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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.

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

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

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

60 2. Literature Review

61 2.1. On-Demand Mapping

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

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

70 Sarjakoski and Sarjakoski [3] implemented the first on-demand mapping proto-
71 type as part of the GiMoDig (2001-2004) project¹. The authors tried to improve the
72 accessibility and interoperability of national topographic databases in a mobile context.
73 The key techniques were data integration and real-time generalization. Custom map
74 specifications are built from context parameters collected from the user and an internal
75 knowledge base. Bucher et al. [4], at the COGIT laboratory of IGN France, specified a
76 series of Web services, to provide on-demand maps based on user’s specifications : a map
77 specification service, a legend definition service, and a legend evaluation service. The
78 first service helps the user defining some of the abstract properties of their map. The two
79 other services make use of the large knowledge base about legends to propose adequate
80 symbolization. Foerster et al. [5] proposed a distributed architecture for on-demand
81 Web mapping by formalizing user requirements in UML and XML models. As core of
82 the architecture, a so-called generalization-enabled Web Map Service is presented to
83 automate the generalization process on the Web. Gould [6] developed an on-demand
84 mapping system based on an ontology for roads and road accidents. He aims to model
85 the process of generalization and devise a method for automatically selecting the appro-
86 priate algorithms for mapping geographic features at multiple scales using an ontology.

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.

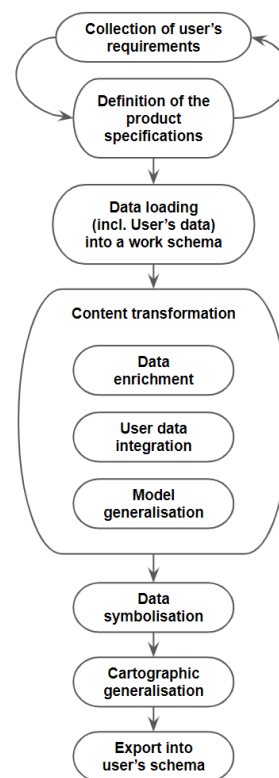


Figure 1. Main steps of the on-demand mapping process [2].

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

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

100 2.2. Contextual Cartography Modeling

101 Before focusing more extensively on the modeling of the cartographic context,
 102 different works exist on context modeling from a general point of view. A commonly
 103 accepted definition of context has been proposed by [8]. According to him, a context
 104 is defined as "any information that can be used to characterize the situation of an entity. An
 105 entity is a person, place, or object that is considered relevant to the interaction between a user
 106 and an application, including the user and applications themselves". In other words, a context
 107 is determined by the state of the values of the parameters relating to the characterization
 108 of a situation. It is a set of information that influences a task performed by a person
 109 or characterizes a specific situation in a computer system. A context-aware system is
 110 defined as follows "A system is context-aware if it uses context to provide relevant information
 111 and/or services to the user, where relevancy depends on the user's task" [9]. Chen and Kotz
 112 [10] defined two classes of context-aware systems: active and passive systems. An
 113 active system is a system that takes into account the change of the dynamic contextual

114 information and adapts its behavior according to the current situation, whereas a passive
 115 system is not able to update its behavior following a change of the context.

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

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

130 Focusing on the literature review on contextual cartography, several research works
 131 have been done in order to introduce the notion of context in cartography, especially
 132 in mobile systems. First attempts to adapt visualization in mobile cartography were
 133 introduced by Reichenbacher [13] and Zipf [14]. Reichenbacher presented a conceptual
 134 framework for mobile cartography based on three essential components for visualization
 135 adaptation: the user, the context, and the task. The notion of context in digital mapping
 136 has been later studied by Nivala and Sarjakoski [15] in their work on digital maps for
 137 mobile systems as part of the GiMoDig project (2001-2004). These researchers first relied
 138 on the definitions of context proposed by Schilit [16] and Dey [8]. Then, they proposed
 139 a context classification adapted to maps to describe a cartographic context in mobile
 140 systems based on five general context categories: Computing, User, Physical, Time, and
 141 History. Each general context category includes a set of context categories for a mobile
 142 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

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

144 2.3. Recommendation Systems

145 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

146 these information systems by prioritizing relevant resources based on their preferences,
147 in order to assist him/her in the different decision-making processes.

