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# An Ontology for Submarine Feature Representation on Charts

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**Abstract.** A landform is a subjective individuation of a part of a terrain. Landform recognition is a difficult task because its definition usually relies on a qualitative and fuzzy description. Achieving automatic recognition of landforms requires a formal definition of the landforms properties and their modelling. In the maritime domain, the International Hydrographic Organisation published a standard terminology of undersea feature names which formalises a set of definition mainly for naming and communication purpose. This terminology is here used as a starting point for the definition of an ontology of undersea features and their automatic classification from a terrain model. First, an ontology of undersea features is built. The ontology is composed of an application domain ontology describing the main properties and relationships between features and a representation ontology deals with representation on a chart where features are portrayed by soundings and isobaths. A database model was generated from the ontology. Geometrical properties describing the feature shape are computed from soundings and isobaths and are used for feature classification. An example of automatic classification on a nautical chart is presented and results and on-going research are discussed.

**Keywords:** Geographical domain ontology, Landform classification, Nautical chart, Digital terrain modelling

## 1 Introduction

On nautical charts, undersea features are portrayed by sets of soundings (depth points) and isobaths (depth contours) from which the map reader can interpret landforms. As defined by [1], “a landform is a part of the Earth’s surface that is characteristically apprehended as a unitary thing or object because of its particular shape”. However describing its shape is a subjective task as a landform is inherently vague. Shape and boundary are defined qualitatively and their appreciation depends on the context or the cultural knowledge of people. Establishing

a list of landform types is therefore not a trivial task. Existing landform classifications usually provide an end-user terminology for the need of a community.

In the maritime domain, the International Hydrographic Organisation (IHO) has published a nomenclature of undersea features which provides a standard terminology for the naming of undersea features on charts and in publications [2]. The objective of this research is to generate a submarine feature classification so that features can be identified automatically from the seafloor representation. Such tool can assist both the cartographer and the map reader in selecting or visualising important features and evaluating the quality of a chart. An ontology of undersea features is designed and an application implementing the concepts is developed. The ontology is divided into two parts. The Application Domain Ontology built directly from the IHO terminology, organises and describes the properties of the features, forming a hierarchy of concepts. The Phenomenological Domain Ontology describes the concepts for representing the seafloor on the chart. Concepts from the ADO are translated so that each feature corresponds to a set of soundings and isobaths and its properties are extracted from the terrain model. A database model is then derived and is implemented in a triplestore database.

This paper first reviews existing works on landform classification and ontologies. Section 3 presents the ADO and PDO detailing how features are classified on the chart. Section 4 presents the database model and discusses classification results obtained from bathymetric data. The last section presents conclusions and directions for future work.

## 2 Ontologies of landforms

### 2.1 Landform classification

Landforms characteristics being by essence fuzzy and scale dependent [3], their description can vary easily according to people's perception and experience. Landform classification in that case is rather a problem of defining formal specifications that correspond to verbal descriptions for the purpose of communication within a community [4]. Existing work in this domain consists in the establishment of a core reference or a domain ontology collecting and formalising knowledge gathered from experts. Major sources of landform taxonomy are provided by spatial data standards such as SDTS and by national mapping agencies such as the IGN-E in Spain [5] and the Ordnance Survey in the UK<sup>3</sup>. Proposed ontologies rely on several ontologies including a topographic ontology and a hydrologic ontology. They provide formal qualitative properties and relations between features. However classification requires the assessment of geometrical properties such as height, length or area and so the definition of some quantitative descriptors. Existing work in this direction mostly relates to identifying specific landforms such as valley [6], bay [7] and reef [8].

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<sup>3</sup> <http://www.ordnancesurvey.co.uk/oswebsite/ontology/>

In the maritime domain, the IHO is the international body engaged in defining standards in order to advance maritime safety. In order to build a common frame for the naming of undersea features, the IHO defined a terminology of undersea feature names [2]. The purpose of the document is to set a standard for communication (the terminology is available in several languages) and for the denomination of undersea features (with a guideline for naming features). Although this document is only a terminology with definitions in natural language, it defines a standard, classifies more terms and provides more precise definitions than the Geo-Wordnet<sup>4</sup> database or USGS's SDTS<sup>5</sup>. Therefore this document provides a uniform view of undersea features solving most semantic difficulties [9] and is used as a base for the definition of the ontology of submarine features.

