From a qualitative description of undersea features to their representation on a chart: How to connect ontologies?

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ABSTRACT
A landform is a subjective geomorphic feature such as a mountain or a valley. On a topographic map, landforms are not explicitly portrayed but perceived by the readers from the organization of cartographic elements such as contours and spot heights. Achieving automatic landform recognition is a difficult task because definitions are usually qualitative and vague. However, in an application such as nautical chart construction, undersea features are selected and portrayed according to their relevance to navigation. Hence recognizing undersea features from sets of soundings and isobaths would help to select significant soundings and isobaths and to automate the generalization process. For that purpose, we propose a framework that helps to bridge the gap between the verbal definition of features and their quantitative representation on the chart. On one side, we define an application ontology where feature descriptions are structured according to formal concepts and on the other side, we define a representation ontology which describes the geometrical elements and properties used to model features on the chart. The connection between the two ontologies is performed by semantic mediators where qualitative concepts are associated with quantitative properties applied to features and measured from soundings and isobaths. The model has been implemented and applied to a bathymetric dataset. Results of this case study are then presented, discussing the reliability of the classification for the description of undersea features.

KEYWORDS
Semantic mediator; undersea feature; geographical domain ontology; nautical chart

1. Introduction

Relief can be seen as a continuous phenomenon and modeled by a field function while features such as buildings, roads and rivers are perceived and modeled as objects on the map. A topographic map provides a representation of the relief and of natural and man-made features. A hydrographic map is a kind of topographic map used to reveal the slopes and contours under water, specifically made to survey the seafloor. A nautical chart is a type of hydrographic map used by navigators on the sea, as a “road map”, and is essential for safe navigation since danger cannot be assessed visually. As a consequence, seafloor representation on nautical charts follows different rules from terrain representation on topographic maps and the cartographers objective is not to represent the terrain as accurately as possible but to select and emphasis terrain features that are relevant to navigation.

Yan, Guilbert, and Saux (2013) firstly introduced a general framework based on ontologies for submarine representation on nautical charts. This framework integrates geographic knowledge about submarine relief and cartographic knowledge about map generalization in logical and representation universes in two separate ontologies, respectively the application domain ontology (ADO) and the phenomenological domain ontology (PDO). As being an integration of different ontologies, Yan, Guilbert, and Saux (2015) provided then both a submarine relief ontology in the ADO to characterise undersea features and describe the seafloor based on the nomenclature of undersea features of the International Hydrographic Organization (IHO) (International Hydrographic Organization, 2008) and a cartographic representation ontology in the PDO to describe the bathymetric elements Yan, Guilbert, and Saux (2014) that are used to represent features on the map using geometric primitives (points, lines, polygons) and terrains descriptors (e.g. slope). These ontologies have been implemented in a triplestore database modeling the concepts, their instances and the relationships between them. As a domain ontology, the submarine relief ontology can be used not only for nautical chart production but also for other applications related to oceanography or navigation.

In order to automatically propose generalization plan under feature types , the geographic description and cartographic information should be connected between the ADO and PDO. However, in the perspective of an automated classification of features, the link between the qualitative description provided by the definitions and the quantitative measurements obtained from the map must be done automatically. Hence, this work proposes a method to associate the conceptual definition of an undersea feature to its representation on the map. Such a tool can assist both the cartographer and the map reader in selecting or visualizing important features and evaluating the quality of a chart.

This paper first reviews existing works on ontologies in cartography. Section 3 introduces the framework of ontologies and concepts in the ADO and PDO. Then, semantic mediators are defined in two parts, predicates and thresholds. Section 4 presents the system design and discusses classification results obtained from bathymetric data with different threshold values. The last section presents conclusions and directions for future work.

2. Ontologies in Cartography

A map represents various geographic information for different applications. Hence, ontology can be used in cartography to organize knowledge and formalize information. Ontology helps to obtain and process all the data and portray them on the map. In existing works, general domain ontologies were defined by mapping agencies, such as the IGN-E in Spain (Gómez-Pérez, Ramos, Rodríguez-Pascual, & Vilches-Blázquez, 2008) and the Ordnance Survey[1] in the UK. The National Geographic Institute of Spain built a taxonomy ontology of geographic feature types, which aims to create an integration framework for maintaining databases and solve heterogeneity problems (Gómez-Pérez, Ramos, Rodríguez-Pascual, & Vilches-Blázquez, 2008). Two stages are used to deal with the heterogeneity of data sources and build automatically a domain ontology about geographic feature types. Ordnance Survey provided several kinds of ontologies to organize knowledge of different domains and represent different datasets in a semantically meaningful way via ontologies, including administrative geography, hydrology and topography. The domain ontologies of Ordnance Survey and IGN-E aim at managing huge amount of geographic information for cartography. The advantages of these ontologies are the improvement of knowledge management for mapping. But

[1] http://data.ordnancesurvey.co.uk/ontology

they do not consider map generalization.