148 According to the literature [17], widely used recommendation approaches are
149 content-based, collaborative filtering and knowledge-based. Collaborative filtering (CF)
150 approaches are based on the opinion of a group of users who have the same preferences -
151 ratings of items by a community of users – to generate recommendations. Collaborative
152 filtering algorithms have the advantage of using only historical data; no knowledge of
153 the items is required. However, they suffer from a “cold-start” problem; a new user can-
154 not receive any recommendations before rating several items and a new item cannot be
155 recommended before being rated by a number of users [18]. Content-based filtering (CB)
156 approaches use item features to recommend items similar to those in which the user has
157 expressed interest. CB has no cold start problem but is unable to provide the serendipi-
158 tious² recommendations that CF generates. Lastly, knowledge-based approaches (KB) use
159 domain knowledge in a structured form to produce personalized recommendations. KB
160 approaches avoid the cold start problem and have the advantage of enhanced reliability
161 as the background knowledge is free of noise. However, knowledge-based systems
162 require considerable knowledge acquisition effort for setup and maintenance during
163 their lifetime [19], which makes them more expensive to develop and maintain.

164 3. Problem Statement and Preferred Orientations

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

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

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

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

196 In order to make the system sensitive to context, the rule base and the ontology
197 formalization can take into consideration the different dimensions of context (see section
198 4.1). In the next section, we will present a methodology to develop a knowledge-based
199 recommendation system which is sensitive to context for on-demand mapping process.

200 4. Methodology

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

213 4.1. Conceptualization

214 In their work on a contextual ontology for service recommendation, Cabrera et al.
215 [21] proposed an approach for conceptualization that consists in building a glossary of
216 terms from the concepts corresponding to the first level of hierarchy of several proposed
217 context models. We used the same approach, adapting their categorization to the field of
218 cartography, taking into account Nivala and Sarjakoski's categorization [15].

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

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

³ <https://protege.stanford.edu/>

245 In order to make the model more generic, we have defined high-level concepts
 246 as a first step, as shown in Table 1. Each high-level concept includes a set of low-
 247 level concepts describing a context in a specific domain of application (e.g., weather,
 248 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)

249 In the following, we decide to focus on the definition of low-level relevant concepts
 250 in the maritime domain that affect the process of on-demand nautical map making. To
 251 do this, we have extracted some knowledge related to the maritime environment and
 252 navigation from reference books [22–24], as well from the SHOM⁴ website. In addition,
 253 we also had discussions with experts in maritime navigation training from the French
 254 Naval Academy.

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

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

⁴ <https://data.shom.fr/>

270 *Policies* could be *Regulation* (e.g., Restricted area, fishery zone, etc.) or *Sovereignty* (e.g.,
271 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

272 4.2. Formalization

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

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

$$\text{Night} - \text{time} \sqsubseteq \text{Time} \quad (1)$$

$$\text{VisibilityDistance} \sqsubseteq \text{WeatherConditions} \quad (2)$$

$$\text{VisibilitySituation} \sqsubseteq \text{Situation} \quad (3)$$

$$\text{VisibilitySituation} \equiv \text{GoodVisibility} \sqcup \text{RestrictedVisibility} \sqcup \text{BadVisibility} \quad (4)$$

$$\text{GoodVisibility} \equiv \text{Situation} \sqcap \exists \text{causedBy} . (\text{VisibilityDistance} \sqcap \exists \text{hasVisibilityDistance} . (> 5)) \quad (5)$$

$$\text{RestrictedVisibility} \equiv \text{Situation} \sqcap \exists \text{causedBy} . (\text{VisibilityDistance} \sqcap \exists \text{hasVisibilityDistance} . (\geq 2) \sqcap \exists \text{hasVisibilityDistance} . (\leq 5)) \quad (6)$$

$$\text{BadVisibility} \equiv \text{Situation} \sqcap \exists \text{causedBy} . (\text{VisibilityDistance} \sqcap \exists \text{hasVisibilityDistance} . (< 2) \sqcup (\exists \text{causedBy} . \text{Night})) \quad (7)$$

$$\text{BadVisibilityContext} \equiv \text{Context} \sqcap \exists \text{generatedBy} . \text{BadVisibility} \quad (8)$$

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".

$$ProfessionalUser \equiv User \sqcap \exists hasExpertise . \{high\} \quad (9)$$

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

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*.