## 2.2 The geographical ontology framework

Conceptualising knowledge for a specific application is done by gathering specific knowledge from a domain and by integrating concepts from higher level ontologies. In order to represent geographic objects from the real world to computer language, [10] introduced a five-universe paradigm. The physical and cognitive universes contain real world phenomena and their representation in the human mind. The logical universe provides explicit ontologies formalising the cognitive universe. The representation universe deals with the description of geographical elements from the logical universe and contains ontologies conceptualising the elements according to the type of representation (e.g. field or object model). Finally, the implementation universe describes algorithms and data structures as implemented in the application.

In order to organise information on geographic worlds into ontologies, [10] considered a multiple-ontology approach where knowledge is shared between the logical universe and the representation universe. [10] defined first the Application Domain Ontology (ADO), concerned with describing specific subjects and tasks, in the logical universe. It is composed of two kinds of ontology: a subject ontology describing the vocabulary related to a generic domain, and a task ontology describing a task or application within a specialisation domain. Second, the Phenomenological Domain Ontology (PDO) in the representation universe manages different properties of the geographical phenomena in the GIS. It is composed of method and measurement ontologies. A method ontology defines a set of algorithms and data structures, and a measurement ontology describes the physical process of recording a geographical phenomenon. Both universes are defined separately. Different representations can be defined for one application or one representation used for different applications. The connection between both ontologies is made by semantic mediators.

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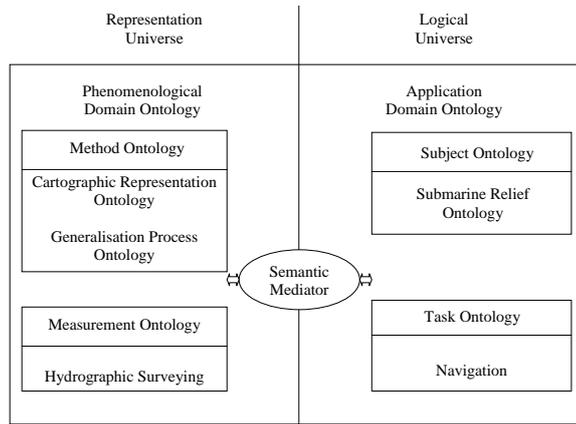
<sup>4</sup> <http://geowordnet.semanticmatching.org/>

<sup>5</sup> <http://mcmweb.er.usgs.gov/sdts/>

### 3 An ontology of undersea features

Following Fonseca’s framework, the undersea feature ontology can be divided into two parts (Figure 1). Concepts that belong to the maritime domain are part of the logical universe. The subject ontology conceptualises knowledge about submarine features and is mostly derived from the IHO terminology. The subject ontology describes any activity that requires or analyses seafloor information. In the context of this work, nautical charts being mainly designed for navigation purpose, the task ontology would logically be related to navigation and route planning.

The representation universe is concerned with the representation of undersea features on the nautical chart. The method ontology focuses on terrain representation techniques including objects on the chart (soundings, isobaths) and operations handling these objects (isobath extraction, generalisation operations) as well as operations matching features from the ADO to the PDO. The measurement ontology refers to data collection techniques (e.g. echo sounding, LIDAR).



**Fig. 1.** Phenomenological and application domain ontologies of undersea features.

This work focuses on the characterisation of undersea features and their representation. Task and measurement ontologies require knowledge about data acquisition or maritime navigation and so are not addressed. The next section presents the subject ontology by defining the properties required to describe undersea features. Section 3.2 describes the method ontology and presents how features from the subject ontology are represented in the method ontology. Ontologies also include information such as value restrictions (e.g. depth values range) and specification of logical relationships between concepts (e.g. each morphological feature must include at least one isobath or a sounding).

