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Article

Knowledge-Based Recommendation For On-Demand Mapping: Application To Nautical Charts

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Abstract: Maps have long been seen as a single cartographic product for different uses, with the user having to adapt their interpretation to his or her own needs. On-demand mapping reverses this paradigm in that it is the map that adapts to the user's needs and context of use. Still often manual and reserved for professionals, on-demand mapping is evolving towards an automation of its processes and a democratization of its use. An on-demand mapping service is a chain of several consecutive steps leading to a target map that precisely meets the needs and requirements of a user. This article addresses the issue of selecting relevant thematic layers with a specific context of use. We propose a knowledge-based recommendation system that aims to guide a cartographer through the process of map-making. Our system is based on high and low-levels ontologies, the latter modeling the concepts specific to different types of maps targeted. By focusing on maritime maps, we address the representation of knowledge in this context of use where recommendations rely on axiomatic and rule base reasoning. For this purpose, we choose Description Logics as a formalism for knowledge representation, in order to make cartographic knowledge machine-readable.

Keywords: Ontology; Knowledge Representation and Reasoning; On-Demand Mapping; Recommendation System; Cartography.

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1. Introduction

The increase in the use of maps over the past few decades in everyday activities, accelerated by the digital production and dissemination of maps and the widespread availability of low-cost location-sensitive devices, has made the work of cartographers and map display designers more challenging. Mapping agencies such as the Ordnance Survey (OS) in UK, the National Institute of Geographic and Forest Information (IGN) or the Hydrographic and Oceanographic Service (SHOM) in France have recognized for a long time this gap between the maps provided to the user and the maps that the user would need. This is one of the reasons why they offer on-demand mapping services. This type of service allows to meet precisely the requirements of a user and to ensure the production of a high quality map. However, despite the scientific and technical progress, it is an expensive service because it requires qualified human resources.

In order to reduce the costs of producing personalized maps, geographic agencies have developed geographic Web services that allow a user to view and download his or her own maps, but independently of a particular need and context of use. The user builds his or her own cartographic representation by merging the thematic layers made available by the storage infrastructure with eventually his/her own. Moreover, the geographic Web services should go beyond the simple proposal of viewing and downloading data. It would be useful to be able to benefit from geographic services that interfere with business logic and understand the specific needs of the user.

We therefore want to propose a recommendation system for the on-demand map based on a context representation model adapted to the design of static and dynamic maps. The objective is to allow a user to obtain the knowledge he/she requires in the course of his/her activities and to obtain a representation of this knowledge in a cartographic format such as could be proposed by a cartographer or a Web service. The design of such an on-demand map service is a multidisciplinary research field whose goal is to develop mechanisms that are capable, without human assistance, of collecting a set of user requirements and interpreting them to build a personalized map.

Automatic map creation is a complex process that has attracted the interest of many cartographers, geographers and computer scientists. The automatic creation of a personalized map raises several scientific issues ranging from data selection, map generalization problems, to visualization. In this paper, we limit ourselves to the process of selecting thematic layers, by a recommendation system that responds to the needs and the activities of a particular user, without addressing visualization and generalization problems. For implementation issues, we have focused our case studies on selecting knowledge for the implementation of on-demand maps in a maritime context but it can be derived to others (topographic, geological, tourism, etc.).

The rest of the paper is organized as follows. In Section 2, we present a literature review on the on-demand mapping process and context modeling with a focus on recommendation systems in the cartographic domain. In Section 3, we describe the research problem with our preferred orientations. Then, we present the implementation of the proposed solution in Section 4. Section 5 focuses on some use case scenarios, and finally a discussion concluded this proposal in Section 6.

2. Literature Review

2.1. On-Demand Mapping

On-demand mapping is the research field that aims to automatically derive customized maps based on users requirements. Many existing research works in the field of Geographic Information Sciences (GIS) are related to on-demand mapping. According to Cecconi [1], on-demand mapping is defined as *"the creation of a cartographic product upon a user request appropriate to its scale and purpose"*.

Figure 1 represents the main steps of an on-demand mapping system. These steps are necessary to derive, manually or automatically, a customized map. Each step listed above is a research field in its own [2].

Sarjakoski and Sarjakoski [3] implemented the first on-demand mapping prototype as part of the GiMoDig (2001-2004) project[1]. The authors tried to improve the accessibility and interoperability of national topographic databases in a mobile context. The key techniques were data integration and real-time generalization. Custom map specifications are built from context parameters collected from the user and an internal knowledge base. Bucher et al. [4], at the COGIT laboratory of IGN France, specified a series of Web services, to provide on-demand maps based on user's specifications : a map specification service, a legend definition service, and a legend evaluation service. The first service helps the user defining some of the abstract properties of their map. The two other services make use of the large knowledge base about legends to propose adequate symbolization. Foerster et al. [5] proposed a distributed architecture for on-demand Web mapping by formalizing user requirements in UML and XML models. As core of the architecture, a so-called generalization-enabled Web Map Service is presented to automate the generalization process on the Web. Gould [6] developed an on-demand mapping system based on an ontology for roads and road accidents. He aims to model the process of generalization and devise a method for automatically selecting the appropriate algorithms for mapping geographic features at multiple scales using an ontology.

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[1] Geospatial Info-Mobility Service by Real-Time Data-Integration and Generalization (GiMoDig) project, IST-2000-30090, funded by the European Union through the Information Society Technologies (IST) program.

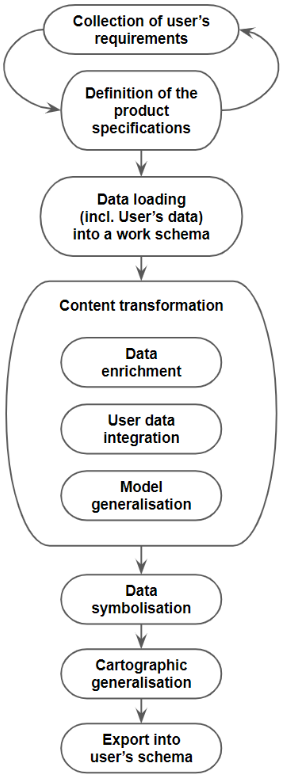


Figure 1. Main steps of the on-demand mapping process [2].

Balley et al. [7] worked on the translation of user requirements to map specifications. Map specifications rely on generalization, data production, data integration and legend design. The authors designed a map specifications model representing the principle of cartographic constraints to support not only generalization, but also other processes required by on-demand mapping, notably data integration. A use case of translation of user preferences to map specifications is shown by collecting user preferences in order to infer appropriate map color and map legend.

The state of the art points out that the existing research studies in the on-demand mapping domain mainly focus on the generalization process, selecting appropriate map color respecting user's tastes, designing map legends, etc. In our research, we address the problem of transforming user's requirements to map specifications, and more precisely, selecting relevant thematic data/layers according to user's requirements and context.