Gould and Chaudhry (2012) developed the operator ontology and algorithm ontology to describe the generalization process and formalized legibility conflicts during change of scale. An operation ontology describes the properties, behaviors and relations of three generalization operations, which are selection, aggregation and collapse. Meanwhile, the generalization operations are organized with geometric objects and worked with an algorithms ontology to resolve one or more conditions automatically. But it cannot automatically provide parameter values to the selected generalization operators especially since two algorithms performing the same generalization operation may have different parameters.

Touya et al. (2012) developed a spatial relationships ontology to describe relations between objects as quantitative (e.g. metric relations) and binary (e.g. topological relations) relations. Meanwhile, relational constraints preserving topological characteristics and the spatial structure are organized in a hierarchy within the constraint ontology. However, the ontologies lack a connection between the spatial relationships ontology and the constraint ontology. The quantifying of spatial relations can help to follow constraints during the map generalization.

In existing works, domain ontologies (Gómez-Pérez et al., 2008) only focus on the formalization of geographic knowledge for mapping, while task or application ontologies (Gould & Chaudhry, 2012; Touya et al., 2012) aim at organizing generalization operations and algorithms in the map generalization process. However, map generalization is an important and complex part in the map construction. In order to improve the map construction, ontology not only need to formalize basic information about features, but also should manage the extra attributes (spatial relationship, geometric information, etc.) of cartographic objects and various factors (e.g. generalization constraints and operations) in the generalization process. Furthermore, it is necessary to associate the conceptual representation of landforms and graphical representation. Additionally, most of existing works cannot apply to undersea features which are not modeled in the bathymetric database. The map generalisation should highlight hazards and show navigation routes. During the generalization, some undersea features must be emphasized and some removed according to their types. However, the undersea features haven't been modeled explicitly in a bathymetric database to support the feature identification on the nautical chart.

In order to organize geographic phenomena of the real world and transform them to the computer language to support the automatic map generalization, it is necessary to develop a multiple-ontology approach to gather specific knowledge. Smith and Mark (2003) provided an object-based ontology of mountains and other landforms that described the common conceptions of the environment, which based on the "primary" theory. Primary theory is part of common sense which we find in all cultures and in all human beings. Primary theory recognizes not only objects but also corresponding attributes (properties, aspects, features) and their relationships. Fonseca (2001) introduced a five-universe paradigm to represent knowledge of the geographic world from human cognition in the physical universe. This framework is beneficial to share knowledge between the logical and representation universes.

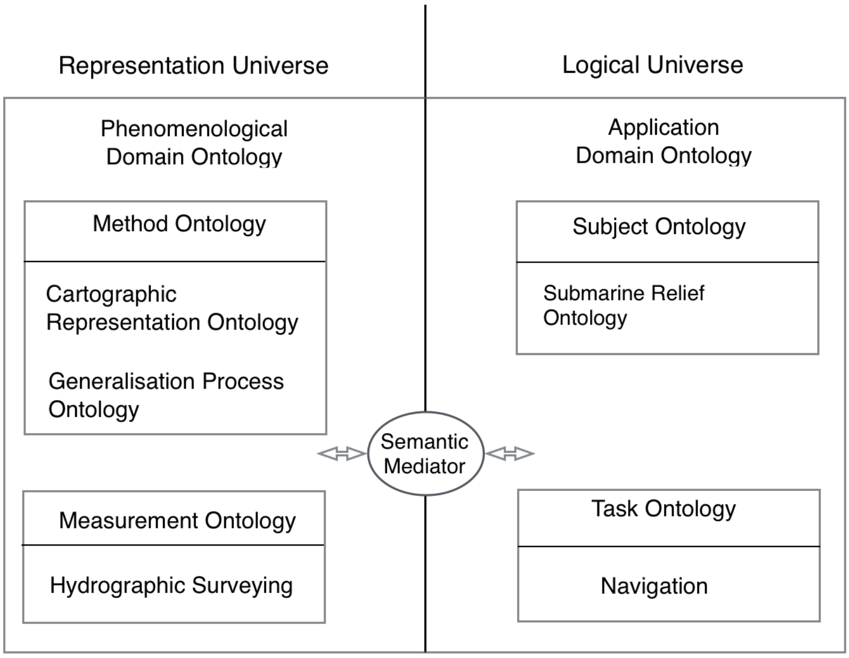


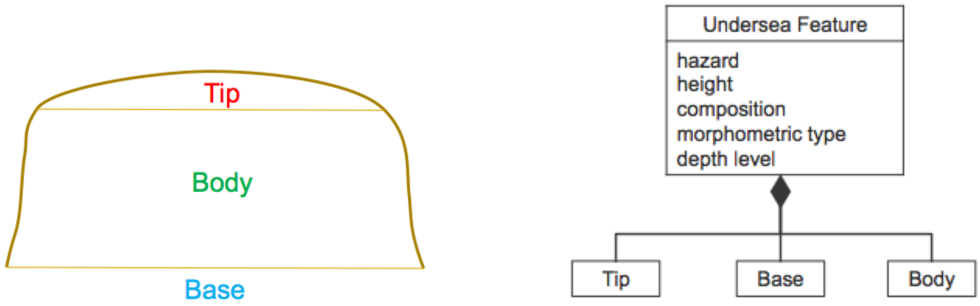
Figure 1.: Bathymetric representation through phenomenological and application domain ontologies. (Yan et al., 2013)