### 3.1 The subject ontology

Building the domain ontology is done in two steps. First, properties and relationships characterising each of the 46 features are identified by analysing the definitions and extracting keywords corresponding to feature characteristics. Second, these characteristics are organised into different concepts (composition, shape) describing the feature properties and relationships (mereological, topological, taxonomic). At the end of the process, a hierarchy of features is defined. IHO features correspond to the most specialised concepts and are at the bottom of the hierarchy, inheriting from one or several more generalised concepts such as depression (a feature which is lower than its surrounding) or prominence (a feature which is higher than its surrounding). The hierarchical structure provides several levels of semantic precision which can be adjusted according to the accuracy of the input data or to the required precision of the description. For example, although a large number of features are part of the ocean floor, a detailed description is not needed on an offshore navigation chart as they cannot be portrayed precisely on a large scale map.

Figure 2 shows the structure of the subject ontology. A full description of properties, relationships and concepts involved at top level and application level is given in [11]. Properties describing the features are the composition (e.g. rock, sand), the depth level and the shape properties. The depth level relates features with parts of the seafloor at different range of depths and having different geomorphological properties.

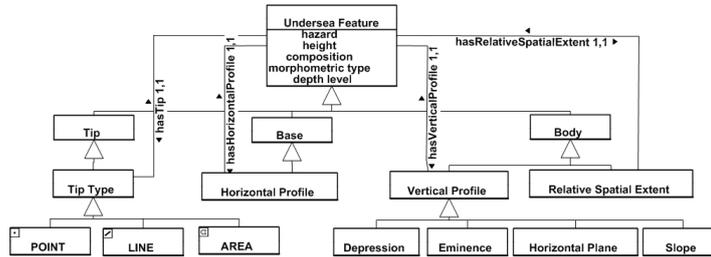


Fig. 2. Concepts describing undersea features.

In order to describe the feature shape, the feature can be divided into three parts: its body, tip and base. The body is described by the feature height, vertical profile and relative spatial extent. The vertical profile defines the overall shape (peak, ridge, plane area) which includes the morphometric class as well as the type of slope (steep, gentle, horizontal). The relative spatial extent indicates if a feature is relatively large or small. The tip concept applies to eminences and depressions and describes the shape of the extremity. For example, a summit can be sharp (like a pinnacle) or flat (like a plateau). Finally, the base is described by the horizontal profile (e.g. elongated, circular).

### 3.2 The method ontology

The method ontology formalises the way submarine features are represented on the chart. It includes concepts and rules defined by hydrographic offices [12, 13]. Four main concepts (chart, isobath, sounding and feature) are defined together with their spatial relationships and properties (Figure 3). The chart concept mostly includes metadata about the scale and the symbology. Isobaths and soundings are the elements portraying the seafloor. A sounding is defined by a depth and a position. Soundings are also classified into different classes according to their importance in characterising features that are relevant to navigation [11]. An isobath is defined by a line and its depth. Topological relationships between soundings and isobaths are also recorded.

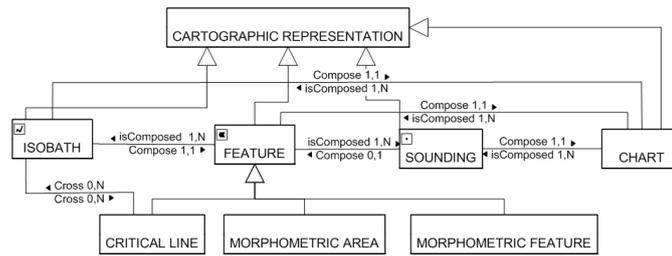


Fig. 3. Chart elements defined in the method ontology.

The chart feature concept corresponds to the representation of an undersea feature from the subject ontology. As mentioned in section 2.1, classification is scale dependent and is based on fuzzy characteristics. In the context of representation on a chart, a feature is portrayed by a set of soundings and isobaths that the reader can interpret. For example, a reef feature is represented by a sounding which is close to the sea level, representing a hazard and an isobath containing the sounding. The method ontology also defines operations extracting the isobaths from a set of soundings and cartographic generalisation operations (e.g. selection, filtering) adapting the chart elements to the scale.

## 4 Implementation

### 4.1 System design

Both ADO and PDO ontologies<sup>6</sup> were built in the Protégé 4.2 platform and exported into a RDF file. Figure 4 is an extract of the undersea feature ontology. The ontological model was then integrated in Virtuoso. It can function as a web application server as well as a host for data-driven web services. Virtuoso offers a triplestore database that is a purpose-built database for the storage and retrieval of triples in RDF terminology in the form of *subject-predicate-object* expressions.