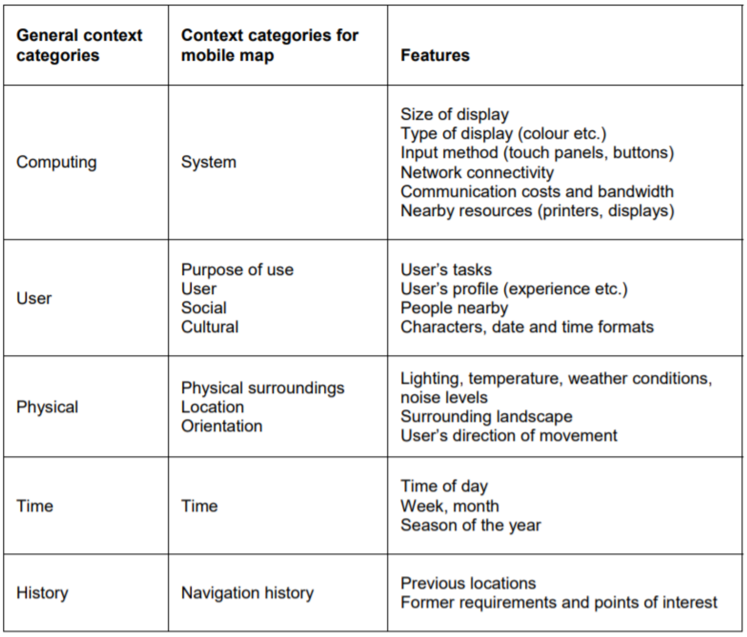
2.2. Contextual Cartography Modeling

Before focusing more extensively on the modeling of the cartographic context, different works exist on context modeling from a general point of view. A commonly accepted definition of context has been proposed by [8]. According to him, a context is defined as *"any information that can be used to characterize the situation of an entity. An entity is a person, place, or object that is considered relevant to the interaction between a user and an application, including the user and applications themselves"*. In other words, a context is determined by the state of the values of the parameters relating to the characterization of a situation. It is a set of information that influences a task performed by a person or characterizes a specific situation in a computer system. A context-aware system is defined as follows *"A system is context-aware if it uses context to provide relevant information and/or services to the user, where relevancy depends on the user's task"* [9]. Chen and Kotz [10] defined two classes of context-aware systems: active and passive systems. An active system is a system that takes into account the change of the dynamic contextual information and adapts its behavior according to the current situation, whereas a passive system is not able to update its behavior following a change of the context.

Strang et al. [11] present a survey of six context modeling approaches: key-value models, markup scheme models, graphical models, object-oriented models, logic-based models and ontology-based models. Their analysis favors the ontology-based model for context modeling. According to Wang [12], the reasons for developing context models based on ontology rely on:

- **Knowledge sharing:** The use of context ontology enables computational entities such as agents and services (e.g., in pervasive computing environments) to have a common set of concepts about context while interacting with one another.
- **Logic Inference:** Based on ontology, context-aware computing can exploit various existing logic reasoning mechanisms to deduce high-level conceptual context from low-level.
- **Knowledge Reuse:** By reusing well-defined ontologies of different domains (e.g., temporal and spatial ontologies), we can compose large-scale context ontology without starting from scratch.

Focusing on the literature review on contextual cartography, several research works have been done in order to introduce the notion of context in cartography, especially in mobile systems. First attempts to adapt visualization in mobile cartography were introduced by Reichenbacher [13] and Zipf [14]. Reichenbacher presented a conceptual framework for mobile cartography based on three essential components for visualization adaptation: the user, the context, and the task. The notion of context in digital mapping has been later studied by Nivala and Sarjakoski [15] in their work on digital maps for mobile systems as part of the GiMoDig project (2001-2004). These researchers first relied on the definitions of context proposed by Schilit [16] and Dey [8]. Then, they proposed a context classification adapted to maps to describe a cartographic context in mobile systems based on five general context categories: Computing, User, Physical, Time, and History. Each general context category includes a set of context categories for a mobile map as presented in Figure 2:



General context categories	**Context categories for mobile map**	**Features**
Computing	System	Size of display Type of display (colour etc.) Input method (touch panels, buttons) Network connectivity Communication costs and bandwidth Nearby resources (printers, displays)
User	Purpose of use User Social Cultural	User's tasks User's profile (experience etc.) People nearby Characters, date and time formats
Physical	Physical surroundings Location Orientation	Lighting, temperature, weather conditions, noise levels Surrounding landscape User's direction of movement
Time	Time	Time of day Week, month Season of the year
History	Navigation history	Previous locations Former requirements and points of interest

Figure 2. Categorization of contexts and their characteristics for mobile cartographic services [15].

2.3. Recommendation Systems

Recommendation systems are tools for interacting with large and complex information systems. The goal of these systems is to provide to a user a personalized view of these information systems by prioritizing relevant resources based on their preferences, in order to assist him/her in the different decision-making processes.

According to the literature [17], widely used recommendation approaches are content-based, collaborative filtering and knowledge-based. Collaborative filtering (CF) approaches are based on the opinion of a group of users who have the same preferences - ratings of items by a community of users – to generate recommendations. Collaborative filtering algorithms have the advantage of using only historical data; no knowledge of the items is required. However, they suffer from a "cold-start" problem; a new user cannot receive any recommendations before rating several items and a new item cannot be recommended before being rated by a number of users [18]. Content-based filtering (CB) approaches use item features to recommend items similar to those in which the user has expressed interest. CB has no cold start problem but is unable to provide the serendipitous[2] recommendations that CF generates. Lastly, knowledge-based approaches (KB) use domain knowledge in a structured form to produce personalized recommendations. KB approaches avoid the cold start problem and have the advantage of enhanced reliability as the background knowledge is free of noise. However, knowledge-based systems require considerable knowledge acquisition effort for setup and maintenance during their lifetime [19], which makes them more expensive to develop and maintain.

3. Problem Statement and Preferred Orientations

The application objective is to develop a system that aims to assist a cartographer, in the process of creating an on-demand map, to select the relevant thematic layers according to user requirements and a given context of use. According to the main steps of the on-demand mapping process presented in Figure 1, we focus exclusively on the definition of thematic layers according to user requirements (i.e., "Definition of the product specifications" step). In order to make a machine able to transmit and infer the cartographic knowledge adapted to a given context derived from user requirements, the machine must be able to understand the knowledge (information) that it handles. This is a step towards the automation of cartographic systems. To make map information machine-readable, it is necessary to model and represent this information. This requires the use of a representation formalism with a defined syntax and formal semantics. The most suitable formalism for knowledge representation is the description logic (DL). DL is known as the reference for the creation of ontologies. DL allows us to formalize simple or complex concepts in a hierarchical way, the properties - roles - that link the concepts and individuals. This formalism is supported by languages, such as OWL (Web Ontology Language), that allow the implementation of formalized ontologies and also have reasoners for inference, such as Pellet, FacT++, or Hermit, taking into account the temporal and spatial dimensions.

One solution for building such systems is the recommendation approach. According to Pathak et al. [20], recommendation systems have proved their ability to improve the decision-making process. In our research, we choose the knowledge-based approach for different reasons. The advantages of this approach can be summarized as follows:

- **No cold start problem:** the recommendation system can start producing recommendations for new users without the need of rating any item before.
- **Assured quality:** Since the knowledge-based recommendation systems try to match between the user's requirements/preferences and the items, so the results of recommendation are accurate and deterministic.
- **Criticality of the domain:** according to Ramezani et al. [18], the cost of a wrong recommendation must be considered. In critical domains, a knowledge-based approach is needed, as a correct and explainable recommendation is impossible with other approaches.

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[2] Serendipity is the luck some people have in finding or creating interesting or valuable things by chance (Collins COBUILD Advanced Dictionary).

In order to make the system sensitive to context, the rule base and the ontology formalization can take into consideration the different dimensions of context (see section 4.1). In the next section, we will present a methodology to develop a knowledge-based recommendation system which is sensitive to context for on-demand mapping process.

4. Methodology

The first step towards context modeling and representation for an on-demand mapping is the *Conceptualization*. This step consists in categorizing the objects of the real world into abstract concepts. Once the concepts are defined, we use description logic as a formalism for knowledge representation in order to represent the semantics of concepts in a structured way and then extract implicit knowledge by ontological reasoning. In order to create our knowledge base, we implement the concepts as an ontological model using *Protégé*[3] with a set of SWRL (Semantic Web Rule Language) rules for a rule-based reasoning. Lastly, we instantiate the model in order to illustrate a concrete use case to infer relevant thematic layers according to a given context of use. Although the methodology is general for the on-demand map, we will focus on the on-demand map in the maritime domain to concretise and illustrate the proposed approach.