3. Semantic Mediator in Nautical Chart Generalization

3.1. Geographical Ontology Framework and Definition

Based on the primary theory and five-universe paradigm, Yan et al. (2013) provides a general ontology framework to organize geographic information about the seafloor in the logical universe and cartographic information in the representation universe (Figure 1). This framework includes two main components, one is a subject ontology describing the vocabulary related to the submarine relief in the Application Domain Ontology (ADO), the other is two method ontologies describe the data structures and operations of the cartographic generalization in the Phenomenological Domain Ontology (PDO). The PDO is defined for a specific representation independently from the ADO. Therefore, the method ontology describes the concepts used for the representation on the chart. That includes among others the graphical elements displayed on the chart (isobaths, soundings) but also the generalization operations required (sounding selection, isobath extraction etc.) to deal with representational issue on a nautical chart and operations matching features from the ADO with the PDO.

Yan et al. (2015) defines the concepts of the seafloor as a subject ontology in the ADO, which is called the submarine relief ontology. The submarine relief ontology formalize knowledge of undersea features based on the IHO terminology. The submarine relief ontology not only describes the characteristics of each kind of undersea feature, but also defines them according to the whole geographic structure of the seafloor and geometric characteristics of undersea features. The benefit of hierarchical structure of the submarine relief ontology is that, depending on the density or quality of the input terrain data or the requirements of the application, the level of description can be adjusted to different granularities. As a domain ontology, the submarine relief ontology can be used not only for nautical chart production, but also for other applications



(a) Three parts of the undersea feature.
(b) Description of the undersea feature.

Figure 2.: Material of undersea feature.

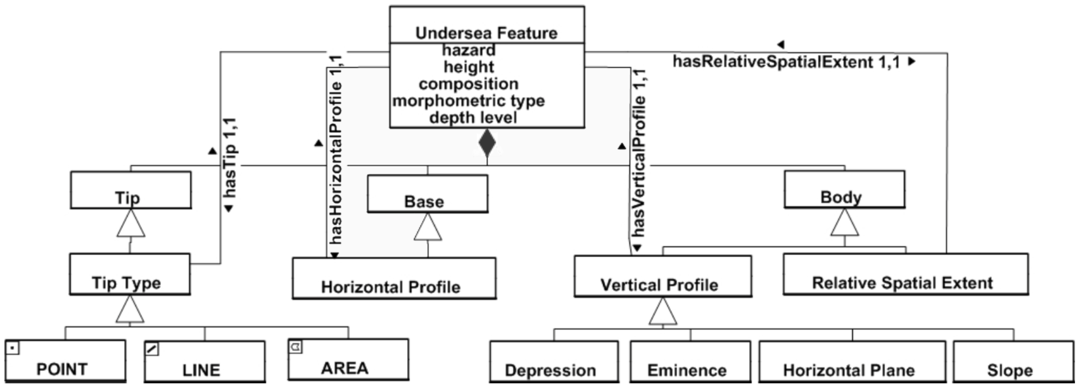


Figure 3.: Conceptual model of submarine relief ontology.

(e.g. oceanography). On top of the IHO definitions, general concepts (e.g. prominence and plane features) are added to provide a description of terminology. These general concepts are useful for undersea features characterization because on one side, the bathymetric database usually does not contain enough data for a full characterization of all features and on the other side, a number of details is adapted to the scale and the purpose of the chart. Submarine relief ontology uses composition relationship to describe an undersea feature in three parts: tip, base and body (Figure 2). Meanwhile, the depth level associated with the is-part-of relationship describes spatial and topological relationships of undersea features. Figure 3 shows the structure of the subject ontology. Properties describing the features are the material (e.g. rock, sand), the depth level and the shape properties. Any feature has a shape of tip, such as a peak has a sharp summit or a basin has a flat bottom. The *tip* concept describes the shape of the extremity. Three concepts are defined to describe the body, which are feature height, *vertical profile* and *relative spatial extent*. The *vertical profile* uses morphometric classes and the types of slope (e.g. steep and gentle) to describes the overall shape of undersea feature, such as peak, ridge and plane. The *horizontal profile* (e.g. elongated, circular) describes the base of the undersea feature. A full description of properties, relationships and concepts involved at the top level and application level is given in (Yan et al., 2015).

