explored ways of bringing together semantic web technologies and geographic standards so as to improve the search functionality in geo-catalogues.

According to the research study, we were able to demonstrate the shortcomings of the search mechanisms based on keywords. This is due to the fact that, registration of metadata does not allow definition of relationships of concepts. Moreover, UDDI used in catalogues achieves syntactic interoperability such that, any search in a geo-catalogue is achieved either through keyword or substring matching. Therefore, keywords return few results, whereas substring matching returns too many results.

We demonstrated that when geographic standards and semantic web technologies (ontologies and annotations) are brought together, the search functionality within geo-catalogues improves. Inasmuch as geospatial catalogues play a pivotal role in discovery of geospatial data and services in distributed environments, they have limitations with regard to the way registration of the services is done. To overcome this limitation, traditional search mechanism need to be augmented with semantic web technologies to improve data and service discovery. The semantic web technologies add meaning to resources.

Ontologies being the cornerstone of semantic web, captures relationships between concepts thus ensuring semantic interoperability in dynamic environments. In the research study we developed an ontology called MetOnto based on severe weather domain. The concepts used came from terms used in forecasting as agreed by WMO. We explored methods of visualization of ontologies

using different techniques as detailed in Section 3.2.6, which give users the freedom to choose the level of detail they intend to view.

We proposed strategies for integrating ontologies and semantic annotation in a geo-catalogue as a proof of concept in which semantic web technologies improve search for data and services complimented by visualization of ontology concepts that represent metadata. Using the MetOnto we demonstrated how semantic annotation could be done at service metadata level by adding pointers to the domain concepts and how the annotations assist users even non-experts in query formulation thus discovering the right information.

We discovered that GN currently is not compatible with OWL, the language used for authoring ontologies, however GN-ebRIM can be customized to handle ontologies and semantic annotations. In the next section we provide answers to the questions given in Section 1.2.2.

6.2 Discussions

In this section the discussion focuses on the findings of the research with respect to the objectives and questions proposed for this research.

1. *How is spatial web search typically done?*

Catalogue services plays an important role as a gateway through which providers users find suitable geographic information over the web. To discover the required information, users use traditional means of searching for information in catalogues which relies on key word based matching. The search terms specified by the user are matched against the metadata descriptions of resources that have been registered with the catalogue service. A metadata schema is defined which gives a common vocabulary supporting the tasks of searching, retrieval and display of data. The query searches the catalogue metadata and returns references to all resources matching the query.

In catalogue services maps are stored as PNG, GIF or JPEG files. Maps are tools for presenting real world phenomena through geospatial data layers. Online maps are available as static or interactive maps. A user is able to use the getCapabilities in WMS and specify the data layers required for the area of interest which is given in the query as bounding box coordinates. The mapping services allows the user to define the spatial extend of the search. The response to such a query is a map of available data layers.

No other description comes with map content except that which is provided in the metadata such as data quality, lineage, originator, among others. This is just limited information which does not suggest much about the content of the maps. as a result the user is left to make their own judgment and definition about map content. The ability of a user to abstract all the information from online maps remains a challenge, especially as more and more data layers becomes available on the web.

In Chapter 2 we showed the shortcomings of traditional search mechanism, in that they are based on syntax matching. Poor query formulation and knowledge of the information sought add up to poor discovery service discovery. In Chapter 3 we proposed the use of semantic web technologies (ontologies and semantic annotations) into geo-catalogues as a solution to overcoming the limitations of keyword based search mechanism.

2. *How can semantic annotations support the use of geo-catalogue services by data providers and consumers?*

Geo-catalogue services offer support to publish and search collections of descriptive GI. Semantic annotations establish a link between geospatial resources, their metadata descriptions and ontologies. Annotations can be achieved at three levels as discussed in section 3.6. OGC CSW currently relies on UDDI which is not flexible enough to allow semantic data registration. No relevance ranking is done when a query is executed. However, if data/resources are semantically defined through the use of ontology concepts in metadata descriptions the service provider increases the efficiency with which their services are discovered.

The task of being able to formulate good queries is taken off the shoulder of the consumer through ontology visualization. When service providers publish their resources on a geo-catalogue, besides availing metadadata descriptions only they also publish ontologies and through the annotation service link the two. When stored in a repository that is accessible to the metadata DB, user queries are referenced to these annotations. The query is executed against the meaning of supplied descriptions instead of the usual keyword based matching.