4.1. Conceptualization

In their work on a contextual ontology for service recommendation, Cabrera et al. [21] proposed an approach for conceptualization that consists in building a glossary of terms from the concepts corresponding to the first level of hierarchy of several proposed context models. We used the same approach, adapting their categorization to the field of cartography, taking into account Nivala and Sarjakoski's categorization [15].

In a manual process of on-demand mapping, the cartographer defines the map specifications (i.e., the relevant data to be mapped), according to the user's profile, the purpose of use, the geographical area, etc. The automation of this process requires additional knowledge or concepts like user's expertise (e.g., expert/non-expert), user's community (e.g., surfing club), the policies and restrictions of the practice area (e.g., caution area).

Towards an automated process of on-demand mapping, a *User* requesting a map has a *Profile*, plans for an *Activity*, and may also belong to a *Community*. The activity takes place in a practice area (i.e., *Location*), has a temporal state (i.e., *Time*) and is surrounded by a physical *Environment*. Based on the domain of application, the *Physical Environment*, a subclass of *Environment*, represents the environmental conditions: *Weather conditions*, *Traffic conditions*, *Oceanographic forecast*, etc. The physical environment may be exposed to *Events* and the practice area might have some *Policies* and restrictions. A *Context Information* is defined by any information describing user's profile/preferences (e.g., Profile, Activity, etc.) or the surrounding environment (e.g., Event, Time, etc.). We have divided *Context Information* into two classes: *Static Context Information* and *Dynamic Context Information*, to make the model useful both for static maps and adaptive maps (i.e., navigation systems that periodically adapt their display according to a given context). A static context information is an information that persists throughout a long time (i.e., during a session of use of the system). For instance, the user's profile or user's activity are static context information since they don't change during the recommendation process. A dynamic context information is an information that may have changes over a short time, maybe several times during a single recommendation session. For instance, traffic information for road maps is a dynamic context information since this information changes during the same recommendation. One or more context information provides a defined *Context*.

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[3] https://protege.stanford.edu/

In order to make the model more generic, we have defined high-level concepts as a first step, as shown in Table 1. Each high-level concept includes a set of low-level concepts describing a context in a specific domain of application (e.g., weather, population density, navigation, tourism maps).

Table 1. High-level concepts for context description.

High-Level Concept	**Description**
Context	A collection of values extracted from context information
Context Information	Any information that can be used to describe user's profile or the surrounding environment
Static Context Information	A context information that persists during the same recommendation session (e.g., user's profile)
Dynamic Context Information	A context information that changes during the same recommendation session (e.g., location)
Situation	A set of values extracted from dynamic context information during a short time
Activity	The purpose of use of the user (e.g., navigation)
Time	The time during which the activity takes place
Location	The area where the activity takes place
Environment	Surrounding physical and computational environments
Event	It might be natural events (e.g., storm, rain, fire) or human events (e.g., collision)
Policy	Regulations applied to a geographical area (e.g., caution area)
User	The end-user of the map
Profile	The user's profile (e.g., profession, expertise, community)

In the following, we decide to focus on the definition of low-level relevant concepts in the maritime domain that affect the process of on-demand nautical map making. To do this, we have extracted some knowledge related to the maritime environment and navigation from reference books [22–24], as well from the SHOM[4] website. In addition, we also had discussions with experts in maritime navigation training from the French Naval Academy.

In order to illustrate some recommendation examples in the maritime domain, we have chosen to conceptualize some knowledge that will be used in the following to illustrate the usability of our approach to make recommendations. In a maritime domain, we consider that the *Physical Environment* consists of *Weather Conditions*, *Oceanographic Forecast*, *Tide Conditions*, etc. We defined the concept of *Visibility Distance* as a subclass of *Weather Conditions*. By definition, the visibility is the distance (in miles) at which an object can be clearly distinguished. The *Visibility Distance* is a class that determines the value of the visibility (in miles). Based on this value, we defined the class *Visibility Situation*, as a subclass of *Situation*, in order to represent the different visibility conditions. The *Visibility Situation* consists of *Good Visibility*, *Restricted Visibility* and *Bad Visibility*.

In our model, a *Situation* implies a *Context*. We have defined a set of *Contexts* related to *Visibility Situations* as follows: *Good Visibility Context*, *Restricted Visibility Context* and *Bad Visibility Context*. Other contexts are defined based on the user's activity like *Navigation Context*, *Fishing Context*, *Sailing Context*, etc. In a maritime environment, an *Event* could be a *Natural Event* (e.g., Intense fire) or *Human Event* (e.g., Collision).

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[4] https://data.shom.fr/

Policies could be *Regulation* (e.g., Restricted area, fishery zone, etc.) or *Sovereignty* (e.g., Contiguous zone, exclusive economic zone, etc.).

Table 2. Some domain concepts describing a context of on-demand nautical map.

High-Level Concept	Domain Concept
Context	Fishing Context, Navigation Context, Surfing Context, etc.
Situation	Bad Visibility, Restricted Visibility, Good Visibility
Activity	Navigation, Transportation, Fishing, etc.
Time	Daytime, Night-time
Location	Practice Area
Physical Environment	Weather Conditions, Tide Conditions, etc.
Event	Storm, Intense Fire, Collision, etc.
Policy	Regulation, Sovereignty

4.2. Formalization

Description logics [25] are a class of knowledge representation formalisms, which can be used to represent the knowledge of an application domain in a structured and formally well-understood way. In DLs, we formalize the relevant notions of an application domain by concept descriptions. A concept description is an expression built from atomic concepts, which are unary predicates, and atomic roles, or binary predicates, by using logical constructors and quantifiers provided by the particular DL language in use. In the following, we will define some concepts using DL that we will use in section 5 in order to illustrate concrete scenarios. We restrict hereinafter to the concept definitions leading to different contexts according to either a *Situation* (e.g., a *Visibility Situation*) or an *Activity* (e.g., *Fishing*).

As presented in section 4.1, we identify three *Visibility Situations*. According to [23], a *Bad Visibility* situation takes place when the *Visibility Distance* is less than 2 miles, or when the *Activity* takes place at *Night*. The *Restricted Visibility* takes place when the *Visibility Distance* is between 2 and 5 miles, and greater than 5 miles for *Good Visibility*. The concept of *Night-time* is a subclass of *Time*, it indicates the time between evening and morning; the time of darkness.

$$Night - time \sqsubseteq Time \tag{1}$$

$$VisibilityDistance \sqsubseteq WeatherConditions \tag{2}$$

$$VisibilitySituation \sqsubseteq Situation \tag{3}$$

$$VisibilitySituation \equiv GoodVisibility \sqcup RestrictedVisibility \sqcup BadVisibility \tag{4}$$

$$\begin{aligned} GoodVisibility \equiv Situation \sqcap \exists causedBy\,.\,(VisibilityDistance \sqcap \\ \exists hasVisibilityDistance\,.\,(>5)) \end{aligned} \tag{5}$$

$$\begin{aligned} RestrictedVisibility \equiv Situation \sqcap \exists causedBy\,.\,(VisibilityDistance \sqcap \\ \exists hasVisibilityDistance\,.\,(\geq 2) \sqcap \exists hasVisibilityDistance\,.\,(\leq 5)) \end{aligned} \tag{6}$$

$$\begin{aligned} BadVisibility \equiv Situation \sqcap \exists causedBy\,.\,(VisibilityDistance \sqcap \\ \exists hasVisibilityDistance\,.\,(<2) \sqcup (\exists causedBy\,.\,Night) \end{aligned} \tag{7}$$

$$BadVisibilityContext \equiv Context \sqcap \exists generatedBy\,.\,BadVisibility \tag{8}$$

According to user's *Expertise*, a user may be professional or standard. We define a *Professional User* as a user whose expertise is equal to the predefined value *"high"*, and a *Standard User* is a user whose expertise is equal to *"low"* or *"medium"*.