Yan et al. (2014) introduces the details of method ontologies in the PDO, which describes the representation of undersea features on the nautical chart. The method ontology formalizes the way submarine features are represented on the chart, which is

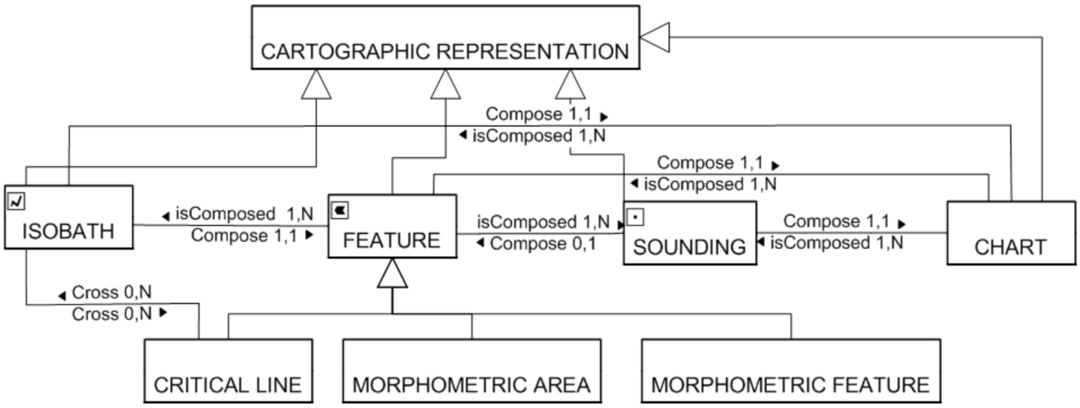


Figure 4.: Conceptual model of cartographic representation ontology.

called cartographic representation ontology. The cartography representation ontology contains four main concepts - chart, isobath, sounding and feature - linked by their spatial relationships and data properties (e.g. density of soundings in a feature) (Figure 4). The chart concept describes metadata of the nautical chart, such as scale and time of chart. Isobaths and soundings are the basic elements to delineate the seafloor on a chart. The sounding includes the depth and location information. Based on the soundings' importance in characterizing features that are relevant to navigation, the soundings have been classified in different groups (Yan et al., 2015). An isobath is described by a line and its depth. Meanwhile, topological relationships between soundings and isobaths are defined in the ontology, which help to identify undersea feature on the chart. (Yan et al., 2015). The feature is a concept defined in the cartographic representation ontology, which is deduced from the isobaths and soundings. Navigators identify dangerous areas and other relevant features on the nautical chart as groups of isobaths combined with soundings and forming specific patterns. Undersea features are not portrayed on the chart like soundings and isobaths but can be perceived from the spatial structure. For example, an elevation is represented by at least a sounding higher than its surrounding or by a set of circular isobaths higher in the center. The concept of the feature includes depth, area and slope as attributes, which are calculated by soundings and isobaths. In addition, topological relationships describe the relationships between isobaths, soundings and features. The definition of feature combines the knowledge of submarine relief and cartographic representation ontologies. The ontology of the generalization process is a method ontology in the representation universe, which describes and manages the whole generalization process. During the generalization process, some factors should be considered to represent terrain surface at different levels, such as generalization operators and constraints (Creac'h, Devogele, Quimerc'h, & Saux, 2000).

When we have conceptual description of geographic world and graphical description of cartography, it lacks a connection to share knowledge between the ADO and PDO. The ADO formalizes the real objects from human cognition to logical universe. The PDO helps to calculate geometric properties of the undersea features. In order to fulfill transformation of the real world from human mind to computer language and identify feature types automatically, we need to connect conceptual description of geographic world and graphical description of cartography. According to the framework, the semantic mediator includes two parts to connect the ADO and PDO, predicates and thresholds. Predicates correspond to descriptive properties in the ADO and PDO, which describe the undersea feature in conceptual and graphical methods. Thresholds define the limits where a set of possible values in the range of a predicate in the PDO correspond to a set of possible values in the range of the predicate in the ADO. At the same time, the threshold values are defined to identify undersea feature from conceptual to graphical descriptors.

3.2. Predicates in Semantic Mediators

Submarine relief ontology describes geographic characteristics of undersea features in the ADO. Cartographic representation ontology integrates geometric properties of the nautical chart in the PDO. In order to identify undersea feature entity in the cartographic representation ontology of the PDO that corresponds to undersea feature concepts in the submarine relief ontology of the ADO, this work designs a series of semantic mediators as measures of association between conceptual and graphical representations. Only features that inherit from the prominence and depression concepts are classified as they are the only ones identified on the chart. To discriminate two given features, there are many relevant representative parameters for feature identification based on the submarine relief ontology. In order to calculate *Tip type*, *Vertical profile*, *Relative Spatial Extent*, *Horizontal Profile* of shape value (Yan et al., 2015) for feature identification, some predicates (TT, VP, RSE, and HP) are defined both in PDO and ADO. On one hand in PDO, the predicates calculate geometric values of features from sets of soundings and isobaths. On the other hand in ADO, the predicates identify the qualitative characteristics of features from the IHO terminology.