$$Fishing \sqsubseteq Activity \quad (11)$$

$$Sailing \sqsubseteq Activity \quad (12)$$

$$FishingContext \sqsubseteq Context \quad (13)$$

$$SailingContext \sqsubseteq Context \quad (14)$$

$$FishingContext \equiv LeisureFishingContext \sqcup ProfessionalFishingContext \quad (15)$$

$$SailingContext \equiv LeisureSailingContext \sqcup ProfessionalSailingContext \quad (16)$$

$$ProfessionalFishingContext \equiv Context \sqcap \exists isTheContextOf . (Fishing \sqcap \exists hasActor . ProfessionalUser) \quad (17)$$

$$LeisureFishingContext \equiv Context \sqcap \exists isTheContextOf . (Fishing \sqcap \exists hasActor . StandardUser) \quad (18)$$

$$ProfessionalSailingContext \equiv Context \sqcap \exists isTheContextOf . (Sailing \sqcap \exists hasActor . ProfessionalUser) \quad (19)$$

$$LeisureSailingContext \equiv Context \sqcap \exists isTheContextOf . (Sailing \sqcap \exists hasActor . StandardUser) \quad (20)$$

289 4.3. Ontology Implementation

290 Based on the concepts formalization of section 4.2, the conceptualization defined in
 291 section 4.1 was implemented as an ontological model using *Protégé*. This implementa-
 292 tion provides support for Description Logics reasoning. The high-level concepts were
 293 implemented as classes in order to obtain a high-level ontology (Figure 3). Then, we
 294 implement the domain concepts as subclasses of the main concepts. Reusing existing
 295 ontologies is a crucial step in ontology development. It provides a useful starting point
 296 to be fully or partially reused. For instance, we used the GeoSPARQL⁵ standard ontology
 297 to represent the spatial dimension, and the OWL-Time ontology [27] to represent the

⁵ <http://www.opengis.net/ont/geosparql#>

298 temporal dimension. The *FOAF*⁶ ontology is used to represent the user's profile. The
 299 classification of maritime activities presented by Le Guyader [26] has been integrated
 300 into our model as classes and subclasses. We also reused the ontological approach
 301 proposed by Tsatcha [28] to model the S-57⁷ standard format. The S-57 model classifies
 302 hydrographic information (i.e., thematic layers) used for nautical charts making. In addition
 303 to hydrographic information, we have extracted two meteorological layers from the
 304 SHOM⁸ geoportal: Oceanographic Forecast and Coastal Observations. These thematic
 305 layers will be useful for the following use cases. All the layers (i.e., S-57, Oceanographic
 306 Forecast, etc.) are subclasses of the class *Resources*.