$$ProfessionalUser \equiv User \sqcap \exists hasExpertise.\{high\} \tag{9}$$

$$StandardUser \equiv User \sqcap (\exists hasExpertise.\{low\} \sqcup \exists hasExpertise.\{medium\}) \tag{10}$$

Le Guyader [26] presents a classification of human activities in the coastal maritime area. In this classification, we have the *Fishing* concept that designates a professional fishing *Activity*, and the *Casual and Pleasure Fishing* concept related to a leisure *Activity*. In order to define contexts related to fishing activities, we have relied on two types of context information: the *Activity* and the user's *Expertise*. We defined the concept of *Fishing Context* with two sub-contexts: the *Professional Fishing* context and the *Leisure Fishing* context. The *Professional Fishing* context indicates a *Fishing* activity carried out by a *Professional User*. The *Leisure Fishing* context takes place when a *Standard User* is engaged in a *Fishing* activity. We have the same principle with the sailing *Activity*.

$$Fishing \sqsubseteq Activity \tag{11}$$

$$Sailing \sqsubseteq Activity \tag{12}$$

$$FishingContext \sqsubseteq Context \tag{13}$$

$$SailingContext \sqsubseteq Context \tag{14}$$

$$FishingContext \equiv LeisureFishingContext \sqcup ProfessionalFishingContext \tag{15}$$

$$SailingContext \equiv LeisureSailingContext \sqcup ProfessionalSailingContext \tag{16}$$

$$\begin{split}ProfessionalFishingContext \equiv Context \sqcap \exists isTheContextOf.(Fishing \sqcap \\ \exists hasActor.ProfessionalUser)\end{split} \tag{17}$$

$$\begin{split}LeisureFishingContext \equiv Context \sqcap \exists isTheContextOf.(Fishing \sqcap \\ \exists hasActor.StandardUser)\end{split} \tag{18}$$

$$\begin{split}ProfessionalSailingContext \equiv Context \sqcap \exists isTheContextOf.(Sailing \sqcap \\ \exists hasActor.ProfessionalUser)\end{split} \tag{19}$$

$$\begin{split}LeisureSailingContext \equiv Context \sqcap \exists isTheContextOf.(Sailing \sqcap \\ \exists hasActor.StandardUser)\end{split} \tag{20}$$

4.3. Ontology Implementation

Based on the concepts formalization of section 4.2, the conceptualization defined in section 4.1 was implemented as an ontological model using *Protégé*. This implementation provides support for Description Logics reasoning. The high-level concepts were implemented as classes in order to obtain a high-level ontology (Figure 3). Then, we implement the domain concepts as subclasses of the main concepts. Reusing existing ontologies is a crucial step in ontology development. It provides a useful starting point to be fully or partially reused. For instance, we used the GeoSPARQL[5] standard ontology to represent the spatial dimension, and the OWL-Time ontology [27] to represent the

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[5] http://www.opengis.net/ont/geosparql#

temporal dimension. The *FOAF*[6] ontology is used to represent the user's profile. The classification of maritime activities presented by Le Guyader [26] has been integrated into our model as classes and subclasses. We also reused the ontological approach proposed by Tsatcha [28] to model the S-57[7] standard format. The S-57 model classifies hydrographic information (i.e., thematic layers) used for nautical charts making. In addition to hydrographic information, we have extracted two meteorological layers from the SHOM[8] geoportal: Oceanographic Forecast and Coastal Observations. These thematic layers will be useful for the following use cases. All the layers (i.e., S-57, Oceanographic Forecast, etc.) are subclasses of the class *Resources*.

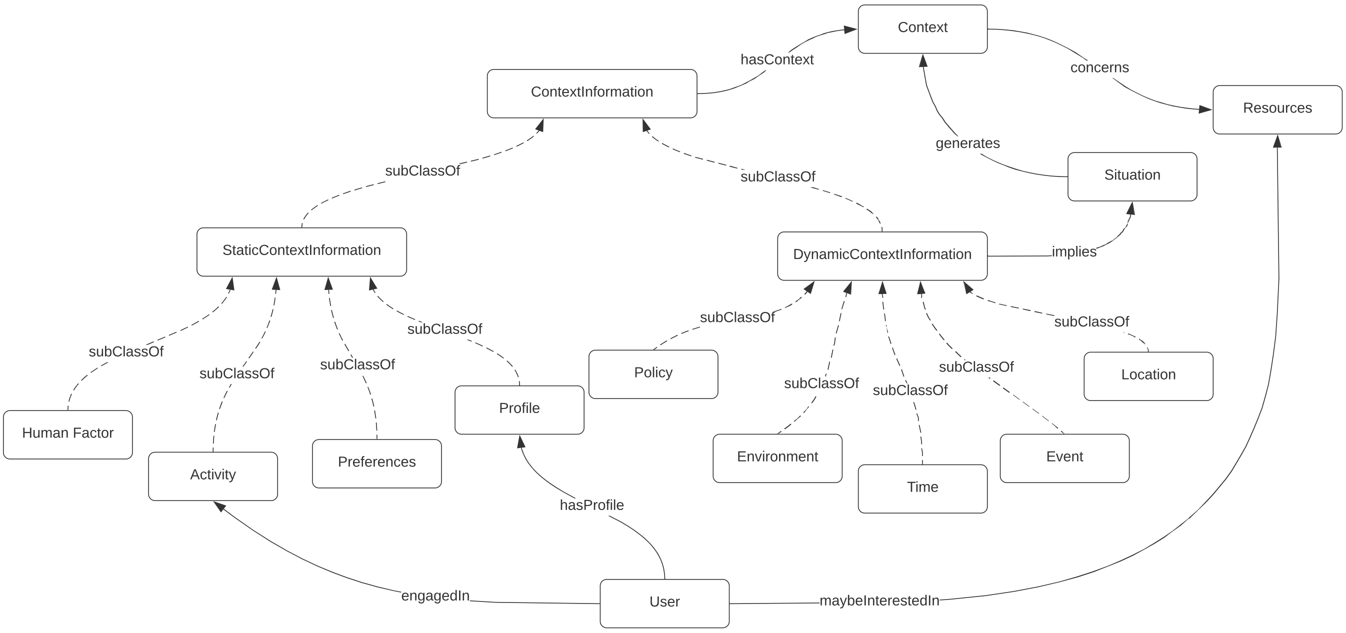

Figure 3. Overview of the proposed upper ontology.

The ontology we provide in this work consists of a set of sub-ontologies describing abstract concepts for on-demand maps. Thereafter, we extend these sub-ontologies by concepts related to a particular domain: on-demand maritime maps. Figure 4 and figure 5 depict the resulting ontologies including their general relationships. In the following, we detail the sub-ontologies with their relationships (Table 3).

User ontology

The user ontology consists of two main branches: the user's profile and his/her activity. On the one hand, the user's profile has an influence on map-making process: it includes the *Profession* of the user, the *Community* to which he/she belongs, his/her *Expertise*, *Disability* and *Interests*. Some of these factors affect the relevant data to be mapped (e.g., Expertise, Interest, etc.) and others affect the semiology of graphics in the maps (i.e., graphic techniques including shape, orientation, color, texture, etc.). For example, certain disabilities (e.g., a color-blind user) will directly affect the graphic semiology. On the other hand, the user is engaged in an activity. The activity is a crucial factor to infer relevant thematic layers (Figure 5).

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[6] http://xmlns.com/foaf/spec/
[7] http://www.s-57.com/
[8] https://data.shom.fr/

Table 3. Object properties between main classes.