- **Conceptual descriptive predicates (ADO)**
  Four groups of conceptual descriptors identify the value of tip, base and body of features. Their values are extracted from submarine relief ontology in ADO (figure 3), which are listed in the following equations respectively.

$$\{Point, Line, Area\} \in ADO\_hasTT \tag{1}$$

$$\{Prominence, Depression, Others\} \in ADO\_hasVP \tag{2}$$

$$\{Large, Medium, Small\} \in ADO\_hasRSE \tag{3}$$

$$\{Elongated, Circular\} \in ADO\_hasHP \tag{4}$$

- **Graphical descriptive predicates (PDO)**
  Related to the cartographic representation ontology in PDO (Figure 4), Feature class includes two attributes, depth and area. We use *F.depth* and *F.area* to discriminate features. A Delaunay triangulation is constructed through isobaths and soundings, which aims to calculate the geometric values of undersea features.

A feature is formed by a set of soundings and isobaths and is delineated by a polygon. The feature area ($F.area$) is this polygon area computed from Delaunay triangulation projected in the horizontal plan. Because each feature is composed by several isobaths, the depth of a feature cannot be expressed by a single value. This work defines $F.depth$ to describe the depth trend of a feature. Hence, the value of $F.depth$ is a set of results of comparison from all the isbaths in a feature ($F.depth = compare(isobath_i.depth, isobath_{i+1}.depth)$).

- A predicate is used to identify the value of *vertical profile* through the value of the slope. Each feature includes several depth values, which are used to compute the slope of the feature. In order to identify the tendency of slopes in the feature, the depth of two adjacent isobaths should be compared. After comparing all the depth values in a feature, we can get a list of values of PDO_hasVP. The results are used to identify the vertical profile of this feature in conceptual description. Three values of PDO_hasVP are identified in equation 5.

$$PDO\_hasVP(F.depth) = \begin{cases} isBelow, & (\forall F.depth = below)) \\ isAbove, & (\forall F.depth = above) \\ isFlat, & (otherwise) \end{cases} \tag{5}$$

- Distinguishing the *Tip types (PDO_hasTT)* requires knowing how the surface varies around the tip. If the tip is a point or a line, the surface drops suddenly around the tip while for other types, the variation is gentler and so a more or less big area around the tip can be identified. The flatness is characterized by a continuous flat area value. PDO_hasTT accounts for the largest flat region of a given feature, i.e. the triangulation's largest continuous surface containing only triangles whose slope is lower than a certain slope threshold. In order to calculate the value of PDO_hasTT, algorithm1 is used to find the sum of triangles face area in a continuous flat area of a feature. In this algorithm, a threshold of slope should be defined to find a relative flat area in a feature. After the computing, equation 6 is used on a feature to calculate its value of PDO_hasTT.

$$PDO\_hasTT = \frac{F.areaflat}{F.area} \tag{6}$$

- The *Relative Spatial Extent* of the shape value in the submarine relief ontology describes the body of a feature. It is defined by the ratio between the feature height and its spatial extent. Therefore, *Relative Spatial Extent* (RSE) is computed by the squared height (or depth) of the feature over the area of the feature (Equation 7).

$$PDO\_hasRSE = \frac{F.depth}{F.area} \tag{7}$$

- The *Horizontal Profile* describes the shape value and points out if a feature is elongated or not. It is a basic criterion giving reliable results to discriminate features (e.g. the difference between channel and basin). To compute

Algorithm 1: computation of the continuous flat area of a feature

```
Input  : A feature (F), all the triangles of F (T_n)
Output: F.areaflat
F.areaflat ← 0 ;
    for each triangle T_i of feature F from T_0 to T_n do
        if T_i.slope < Threshold then
            flatfaces.push_back(T_i)
        end
    end
    for each triangle T_i of feature F from T_0 to T_n do
        if (T_i.depth = F.depthmax||T_i.depth = F.depthmin)&&T_i in flatfaces
    then
            tipface = Ti
        end
        F.areaflat ← tipface.area
    end
faces = tipface.neighbours if  faces! = null then
        Neighbour(faces)
    end
    if  neighbourfaces! = null then
        Neighbour(neighbourfaces)
    end
function Neighbour(faces)
for each triangle faces_i of faces from faces_0 to faces_n do
        if faces_i in flatfaces then
            F.areaflat ← F.areaflat + face.area
        neighbourfaces = faces_i.neighbours
        end
        return neighbourfaces
    end
end function
    return F.areaflat
```

this criterion the coordinates of faces of the spatial extent of the feature F $(\max(F(x)), \min((F(x)), \max((F(y)), \min((F(y)))$ are identified. Equation 8 computes the value of the horizontal profile predicate, which should be between 0 to 1.

$$PDO\_hasHP = \frac{F.area}{(\max\{\max(F(x)) - \min(F(x)), \max(F(y)) - \min(F(y))\})^2} \tag{8}$$

3.3. Thresholds in Semantic Mediators

In order to characterize the feature criteria (Tip Type, Vertical Profile, Relative Spatial Extent and Horizontal Profile), thresholds are defined to connect conceptual and graphical descriptors in the semantic mediators. Four groups of thresholds are defined in the following equations.