3. *What kind ontologies are suitable for annotation?*

There exist different kinds of ontologies as explained in section 3.6 which are based on geospatial evidences. Domain and application ontologies exist. In the geospatial domain, modeled ontologies should allow for spatial reasoning and inferences to be made. Domain ontologies allow annotations to be done at metadata level. Application ontologies allow annotation to be done at data model and data entities level. These ontologies need to be formal . While we may locate services, however the end result should allow binding to access their data. A feature type ontology enables geospatial operations (*within, adjacent* and others) to be defined and used where spatial reasoning is required. However this is an area that is still open to research.

4. *How can OGC catalogue services such as GeoNetwork be enhanced with ontological visualization and annotations?*

In this research we showed that while Geonetwork provides a solution to the portal of communication with users searching for spatial data, it has the same flaw like other catalogues. The traditional approach where users supply keywords or specify a bounding box when searching for information misses some key information that may be required for the purposes of

decision making. GN borrows upon SOA concepts which accounts only for syntactic interoperability.

To improve the search functionality of GeoNetwork, we proposed methods of integrating ontologies and semantic annotations in the system architecture as described in Sections 4.4 and 5.3. To demonstrate the potential of the method in GN, a use case in which data is required for situation awareness in view of severe weather events was developed. In the use case semantic annotation was done at metadata through the use of an annotation service and concepts defined in the W3C SAWSDL. We demonstrated the advantage of a semantically augmented GN CSW over the one currently in use. We also demonstrated how ontology visualization of concepts help the user in query formulation thus resulting in higher precision in retrieved results.

Another approach of using the basic extension package within GN-ebRIM was developed. This approach is tailor made to suit user requirements. EbRIM is more flexible than UDDI used in CSW and as a result semantic registration of data/services is possible. OWL constructs were mapped to ebRIM elements and ontologies and semantic annotations are stored in the ebRIM repository just like metadata.

6.3 Conclusion

With reference to the objectives that have driven this research project the following conclusions can be drawn:

- Integration of geographic metadata standards and semantic web technology results in improved search functionality.
- Standardized and rich geospatial ontologies increases the usefulness and effectiveness of geospatial data published through geo-catalogue services. The relationships existing between concepts can be made use when searching for services/data thus increasing the search space.
- Ontology visualization improves query formulation, in that a user is able to interact with the hierarchy of concepts which are linked to resources through their metadata descriptions from which they can choose the appropriate search concept.
- GeoNetwork, a standard catalogue allows better search and retrieval of spatial data when integrated with semantic web technologies, moreso within the ebRIM environment where tailored products can be made for specific users.

6.4 Recommendations

Based on the results of this research, the following points are recommended for future development of geo-catalogues.

1. Fully explore and extend GN-ebRIM to allow automatic transformation and mapping of ontologies to ebRIM registries. In the same manner develop tools or plugin that allow direct conversion of OWL constructs into geocatalogues by use a middleware so that they can be directly stored into the catalogue DBMS.
2. Extend the functionality of geo-catalogue services by linking ontologies to databases. This will allow storage of semantic workflows in the same database.
3. Develop a standard annotation services which automatically annotates resources to their ontology concepts while at the same time allowing annotation of non feature type ontologies which are needed and support discovery of features in maps.
4. Develop standards for Ontology Development and Semantic annotations in a format such as XML which is compatible with the metadata schema.
5. Development of an ontology visualizer that is compatible with Geonetwork, current ontology visualizers do not allow direct integration of ontologies with GeoNetwork. The visualizer should be flexible in the amount of detail that can be viewed, should allow zooming and panning among others. The possibility of exporting scalable vector graphics (SVG) into GeoNetwork for dynamic ontology visualization should be explored.