Object Property	Domain Class	Range Class
engagedIn	User	Activity
hasActor ($\equiv$ engagedIn^{-1})	Activity	User
hasExpertise	User	Expertise
maybeInterestedIn	User	Resources
hasEnvironment	Activity	Environment
hasTime	Activity	Time
LocatedIn	Activity	Location
hasContext	ContextInformation	Context
isTheContextOf ($\equiv$ hasContext^{-1})	Context	ContextInformation
exposedTo	PhysicalEnvironment	Event
implies	DynamicContextInformation	Situation
causedBy ($\equiv$ implies^{-1})	Situation	DynamicContextInformation
generates	Situation	Context
generatedBy ($\equiv$ generates^{-1})	Context	Situation
concerns	Context	Resources
hasConditions	PhysicalEnvironment	WeatherConditions

Activity ontology

Identifying the activity of the user is the most important stage in order to select the relevant thematic layers in the context of use related to it. An activity has a temporal dimension, either qualitative (e.g., Day/Night) or quantitative using the OWL-Time ontology. An activity is located in a *Practice Area*, the area where the user is planning to carry out his/her activity. The practice area may have some restrictions like *Regulations* (e.g., Caution area, Fishery zone, etc.) or *Sovereignty* (e.g., Contiguous Zone, Exclusive Economic Zone, etc.). The activity is also associated to a surrounding *Physical Environment* (Figure 5).

Environment ontology

Environmental factors have a potential influence on the map display. This concept consists of two types: physical environment and computational environment. On the one hand, the computational environment describes the device used by the end-user (e.g., network connectivity, size of output display, etc.). These factors are related to the visual representation of the map (e.g., semiology, cartographic generalization, etc.). On the other hand, the physical environment has an impact on the process of selecting relevant thematic layers. For example, according to *Weather Conditions* the map may have different layers in different contexts of use. We defined the weather conditions as one of the physical environment factors (Figure 5).

Location ontology

In order to take into consideration the spatial dimension, we used the GeoSPARQL ontology standard. The spatial dimension is limited to the user location, the geographical area where his/her activity takes place and the geographical coordinates of cartographic entities which instantiate the thematic layers (Figure 5).

Time ontology

The temporal dimension consists of two types: qualitative and quantitative. The OWL-Time ontology is used to represent the quantitative time. Furthermore, the qualitative time could be represented with concepts like *Day-time*, *Night-time*, etc (Figure 5).

Event ontology

This ontology is limited to a set of predefined events that can occur during the user's activity. There are two types of events: *Human Events* like boat collisions or regatta, and *Natural Events* (e.g., intense fire, storm, etc.) (Figure 5).

Context ontology

It is the most important part of the ontology. The class *Context* is a generic concept, from which we can define a set of contexts related to different application domains of on-demand maps (e.g., maritime cartography or land cartography). For implementing our case studies, we have defined a set of contexts related to maritime cartography. One or more context information forms a context of use. Each defined context is associated to a set of relevant thematic layers using the object property *"concerns"* (Figure 4).

Situation ontology

The situation ontology represents the state of the system during a short time. The state is derived from dynamic context information which can change their values over a short time (i.e., during a recommendation session). A situation could be a danger, a capacity for visibility, etc. Each situation generates a defined context. In the following case studies, we defined some situations related to visibility states (Bad, Restricted, or Good Visibility situations) varying according to the weather and time conditions (Figure 4).

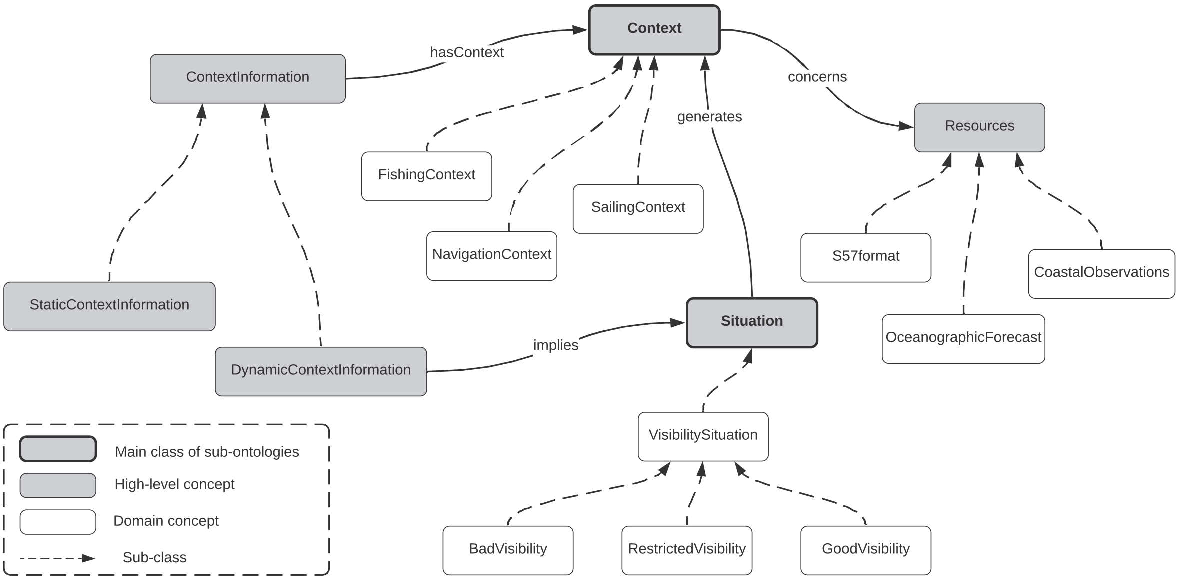

Figure 4. Partial taxonomy overview of concepts related to the sub-ontologies: Context and Situation.

4.4. Reasoning

The proposed approach aims to recommend to a user, the relevant thematic layers according to a given context of use. The reasoning process is the core of such recommendations. It consists of two ontological reasoning types: axiomatic reasoning and rule-based reasoning. Axioms are used to represent real-world knowledge in the ontologies using the OWL syntax, while complex problems need additional description techniques. Our initial ontology formalization (section 4.2) has been extended with a defined rule base. These rules are formalized using the Semantic Web Rule Language (SWRL) to express the required statements. SWRL is an expert-level solution or an