- According to the list value of PDO_hasVP in a feature, the vertical profile of the feature can be identified. If all the values are equal to *isAbove*, the undersea feature is a prominence feature. If all the values of PDO_hasVP are equal to *isBelow*, the undersea feature is a depression feature. Otherwise, the undersea feature is a mixed feature.

$$(ADO\_hasVP = Prominence) \Leftrightarrow (\forall PDO\_hasVP_i = isAbove) \tag{9a}$$

$$(ADO\_hasVP = Depression) \Leftrightarrow (\forall PDO\_hasVP_i = isBelow) \tag{9b}$$

$$(ADO\_hasVP = Others) \Leftrightarrow (\exists PDO\_hasVP_i \in PDO\_hasVP) \tag{9c}$$

- Relative spatial extent also uses two threshold values to identify three type of spatial extent.

$$(ADO\_hasRSE = Small) \Leftrightarrow (PDO\_hasRSE > TH_1\_RSE) \tag{10a}$$

$$(ADO\_hasRSE = Medium) \Leftrightarrow (TH_1\_RSE > PDO\_hasRSE > TH_2\_RSE) \tag{10b}$$

$$(ADO\_hasRSE = Large) \Leftrightarrow (TH_2\_RSE > PDO\_hasRSE) \tag{10c}$$

- The value of PDO_hasHP is between 0 to 1. According to the threshold of horizontal profile, we can get the horizontal profile type of feature from following equations.

$$(ADO\_hasHP = Circular) \Leftrightarrow (1 > PDO\_hasHP > TH\_HP) \tag{11a}$$

$$(ADO\_hasHP = Elongated) \Leftrightarrow (TH\_HP > PDO\_hasHP > 0) \tag{11b}$$

- The tip type should be identified by the value of PDO_hasTT and the result of PDO_hasHP. There are two threshold values. Firstly, when the value of PDO_hasTT is less than a threshold value, the tip of the feature is a point. Secondly, when the value of PDO_hasTT is larger than a threshold value, the tip of the feature is a line or area. Then, we need to check the feature's horizontal profile. If the feature is elongated, this feature's tip is a line. If the feature is circular, this feature's tip is an area. At last, if the value of PDO_hasTT is larger than the other threshold value, this is a special case that means this feature's tip is a huge flat area, such as plane feature.

$$((ADO\_hasTT = Point) \Leftrightarrow (PDO\_hasTT < TH_1\_TT) \tag{12a}$$

$$(ADO\_hasTT = Line/Area) \Leftrightarrow (TH_1\_TT < PDO\_hasTT < TH_2\_TT) \tag{12b}$$

$$(ADO\_hasTT = Area) \Leftrightarrow (TH_2\_TT < PDO\_hasTT) \tag{12c}$$

Equation 13 uses an example to illustrate the transformation process from conceptual to graphical representation and deduce the type of an undersea feature. Based on the predicates and threshold values, we can get the conceptual description of a feature using this equation. According to the four kinds of conceptual descriptive predicates, we can know the undersea feature is a channel.

$$\left.\begin{array}{r}\left.\begin{array}{l}TH\_HP > PDO\_hasHP > 0 \Leftrightarrow \\ \qquad ADO\_hasHP = Enlongated \\ TH\_TT < PDO\_hasTT\end{array}\right\} \Leftrightarrow ADP\_hasTT = Line \qquad\qquad \\ PDO\_hasRSE < TH\_RSE \Leftrightarrow ADO\_hasRSE = Large \\ \forall PDO\_hasVP_i = isBelow \Leftrightarrow ADO\_hasVP = Depression\end{array}\right\} \Rightarrow Channel \tag{13}$$

4. Implementation

4.1. System Design

Ontologies were built in Protégé 4.2 and exported into a RDF file. In order to implement the ontologies to identify undersea features from a nautical chart and extend to cartographic application, Yan et al. (2014) designs a system to connect the ontologies, the bathymetric database and the application platform. All the ontologies and bathymetric data are stored in the ontology database to support cartographic applications. Virtuoso, as a high performance object-relational SQL database service, is used to directly stored in the form of subject-predicate-object expressions, which is called triplestore. Predicates in this database connect data together (e.g. a feature F in PDO has a vertical profile equal to *isBelow*) and data with concepts (e.g. feature F has a tip type which is a point concept). These expressions are known as triples in RDF terminology. A key feature of many triplestores is the ability to do inference. As a Database Management System, triplestore offers the capacity to deal with concurrency, security, logging, recovery, and updates, in addition to loading and storing data.

SPARQL is a query language for ontology databases, able to retrieve and manipulate data stored in RDF format. OpenLink Virtuoso supports SPARQL is the standard query language for RDF and the semantic web, embedded into SQL for querying RDF data stored in Virtuosos database.