<sup>6</sup> [www.dropbox.com/s/2hssg1cty1dvfji/undersea.owl](http://www.dropbox.com/s/2hssg1cty1dvfji/undersea.owl)

Triplestore is in coherence with the current emphasis on development of native stores since their performance are optimised for the storage and retrieval of triples. Information or knowledge is accessible via SPARQL. The Jena API was used to read from and write to the RDF graph. An example of such a RDF graph is proposed in figure 5. The *Hill* concept, defined in the IHO terminology, inherits from the *HillFeature* and the *PointFeature* concepts and describes a feature having a point tip. The *HillFeature* concept is a generalisation of different concepts which differ by the type of tip and their possible location.

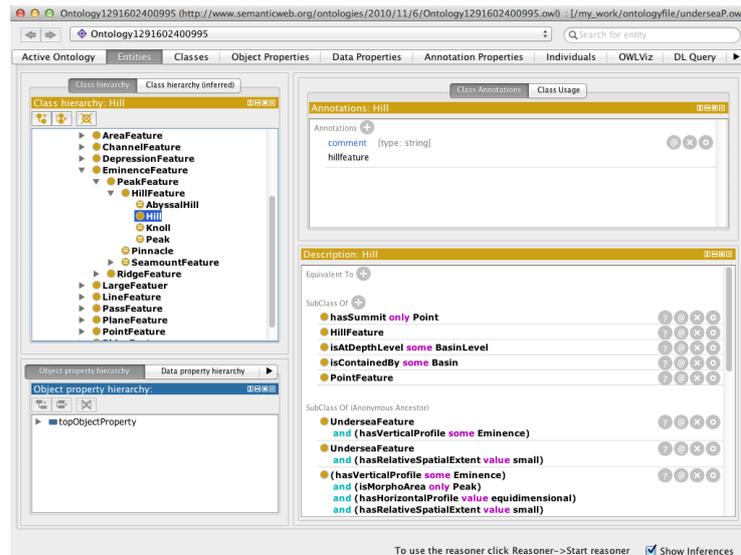


Fig. 4. Extract of the ADO in Protégé: the Hill concept.

A triplestore is also built for the storage of the bathymetric data of a chart (soundings, isobaths, undersea features). Its schema is generated by the ontological triplestore. Predicates in this database connect data together (e.g. isobath *I belongs to* feature *F*) and data with concepts (e.g. isobath *I is an instance of* the isobath concept). Finally, the ontological and data knowledge are connected to the geographical information system. As our information system was initially developed in C++ language, Java Native Interface (JNI) is used to connect Java (i.e. Jena) and C++.

## 4.2 Results

The model was tested on a set of soundings provided by the French Hydrographic Office for a large scale map (1:12500) of a coastal area. Isobaths were extracted with a 1 metre vertical interval by interpolation. A first step before feature classification is their identification. On such a chart, cartographers and readers mostly make use of isobaths to delineate hazards and navigation routes. Therefore, features are characterised by one or several isobaths at the same depth marking

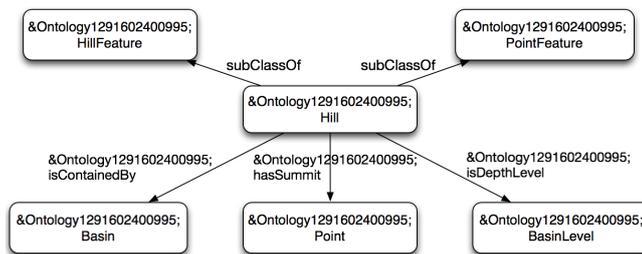


Fig. 5. Graph associated to the RDF/XML description of the Hill concept.