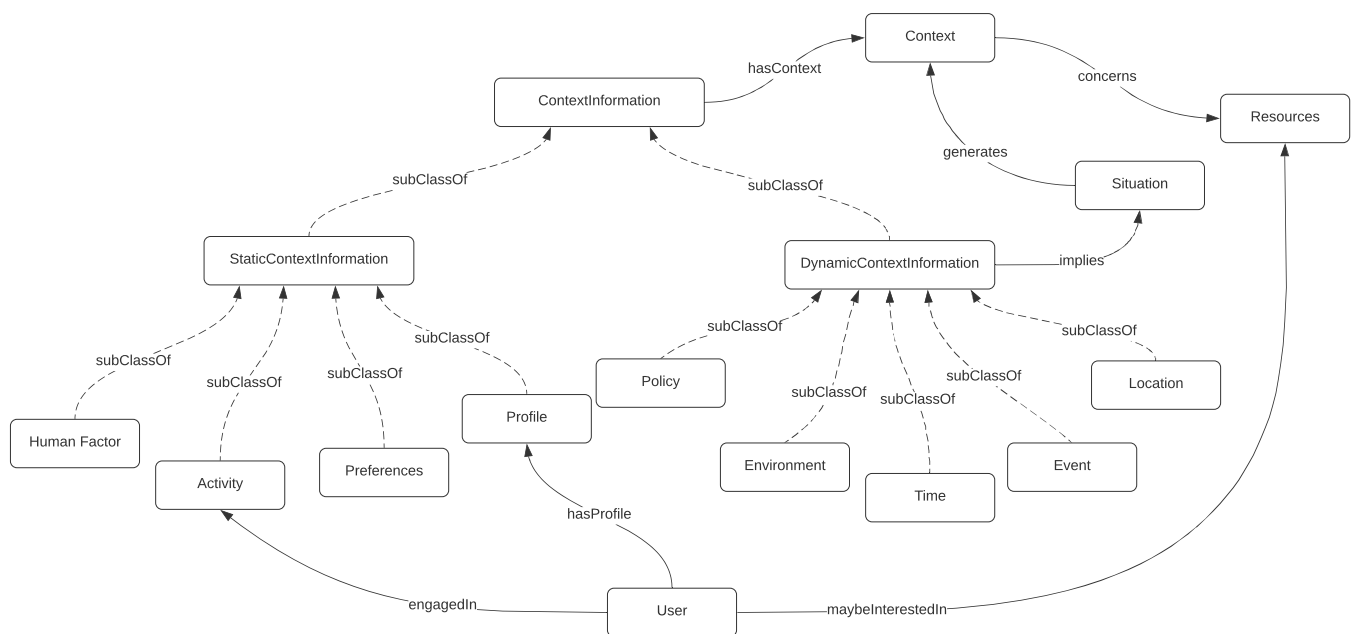


Figure 3. Overview of the proposed upper ontology.

307 The ontology we provide in this work consists of a set of sub-ontologies describing
 308 abstract concepts for on-demand maps. Thereafter, we extend these sub-ontologies by
 309 concepts related to a particular domain: on-demand maritime maps. Figure 4 and figure
 310 5 depict the resulting ontologies including their general relationships. In the following,
 311 we detail the sub-ontologies with their relationships (Table 3).

312 User ontology

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

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

322 Activity ontology

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

331 Environment ontology

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

341 Location ontology

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

346 Time ontology

347 The temporal dimension consists of two types: qualitative and quantitative. The
 348 OWL-Time ontology is used to represent the quantitative time. Furthermore, the qual-
 349 itative time could be represented with concepts like *Day-time*, *Night-time*, etc (Figure
 350 5).

351 Event ontology

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

355 Context ontology

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

362 Situation ontology

363 The situation ontology represents the state of the system during a short time. The
 364 state is derived from dynamic context information which can change their values over
 365 a short time (i.e., during a recommendation session). A situation could be a danger, a
 366 capacity for visibility, etc. Each situation generates a defined context. In the following
 367 case studies, we defined some situations related to visibility states (Bad, Restricted, or
 368 Good Visibility situations) varying according to the weather and time conditions (Figure
 369 4).

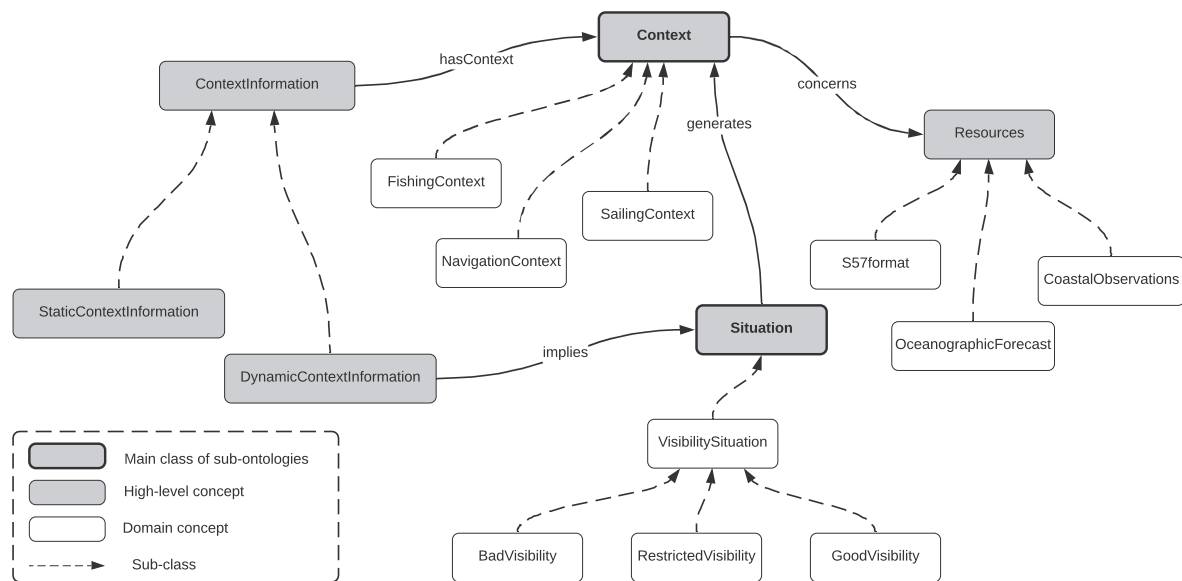


Figure 4. Partial taxonomy overview of concepts related to the sub-ontologies: Context and Situation.