The database server was connected to an existing generalization platform (Guilbert, 2013) that is developed in C++ using Qt and CGAL libraries. Yan et al. (2014) extends to extract undersea features and add them in the bathymetric database. In order to manage all the data and relationships in the database, the Jena API was used to read from and write to the RDF graph in the Java platform. As our information system was initially developed in C++ language, Java Native Interface (JNI) is used to connect Java (i.e. Jena) and C++. All the predications in semantic mediators are realized in this platform.

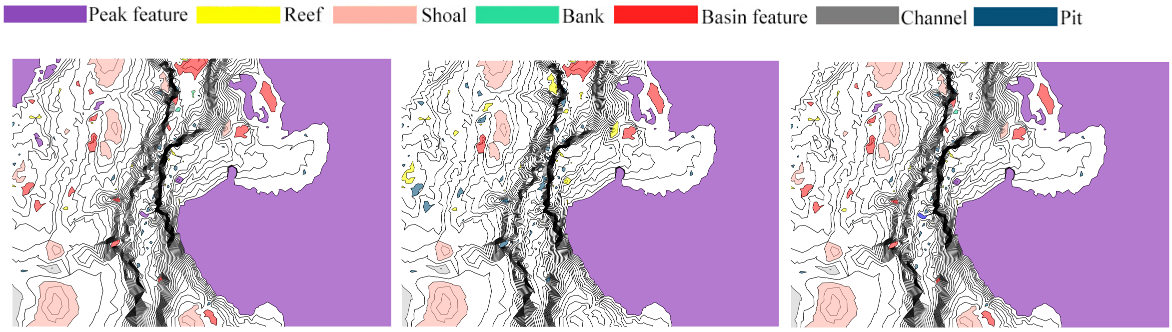
4.2. Results

The study area of this work is the channel between the tip of Port Navalo and Kerpenhir at the entrance of the Gulf of Morbihan in France. The bathymetric dataset is supported by the French Hydrographic Office for a large scale map (1:12500). Isobaths were extracted with a 1 meter vertical interval by interpolation. A first step before feature classification is extraction of undersea features based on depth variations between adjacent isobaths and yields a feature tree (Guilbert, 2013). Soundings and isobaths inside each feature are triangulated to generate the feature surface and compute its shape properties in order to classify them. After triangulation and calculation, the semantic mediators are used to identify links, for particular feature types, between cartographic representation ontology to submarine relief ontology.

Seven types of undersea features are identified on the chart. The tip and body properties of a feature are computed from the soundings and isobaths. The base property is computed from the boundary contours. The property of the feature is computed by the highest or deepest sounding and by adding neighboring triangles to extract the largest possible horizontal surface. The result to identify tip type of feature in the following steps. Threshold values are tested on the nautical chart to obtain satisfactory results of undersea features identification. Three groups of threshold values are tested in this work:

- tv_A: $0.2 < PDO\_hasTT \leq 0.8$ and $0.0001 < PDO\_hasRSE \leq 0.000625$;
- tv_B: $0.6 < PDO\_hasTT \leq 0.8$ and $0.0001 < PDO\_hasRSE \leq 0.000625$;
- tv_C: $0.2 < PDO\_hasTT \leq 0.8$ and $0.001 < PDO\_hasRSE \leq 0.0625$

The group tv_A means if the value of tip type is less than 0.2, the tip type should be a point; if the value of tip type is between 0.2 and 0.8, the tip type should be a line or area; if the value of tip type larger than 0.8, the tip type will be a big flat area. If the PDO_hasRSE is less than 0.001, the feature is large; if the value of PDO_hasRSE is between 0.0001 and 0.000625, the feature is medium; if the PDO_hasRSE is larger than 0.000625, the feature is small. In the tv_B, the threshold value of tip type has been increased, which means much more features might be identified as point feature. In the tv_C, the threshold value of body has been enlarged, which means some small features haven't been considered. Figure 5 compares all the features are extracted with three groups of threshold values. Table 1 shows a statistics of feature types and numbers in three groups. Seven types of feature (peak feature, reef, bank, shoal, pit, channel and basin feature) were identified and characterized (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. It is clearly find the total number of features of group tv_A is larger than that of another groups. A lot of features are identified as small features in the tv_B, such as pit. The peak feature of the group tv_C is far less than that of another groups. Through figure 5, we also can find some large features are missed in the tv_B and tv_C.



(a) tv_A (b) tv_B (c) tv_C

Figure 5.: Comparison all the features with different threshold values.