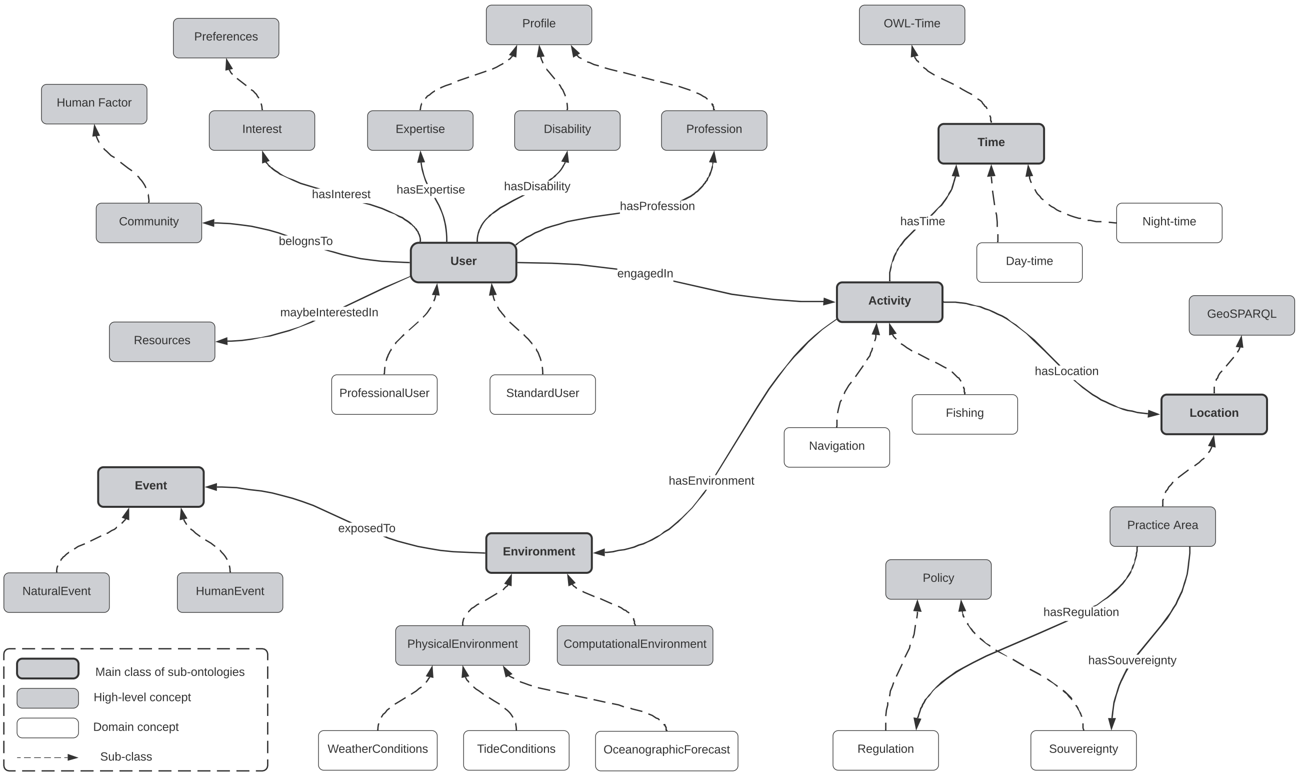

Figure 5. Partial taxonomy overview of concepts related to the sub-ontologies: Event, User, Activity, Location, Time, and Environment.

adaptation for rule-based systems in the semantic Web domain. Note that in order to preserve decidability in the reasoning process, SWRL rules are DL-Safe rules (i.e., they can only be applied explicitly to existing individuals in the knowledge base and not to language components).

The axiomatic reasoning process aims to infer implicit knowledge from a set of asserted facts and axioms (see section 4.2). We use ontological reasoning to infer the appropriate contexts of the user, the situations that take place during a session of use, and the user's class (i.e., professional or standard). On one side, a context is defined based on a set of asserted context information or based on a defined situation. On the other side, the situations may be inferred based on dynamic context information. Each situation generates a defined context. As a result, knowing the user's profile, the activity and the surrounding environment, one can deduce the context(s) of use in which the user is involved. Each defined context is associated to a set of thematic layers. The following example shows how a context is associated to some relevant thematic layers, using the Manchester OWL syntax[9]:

```
Class: Context1
    SubClassOf: concerns  value  Layer1
    SubClassOf: concerns  value  Layer2
    ...
```

Listing 1: An example illustrating a class *Context1* defined as a restriction on the data property *concerns* whose values are associated with the relevant thematic layers for the class.

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[9] https://www.w3.org/2007/OWL/draft/ED-owl2-manchester-syntax-20081128/

In addition to axiomatic reasoning, the rule-based reasoning process consists of inferring relevant thematic layers to the user's needs. Once the context(s) are inferred, we apply SWRL rules to infer the relation *"maybeInterestedIn"* between a user and some appropriate thematic layers. In the following, we present an example of three rules used in the reasoning process:

$$Rule\,1 : User(?u) \wedge engagedIn(?u, ?a) \wedge hasContext(?a, ?c) \wedge concerns(?c, ?e) \\ \rightarrow maybeInterestedIn(?u, ?e)$$

$$Rule\,2 : User(?u) \wedge engagedIn(?u, ?a) \wedge hasTime(?a, ?t) \wedge implies(?t, ?s) \\ \wedge generates(?s, ?c) \wedge concerns(?c, ?e) \rightarrow maybeInterestedIn(?u, ?e)$$

$$Rule\,3 : User(?u) \wedge engagedIn(?u, ?a) \wedge hasEnvironment(?a, ?env) \\ \wedge hasCondition(?env, ?condition) \wedge implies(?condition, ?s) \\ \wedge generates(?s, ?c) \wedge concerns(?c, ?e) \rightarrow maybeInterestedIn(?u, ?e)$$

The first rule infers the thematic layers provided by a context related to some activities. The second one deals with inference related to qualitative temporal dimension. Finally, the third one provides recommendations based on environmental conditions.

4.5. Architecture Framework

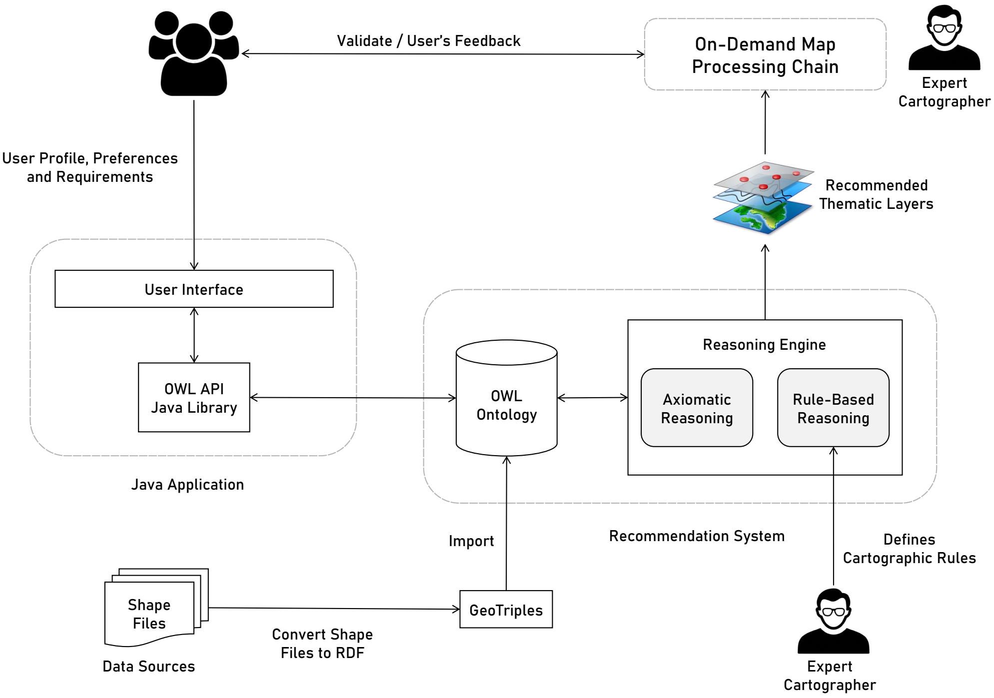

Figure 6. Architecture framework for the recommendation of thematic layers.

Figure 6 presents an overview of the proposed recommendation system. This system is developed in Java programming language using OWL-API[10], a Java library to

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[10] https://github.com/owlcs/owlapi/

deal with ontologies. The instantiation by assertion of the different classes and properties are realized in different ways: directly from the imported ontologies (e.g., the thematic layers from the ontology proposed by Tsatcha [28] to model the S-57 standard format), manually (e.g., for the classification proposed by Le Guyader [26] for the human activities in the coastal maritime area) or using an interface. For the latter case, Gatin and De Montaignac [29] developed a Java application with an interface allowing a user to enter his or her own data (profile, activity, etc.).

Once the required information stored into the ontology, we apply the reasoning process. The results are a set of thematic layers relevant in some inferred context of use that will be recommended to the cartographer to produce his on-demand map and indirectly to the user. The rule base has been developed with the assistance of expert cartographers in order to select which thematic layers are relevant for each defined context. To go one step beyond the thematic layers selection, we have converted the data of some layers of some electronic navigational charts (ENCs) from shapefile to RDF formats. The resulting triples are a set of cartographic entities with spatial coordinates, giving the possibility to make spatial inferences (see Discussion section).