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Appendix A

XLST transformation code

```
<?xml version="1.0" encoding="UTF-8"?>
<!--
Mapping from OWL ontologies to ebRIM RegistryPackage
-->
<xsl:stylesheet version="2.0"
xmlns:xsl="http://www.w3.org/1999/XSL/Transform"
xmlns:xs="http://www.w3.org/2001/XMLSchema"
xmlns:fn="http://www.w3.org/2005/xpath-functions"
xmlns:xsp="http://www.owl-ontologies.com/2005/08/07/xsp.owl#"
xmlns:swrlb="http://www.w3.org/2003/11/swrlb#"
xmlns:swrl="http://www.w3.org/2003/11/swrl#"
xmlns:protege="http://protege.stanford.edu/plugins/owl/protege#"
xmlns:rdf="http://www.w3.org/1999/02/22-rdf-syntax-ns#"
xmlns:xsd="http://www.w3.org/2001/XMLSchema#"
xmlns:rdfs="http://www.w3.org/2000/01/rdf-schema#"
xmlns:owl="http://www.w3.org/2002/07/owl#"
xmlns:rims="urn:oasis:names:tc:ebxml-regrep:xsd:rims:3.0"
exclude-result-prefixes="xsl xs fn xsp swrlb swrl protege rdf xsd rdfs owl">

<xsl:output method="xml" version="1.0" encoding="UTF-8"
indent="yes" byte-order-mark="no"/>

<xsl:variable name="severeWeatherRegistryPackage">
<xsl:text>urn:owl:def:ebRIM-RegistryPackage:SevereWeather</xsl:text>
</xsl:variable>

<xsl:variable name="severeWeatherClassificationScheme">
<xsl:text>urn:owl:def:ebRIM-ClassificationScheme:SevereWeather</xsl:text>
</xsl:variable>

<xsl:variable name="isSubClassOfAssociationType">
<xsl:text>urn:owl:def:ebRIM-AssociationType:IsSubClassOf</xsl:text>
```

```

</xsl:variable>

<!-- end of constants -->

<!-- main transformation -->
<xsl:template match="/">

<rim:RegistryPackage
  xmlns:xi="http://www.w3.org/2001/XInclude"
  xmlns:rim="urn:oasis:names:tc:ebxml-regrep:xsd:rim:3.0"
  xmlns:xsi="http://www.w3.org/2001/XMLSchema-instance"
  xmlns:xlink="http://www.w3.org/1999/xlink"
  id="{ $severeWeatherRegistryPackage } "
  objectType="urn:oasis:names:tc:ebxml-regrep:ObjectType:
    RegistryObject:RegistryPackage">

  <rim:Slot name="Modified">
    <rim:ValueList>
      <rim:Value>2009-11-11T18:00:00Z</rim:Value>
    </rim:ValueList>
  </rim:Slot>

  <rim:Name>
    <rim:LocalizedString xml:lang="en" value=
      "ebRIM Package representation of OWL ontology for Severe Weather" />
  </rim:Name>

  <rim:Description>
    <rim:LocalizedString xml:lang="en" value=
      "Provides a classification for Severe Weather concepts"/>
  </rim:Description>

  <rim:RegistryObjectList>
    <xsl:apply-templates select="//owl:Class/@rdf:ID"/>
  </rim:RegistryObjectList>

</rim:RegistryPackage>

</xsl:template>
<!-- end main transformation -->

<!-- transform all Class rdf:IDs -->
<xsl:template match="//owl:Class/@rdf:ID">
  <xsl:variable name="ID" select="." />
  <xsl:variable name="objectType" select=
    "concat('urn:owl:severe-weather:ebrim:ObjectType:', .)" />

```

```
<rim:ClassificationNode code="{ $ID }"
objectType="{ $objectType }"
lid="{ $objectType }"
id="{ $objectType }"
parent="{ $severeWeatherClassificationScheme }">
<rim:Name>
<rim:LocalizedString value="{ $ID }" />
</rim:Name>
<rim:Description>
<rim:LocalizedString xml:lang="en" value="No description available"/>
</rim:Description>
</rim:ClassificationNode>

<xsl:variable name="parentClassName" select=
"../rdfs:subClassOf/owl:Class/@rdf:ID" />
<xsl:if test="string($parentClassName)">
<xsl:variable name="parentClassID" select=
"concat('urn:owl:severe-weather:ebRim:ObjectType:',
$parentClassName)" />
<xsl:variable name="subClassAssociationID" select=
"concat('urn:owl:def:ebRIM-AssociationType:IsSubClassOf-', $ID, '-',
$parentClassName)" />
<rim:Association id="{ $subClassAssociationID }"
sourceObject="{ $ID }"
associationType="{ $isSubClassOfAssociationType }"
targetObject="{ $parentClassID }" />
</xsl:if>

</xsl:template>
<!-- end transform all Class rdf:IDs -->

<xsl:template match="//owl:Class/@rdf:about">
</xsl:template>

<xsl:template match="//owl:Class/@rdf:resource">
</xsl:template>

</xsl:stylesheet>
```