370 4.4. Reasoning

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

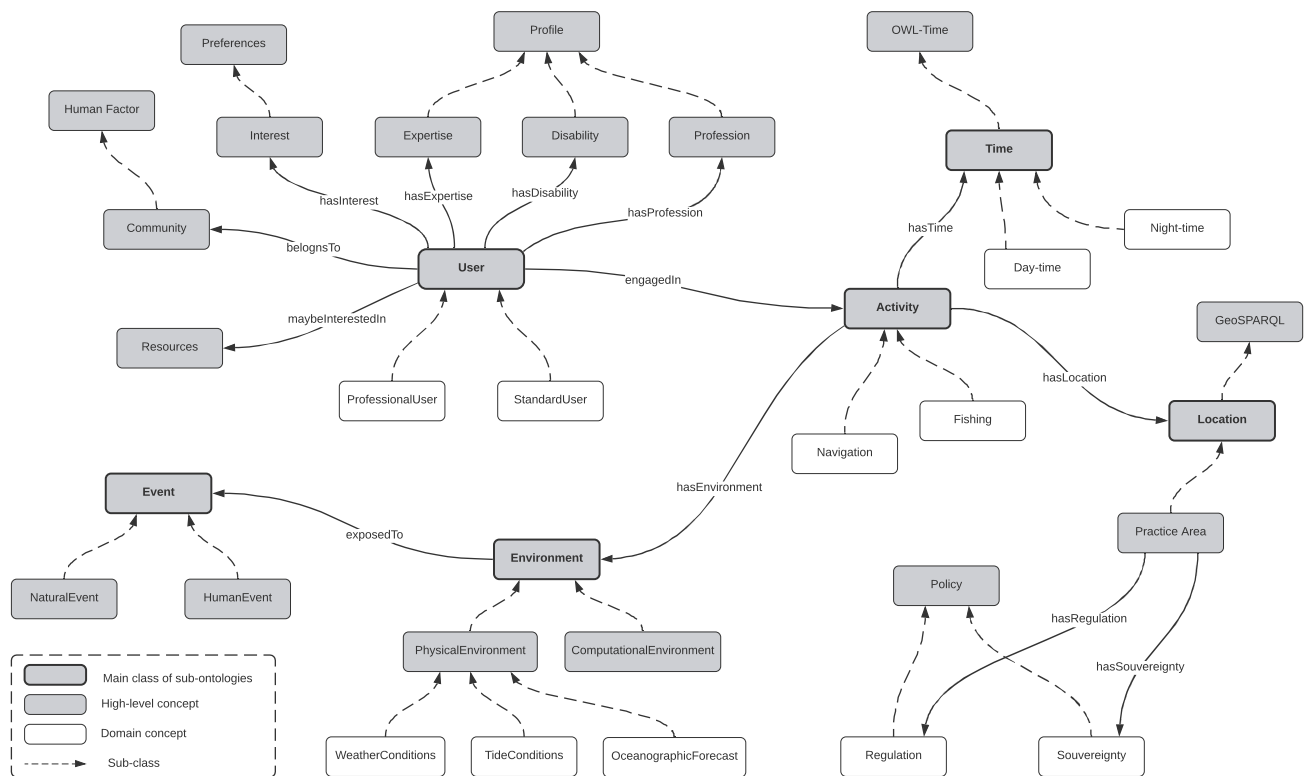


Figure 5. Partial taxonomy overview of concepts related to the sub-ontologies: Event, User, Activity, Location, Time, and Environment.

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

383 The axiomatic reasoning process aims to infer implicit knowledge from a set of
 384 asserted facts and axioms (see section 4.2). We use ontological reasoning to infer the
 385 appropriate contexts of the user, the situations that take place during a session of use,
 386 and the user's class (i.e., professional or standard). On one side, a context is defined
 387 based on a set of asserted context information or based on a defined situation. On the
 388 other side, the situations may be inferred based on dynamic context information. Each
 389 situation generates a defined context. As a result, knowing the user's profile, the activity
 390 and the surrounding environment, one can deduce the context(s) of use in which the
 391 user is involved. Each defined context is associated to a set of thematic layers. The
 392 following example shows how a context is associated to some relevant thematic layers,
 393 using the Manchester OWL syntax⁹:

```
394
395 Class: Context1
396   SubClassOf: concerns value Layer1
397   SubClassOf: concerns value Layer2
398   ...
399
```

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.