5. Use Case Scenarios

In this section, we present two use case scenarios for the recommendation of themes for an on-demand nautical chart. For each scenario, we present a table showing the instantiations and inferences of the model.

Scenario 1

Bob is an expert fisherman. He is planning a fishing trip next Tuesday. The weather forecast shows that the visibility distance will be very low, about 1.5 miles. He is asking for a map that meets his needs and requirements.

Table 4 summarizes the concepts and roles assertions that model the first scenario. On the one hand, knowing that the user has a *"high"* expertise , the reasoner classifies Bob as a professional user. Bob is engaged in an activity *a*, an instance of the *Fishing* class. This activity, being a subclass of context information has a *Context*. The context of this activity is represented with instance *c1*. Based on contexts formalization (see section 4.2), the system classifies *c1* as a *ProfessionalFishingContext*. On the other hand, the physical environment *e* of the activity has *VisibilityDistance vd* about 1.5 miles. The visibility distance, as a dynamic context information, implies a situation *s*. Once again, the reasoner infers the class of the situation based on the *Situation* formalization presented in section 4.2. The inferred *BadVisibility* situation generates a context *c2*. Then, the system classifies *c2* as an instance of *BadVisibilityContext*. The object properties *hasActor*, *isTheContextOf*, *causedBy*, *generatedBy* are inferred as inverse properties of *engagedIn*, *hasContext*, *implies* and *generates*, respectively. Each *Context* is related to a set of thematic layers as follows:

```
Class: ProfessionalFishingContext
    SubClassOf: concerns  value  Fishery_zone
                concerns  value  Fishing_ground
                concerns  value  Fishing_facilities
                concerns  value  RONIM_tide_gauges
                concerns  value  Waves_height_and_direction
                concerns  value  Depth_contour
```

Listing 2: Thematic layers associated to *ProfessionalFishingContext*.

```
Class: BadVisibilityContext
    SubClassOf: concerns  value  Light
                concerns  value  Fog_signal
```

Listing 3: Thematic layers associated to *BadVisibilityContext*.

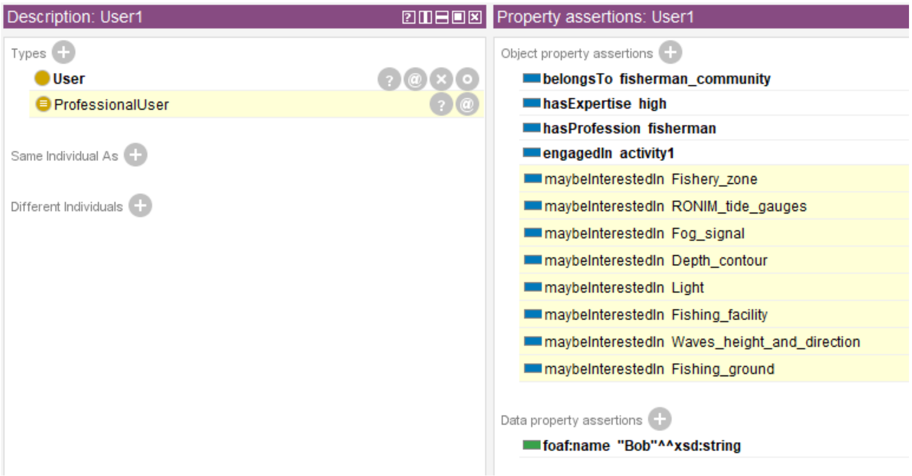
Table 4. Model instantiation by assertion and reasoning. Last column indicates the origin of the inference.

Concepts and roles	Asserted	Inferred	Inference Explanation
User(*Bob*)	✓		
hasExpertise(*Bob*, *high*)	✓		
ProfessionalUser(*Bob*)		✓	(9)
Fishing(*a*)	✓		
engagedIn(*Bob* ,*a*)	✓		
TemporalEntity(*t*)	✓		
Instant(*i*)	✓		
hasBegining(*t*, *i*)	✓		
inTemporalPosition(*i*, *Tuesday*)	✓		
hasTime(*a*, *t*)	✓		
hasLocation(*a*, *l*)	✓		
Feature(*l*)	✓		
hasGeometry(*l*, *g*)	✓		
Context(*c1*)	✓		
hasContext(*a*, *c1*)	✓		
isTheContextOf(*c1*, *a*)		✓	hasContext^{-1}
hasActor(*a*, *Bob*)		✓	engagedIn^{-1}
ProfessionalFishingContext(*c1*)		✓	(16)
Resources(*layer1*)	✓		
concerns(*c1*, *layer1*)	✓		
maybeInterestedIn(*Bob*, *layer1*)		✓	Rule 1
PhysicalEnvironment(*e*)	✓		
hasEnvironment(*a* ,*e*)	✓		
VisibilityDistance(*vd*)	✓		
hasVisibilityDistance(*vd*, *1.5*)	✓		
hasConditions(*e*, *vd*)	✓		
Situation(*s*)	✓		
implies(*vd*, *s*)	✓		
causedBy(*s*, *vd*)		✓	implies^{-1}
BadVisibility(*s*)		✓	(7)
Context(*c2*)	✓		
generates(*s*, *c2*)	✓		
generatedBy(*c2*, *s*)		✓	generates^{-1}
BadVisibilityContext(*c2*)		✓	(8)
Resources(*layer2*)	✓		
concerns(*c2*, *layer2*)	✓		
maybeInterestedIn(*Bob*, *layer2*)		✓	Rule 3

In Table 4, *layer1* and *layer2* are instances of the *Resources* class, and represent the set of thematic layers related to *ProfessionalFishingContext* and *BadVisibilityContext* respectively. Once the appropriate contexts have been deduced, the rule-based reasoning is applied to recommend the relevant thematic layers related to the contexts of use in which the user is involved. In the first scenario, Rules 1 and Rule 3 infer the object property *maybeInterestedIn* between *Bob* and the thematic layers related to the inferred contexts of use (Figure 7).

Scenario 2

Alice is a German tourist. She plans to rent a sailing boat with her friends during their holidays. She is an average sailor. She plans to sail from Jersey to Guernsey on the night of 8-9 November 2021. She is therefore looking for a map to guide her on her journey.


Description: User1

Types
User
ProfessionalUser

Same Individual As

Different Individuals

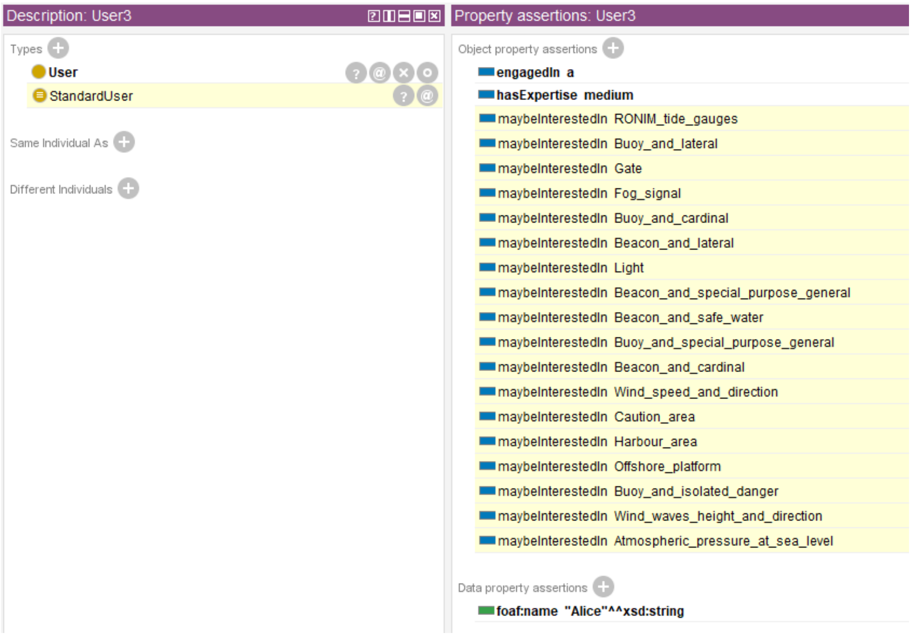
Property assertions: User1

Object property assertions
belongsTo fisherman_community
hasExpertise high
hasProfession fisherman
engagedIn activity1
maybeInterestedIn Fishery_zone
maybeInterestedIn RONIM_tide_gauges
maybeInterestedIn Fog_signal
maybeInterestedIn Depth_contour
maybeInterestedIn Light
maybeInterestedIn Fishing_facility
maybeInterestedIn Waves_height_and_direction
maybeInterestedIn Fishing_ground

Data property assertions
foaf:name "Bob"^^xsd:string

Figure 7. Results of inferences for scenario 1 using *Protégé*. Recommendation of thematic layers for Bob's on-demand map.