Appendix B

Part of MetOnto OWL Code

```
<rdf:RDF xmlns="http://www.semanticweb.org/ontologies/2009/11/Storm.owl#"

  <rdf:Description rdf:about="&owl;AllDisjointClasses"/>
  <rdf:Description rdf:about="&owl;members"/>
  <owl:ObjectProperty rdf:ID="associatedWith"/>
  <owl:Thing rdf:ID="AtlanticOcean">
    <rdf:type rdf:resource="#Origin"/>
  </owl:Thing>
  <owl:ObjectProperty rdf:ID="causes"/>
  <owl:Class rdf:ID="CyclonicMotion">
    <rdfs:subClassOf rdf:resource="#TropicalCyclone"/>
  </owl:Class>
  <owl:Class rdf:ID="DestructiveCore">
    <rdfs:subClassOf rdf:resource="#Threat"/>
  </owl:Class>
  <ModerateTropicalStorm rdf:ID="ElineExample">
    <rdf:type rdf:resource="&owl;Thing"/>
    <hasWindSpeed rdf:datatype="&xsd:string">52</hasWindSpeed>
  </ModerateTropicalStorm>
  <owl:Class rdf:ID="Flooding">
    <owl:equivalentClass rdf:resource="#Floods"/>
    <rdfs:subClassOf rdf:resource="#Threat"/>
  </owl:Class>
  <owl:Class rdf:ID="FloodPlains">
    <rdfs:subClassOf rdf:resource="#SusceptibleAreas"/>
  </owl:Class>
  <owl:Class rdf:ID="Floods">
    <rdfs:subClassOf rdf:resource="#RelatedHazard"/>
  </owl:Class>
  <TropicalStorm rdf:ID="GraceExample">
    <rdf:type rdf:resource="&owl;Thing"/>
    <hasWindSpeed rdf:datatype="&xsd:string">62</hasWindSpeed>
  </TropicalStorm>
  <owl:ObjectProperty rdf:ID="hasDirection"/>
```

```

<owl:ObjectProperty rdf:ID="hasLocation"/>
<owl:ObjectProperty rdf:ID="hasOceanOfOrigin"/>
<owl:ObjectProperty rdf:ID="hasRadius">
  <rdfs:domain rdf:resource="#Threat"/>
  <rdfs:range rdf:resource="#SusceptibleAreas"/>
</owl:ObjectProperty>
<owl:FunctionalProperty rdf:ID="hasSeverity">
  <rdf:type rdf:resource="&owl;ObjectProperty"/>
  <rdfs:range rdf:resource="#Severity"/>
</owl:FunctionalProperty>
<owl:ObjectProperty rdf:ID="hasSpatialExtend">
  <rdfs:domain rdf:resource="#TropicalCyclone"/>
  <rdfs:range rdf:resource="#RelatedHazard"/>
</owl:ObjectProperty>
<owl:ObjectProperty rdf:ID="hasSpeed"/>
<owl:ObjectProperty rdf:ID="hasTime">
  <rdfs:domain rdf:resource="#TropicalCyclone"/>
  <rdfs:range rdf:resource="#Time"/>
</owl:ObjectProperty>
<owl:DatatypeProperty rdf:ID="hasWindSpeed"/>
<owl:ObjectProperty rdf:ID="hasWindStrength">
  <rdfs:domain rdf:resource="#TropicalCyclone"/>
  <rdfs:range rdf:resource="#WindSpeed"/>
</owl:ObjectProperty>
<owl:Class rdf:ID="HeavyRainfall">
  <rdfs:subClassOf rdf:resource="#Threat"/>
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#causes"/>
      <owl:someValuesFrom rdf:resource="#Flooding"/>
    </owl:Restriction>
  </rdfs:subClassOf>
</owl:Class>
<owl:Class rdf:ID="Hurricane">
  <owl:equivalentClass rdf:resource="#Typhoon"/>
  <rdfs:subClassOf rdf:resource="#TropicalCyclone"/>
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#hasOceanOfOrigin"/>
      <owl:hasValue rdf:resource="#AtlanticOcean"/>
    </owl:Restriction>
  </rdfs:subClassOf>
  <rdfs:subClassOf>
    <owl:Restriction>
      <owl:onProperty rdf:resource="#hasSeverity"/>
      <owl:someValuesFrom rdf:resource="#Intense"/>
    </owl:Restriction>
  </rdfs:subClassOf>

```

```
</rdfs:subClassOf>

  <owl:ObjectProperty rdf:ID="sameAs"/>
  <owl:Class rdf:ID="Severe">
    <rdfs:subClassOf rdf:resource="#Severity"/>
  </owl:Class>
  <owl:Class rdf:ID="SevereTropicalStorm">
    <owl:equivalentClass>
      <owl:Restriction>
        <owl:onProperty rdf:resource="#hasSeverity"/>
        <owl:someValuesFrom rdf:resource="#Severe"/>
      </owl:Restriction>
    </owl:equivalentClass>
  </owl:Class>

```