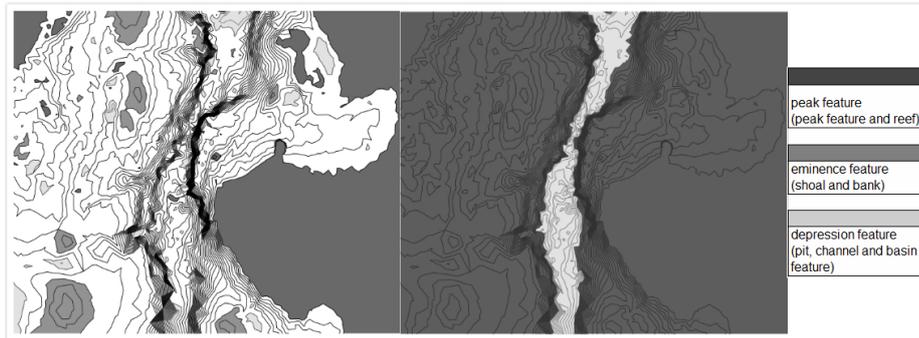
their boundary [14]. A current limitation of this approach is that only depressions and prominences are considered. The method extracts features based on depth variations between adjacent isobaths and yields a feature tree providing topological relationships between features (adjacency and inclusion). Relationships between isobaths and soundings are defined by a constrained Delaunay triangulation.

Only features that inherit from the prominence and depression concepts are classified as they are the only ones identified on the chart. Shape properties are computed from the soundings and isobaths composing a feature. Base properties are computed from the boundary contours. The tip is defined by starting from the highest or deepest sounding and by adding neighbouring triangles to extract the largest possible horizontal surface. Figure 6 presents a set of classified features. Figure 6A shows leaves of the feature tree, i.e. feature which do not contain any other features. Figure 6B shows features at the top of the hierarchy. The hierarchy of feature concepts defined in the ADO was used as a decision tree to reach the highest level of precision. Seven types of feature (peak feature, reef, bank, shoal, pit, channel and basin feature) were identified and characterised (Table 1). The first four features are prominences and three of them are defined in the IHO terminology. The last three are depressions and are not in the terminology because in shallow areas, noticeable features are mainly features which represent a danger for navigation. A channel corresponds to an elongated depression. The largest one, shown on Figure 6B, indicates a navigation route. Others are indeed contained by the first one.

Table 1. Undersea features (features defined in the IHO terminology in bold).

Peak feature	<b>Reef</b>	<b>Bank</b>	<b>Shoal</b>	Pit	Channel	Basin feature	Total
25	6	4	9	34	6	17	101

<sup>8</sup> <https://dl.dropboxusercontent.com/u/85206736/results-1.jpg>



**Fig. 6.** Results of undersea features characterization. The colour figure with more details of undersea features is accessible on line<sup>8</sup>.

## 5 Conclusion

This paper introduced an ontology of undersea features for landform classification. The concepts were implemented into a cartographic application to enrich the bathymetric database for purpose of cartographic and model generalisation. The ontology is divided into an application domain, defining the feature properties, and a phenomenological domain, addressing their representation on a chart. On top of the IHO definitions, general concepts were added to provide a description at different precisions. These general concepts are useful for the representation because on one side, the bathymetric database usually does not contain enough data for a full characterisation of all features and on the other side, the amount of details is adapted to the scale and the purpose of the chart.

All concepts defined in the ontology have not been implemented yet. Only features that are bounded by one or several isobaths are identified. Due to the inherent vagueness of landforms, delineating undersea features with a crisp boundary is subjective however it corresponds to the representation that is given on the chart and provides a rigorous definition for shape properties. Further work can be done by representing features by one or several soundings (e.g. a seamount where only the summit is marked) or by dealing with plane features. In such cases, features are not represented on the chart with a crisp boundary and therefore vagueness has to be taken into account in the position and computation of geometric properties [15]. As the level of complexity would increase greatly with the number of feature concepts involved, the decision tree may be pruned according to the type of chart (large or small scale, coastal or offshore navigation) to limit the number of features considered.

This work is part of a larger project on the cartographic and model generalisation of the seafloor for nautical chart production. Therefore the next step is the integration of cartographic rules and generalisation constraints and operators in the method ontology. The feature ontology may also be extended by adding more information about relevance to navigation: some prominences are

already marked as hazards, channels can also be marked as navigation routes to be preserved. Based on this knowledge, the application shall be able to infer plans for automatic processing and to evaluate the quality of the generalised data.

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