Table 5 shows the instantiation of the second scenario. Alice is engaged in a *Sailing* activity with a medium expertise. Using ontological reasoning, the system classifies the *Context* related to this activity as a *SailingContext*. The navigation context refers to the basic map layers/entities that help the traveler to navigate in normal conditions, such as weather, currents, tide, signals, beacons or guidance equipment (Figure 8). The activity takes place at *Night*. This temporal dimension implies a *Situation*. Based on the definitions of the situations, the reasoner classifies it as a *BadVisibilitySituation*. Sailing in a bad visibility situation requires additional layers concerning lighting or radar beacons (e.g., Light or Fog_signal layers in Figure 8). Thus, a second *Context* is inferred: *BadVisibilityContext*. In this scenario, the Rules 1 and 2 infer the recommendations to the cartographer. Figure 8 presents the result of the reasoning process and the set of thematic layers recommended to the user's on-demand map.


Description: User3

Types
User
StandardUser

Same Individual As

Different Individuals

Property assertions: User3

Object property assertions
engagedIn a
hasExpertise medium
maybeInterestedIn RONIM_tide_gauges
maybeInterestedIn Buoy_and_lateral
maybeInterestedIn Gate
maybeInterestedIn Fog_signal
maybeInterestedIn Buoy_and_cardinal
maybeInterestedIn Beacon_and_lateral
maybeInterestedIn Light
maybeInterestedIn Beacon_and_special_purpose_general
maybeInterestedIn Beacon_and_safe_water
maybeInterestedIn Buoy_and_special_purpose_general
maybeInterestedIn Beacon_and_cardinal
maybeInterestedIn Wind_speed_and_direction
maybeInterestedIn Caution_area
maybeInterestedIn Harbour_area
maybeInterestedIn Offshore_platform
maybeInterestedIn Buoy_and_isolated_danger
maybeInterestedIn Wind_waves_height_and_direction
maybeInterestedIn Atmospheric_pressure_at_sea_level

Data property assertions
foaf:name "Alice"^^xsd:string

Figure 8. Results of inferences for scenario 2 using *Protégé*. Recommendation of thematic layers for Alice's on-demand map.

Table 5. Scenario 2 instantiation by assertion and reasoning. Last column indicates the origin of the inference.

Concepts and roles	**Asserted**	**Inferred**	**Inference Explanation**
User(*Alice*)	✓		
hasExpertise(*Alice* , *medium*)	✓		
StandardUser(*Alice*)		✓	(10)
Sailing(*a*)	✓		
engagedIn(*Alice* , *a*)	✓		
hasLocation(*a* , *l*)	✓		
Feature(*l*)	✓		
hasGeometry(*l* , *g*)	✓		
Context(*c1*)	✓		
hasContext(*a, c1*)	✓		
SailingContext(*c1*)		✓	(20)
hasActor(*a* , *Alice*)		✓	engagedIn^{-1}
isTheContextOf(*c1* , *a*)		✓	hasContext^{-1}
Resources(*layer1*)	✓		
concerns(*c1* , *layer1*)	✓		
maybeInterestedIn(*Alice* , *layer1*)		✓	Rule 1
Night(t)	✓		
hasTime(*a* , *t*)	✓		
Situation(*s*)	✓		
implies(*t* , *s*)	✓		
causedBy(*s* , *t*)		✓	implies^{-1}
BadVisibility(*s*)		✓	(7)
Context(*c2*)	✓		
generates(*s* , *c2*)	✓		
generatedBy(*c2* , *s*)		✓	generates^{-1}
BadVisibilityContext(*c2*)		✓	(8)
Resources(*layer2*)	✓		
concerns(*c2* , *layer2*)	✓		
maybeInterestedIn(*Alice* , *layer2*)		✓	Rule 3

6. Conclusion and Discussion

In this paper, we present a knowledge-based recommendation approach for an on-demand mapping system. We address the first step of an on-demand mapping process, by recommending to a cartographer the appropriate thematic layers according to the user's requirements and context of use. For this, we propose a context modeling approach for contextual cartography based on a high-level ontology taking into account different context dimensions (user, activity, time, location, environment, event, situation, policy). Each high-level concept may be extended to a set of low-level concepts describing a context in a specific domain of application. For the purposes of this paper, we limit our case studies to maritime maps and therefore detail the low-level concepts involved, but the approach can be derived to other types of maps.

The knowledge-based recommendation approach relies on an ontological reasoning principle. Two types of reasoning are used to infer knowledge of interest for on-demand maps: axiomatic reasoning and rule-based reasoning. The former infers the context(s) from contextual information, while the latter infers the relevant thematic layers based on the inferred context(s). In order to demonstrate the usability of the approach, we deal with a particular domain: nautical maps. Some concepts related to the maritime domain were formalized in description logic for the axioms and in SWRL for the rules. The recommendation process was applied on two different scenarios. Although experts in mapping and knowledge engineering are needed to represent the application domain and define a set of contexts, the knowledge-based approach assures the cartographer of the quality of the recommendations through a reasoning process that matches the user's requirements to the relevant thematic layers.

The recommendation process of our approach could be enhanced by going beyond the single recommendation of thematic layers presented in this paper. As a first way, we can recommend to the cartographer, not only some thematic layers, but also the cartographic entities of interest, specific to each recommended layer. For example, if a user is involved in a *Navigation Context* where the *Boycar* layer (i.e., Cardinal buoys) has been recommended to him or her, then depending on his/her location (spatial dimension), the system can recommend the set of cardinal buoys that exist in the practice area where he/she is planning for his/her activity. In the same way, the system can recommend entities taking into account the temporal dimension. For example, in a *Tourism Context*, the system can recommend cultural sites that are open during the user's activity.

Another way to be explored is to introduce a serendipity aspect in the recommendation process. Serendipitous recommendations would present some relevant, novel and unexpected thematic layers for the user. Unlike the proposed approach where recommendations are derived from knowledge internal to the system (i.e., stored in the knowledge base), here we are looking for recommendations derived from knowledge external to the system like Wikipedia categories, Wordnet or DBpedia. The main idea is to explore new recommendations having strong semantic links with the user's needs and that may be of interest. For instance, a standard user requesting an on-demand map in a fishing context, may be recommended to have the wrecks sites. Indeed, the system having determined a *Fishing Context*, could infer an interest in diving as the two activities have a strong semantic relationship. Then by analyzing the subcategories of diving in the Wikipedia categories, the system could finally recommend the diving sites or wrecks layers. On the one hand, this layer could be rather relevant and unexpected for a user, but on the other hand, it could reduce the quality or security of the recommendation which may be important criteria for some applications. As a result, depending on the context of use, we will have to weight the recommendation results between serendipitous recommendations (e.g., Tourism Context) and safe recommendations (e.g., Navigation Context).

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