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

Threshold values	Peak feature	**Reef**	**Bank**	**Shoal**	Pit	Channel	Basin feature	Total
tv_A	25	6	4	9	34	6	17	101
tv_B	14	16	0	5	40	3	4	82
tv_C	7	16	1	10	31	6	16	87

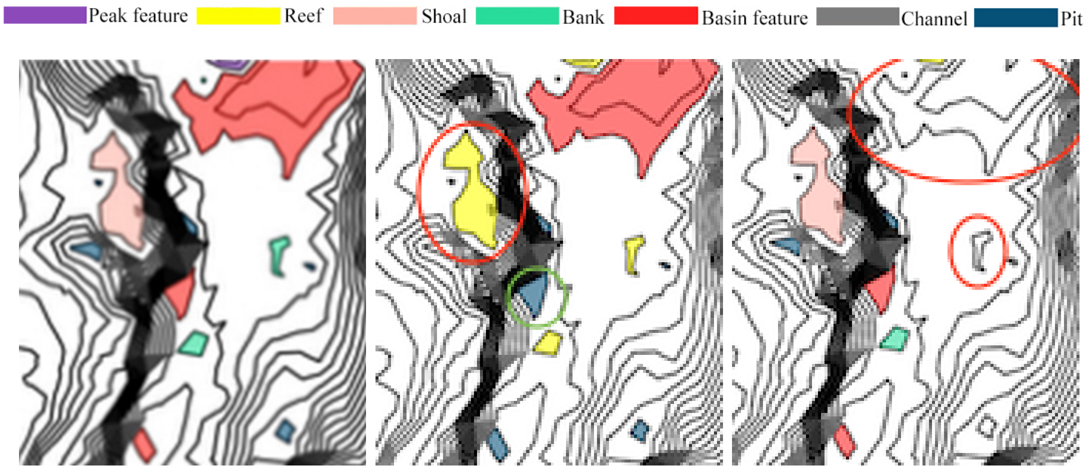
The comparison at global level is not enough to evaluate the results. Hence, the figure 6 provides a comparison of features' details in a selection region. Comparing figure 6a and 6b, we can easily found a feature is identified as a reef in the red circle (Figure 6b). According to the definition in the submarine relief ontology, the reef is a prominence feature with point tip and small size. Apparently, this feature with the red circle is a relatively large size feature in figure 6b. Meanwhile, a relative small feature with the green circle (Figure 6b) is identified as a pit feature. Because the size of reef and pit feature should be similar, these results are not reasonable. In figure 6c, the threshold values of relative spatial extent are changed to 0.01 and 0.0625. Obviously, some important features are missed in the red circles of figure 6c. After testing different threshold values, the threshold values of Table 2 produce satisfactory results.

5. Conclusion

Undersea features are parts of the seafloor whose definitions are usually vague and qualitative. Although they are easily understood by map readers, their characterization from bathymetric data is still a problem. We have proposed in this paper an

Table 2.: Threshold values.

Feature components	Description predicates	Conceptual values	Graphical values
Tip	TT	$PDO\_hasTT \leq 0.2$	point (e.g. pit)
		$0.2 < PDO\_hasTT \leq 0.8$	line or area
		$PDO\_hasTT > 0.8$	big flat area (e.g. plane feature)
Body	RSE	$PDO\_hasRSE \leq 0.0001$	large (e.g. bank)
		$0.0001 < PDO\_hasRSE \leq 0.000625$	medium (e.g. ridge)
		$PDO\_hasRSE > 0.000625$	small (e.g. peak)
Base	VP	$0 < PDO\_hasHP < 0.2$	elongated
		$0.2 < PDO\_hasHP < 1$	circular
Body	HP	isBelow	Depression
		isAbove	Prominence
		isFlat	Other



(a) tv_A (b) tv_B (c) tv_C

Figure 6.: Comparison details of features with different threshold values.

approach where features are described in two different ontologies as a way to facilitate the recognition of undersea features directly from bathymetric data. Qualitative knowledge is formalized in an application domain ontology so that all features follow a similar pattern. Representation on a chart is described in another ontology. On top of considering bathymetric data such as soundings and isobaths which are portrayed on the chart, we also consider undersea features as objects. These features are defined by sets of isobaths and soundings and can also have their own morphometric and thematic properties. Feature objects developed in the PDO are used to represent features defined in the ADO. The link between the two ontologies is performed by semantic mediators. They are predicates which associate qualitative concepts from the ADO with quantitative measurements made in the PDO. The definition of a predicate also includes a threshold value defining its limits.

At last, this work provides an implementation performing undersea feature identification from a bathymetric dataset. Classification was performed with different threshold values for different properties and showed that, although the results depend on the choices of values made by the user, they remain relatively robust. Currently, only features bounded by one or several isobaths are classified in the PDO. The undersea features are identified by the crisp boundary subjectively. However, it is difficult to clearly determine the boundary of undersea features from the inherent vagueness of landforms. Therefore, we can try to use one or several soundings (e.g. a seamount where only the summit is marked) to represent undersea features in future work. In addition, much more feature concepts might be involved, which lead to the details of features and levels of feature tree will become much more complex. In order to limit the number of features, the decision tree may be simplified according to the type of chart (large or small scale, coastal or offshore navigation).

Applying the framework to different contexts would require users to be able to define thresholds according to their contexts, which would require a sufficient level of training and expertise. Hence, further work is required to try and reduce the number of thresholds by considering contextual variables such as the local context and the scale at which features are described. This would require further knowledge that shall be provided by domain experts (e.g. geomorphologists) and introduced in the ontology to infer these threshold values.

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