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:

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

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

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

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

403 4.5. Architecture Framework

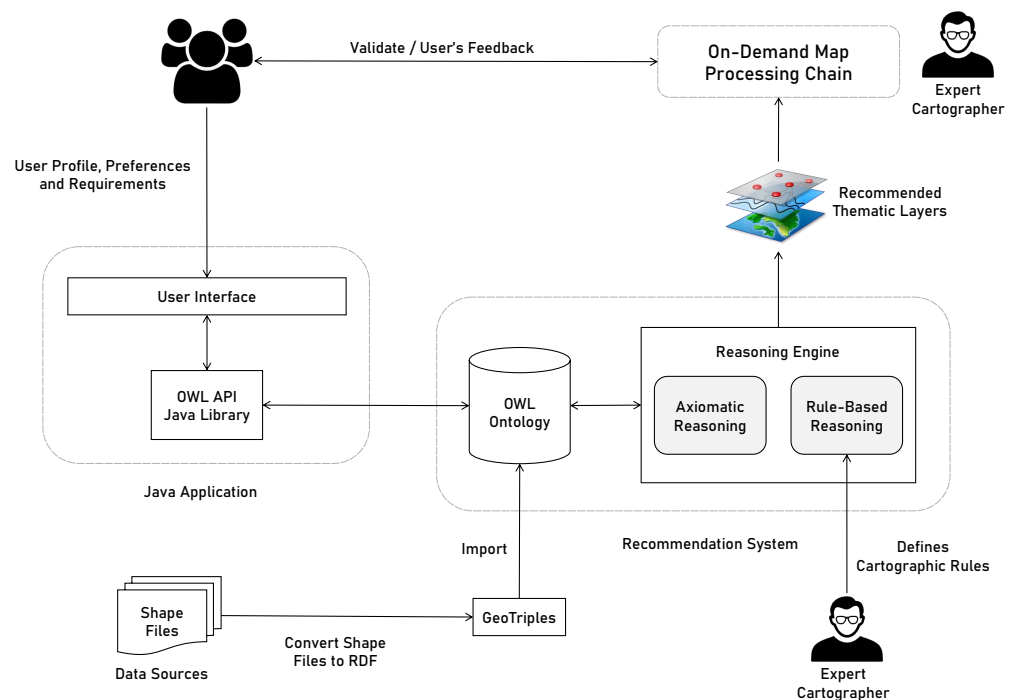


Figure 6. Architecture framework for the recommendation of thematic layers.

404 Figure 6 presents an overview of the proposed recommendation system. This
 405 system is developed in Java programming language using OWL-API¹⁰, a Java library to

¹⁰ <https://github.com/owlcs/owlapi/>

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

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

422 5. Use Case Scenarios

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

426 Scenario 1

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

430 Table 4 summarizes the concepts and roles assertions that model the first scenario.
 431 On the one hand, knowing that the user has a "high" expertise, the reasoner classifies
 432 Bob as a professional user. Bob is engaged in an activity *a*, an instance of the *Fishing* class.
 433 This activity, being a subclass of context information has a *Context*. The context of this
 434 activity is represented with instance *c1*. Based on contexts formalization (see section 4.2),
 435 the system classifies *c1* as a *ProfessionalFishingContext*. On the other hand, the physical
 436 environment *e* of the activity has *VisibilityDistance* *vd* about 1.5 miles. The visibility dis-
 437 tance, as a dynamic context information, implies a situation *s*. Once again, the reasoner
 438 infers the class of the situation based on the *Situation* formalization presented in section
 439 4.2. The inferred *BadVisibility* situation generates a context *c2*. Then, the system classifies
 440 *c2* as an instance of *BadVisibilityContext*. The object properties *hasActor*, *isTheContextOf*,
 441 *causedBy*, *generatedBy* are inferred as inverse properties of *engagedIn*, *hasContext*, *implies*
 442 and *generates*, respectively. Each *Context* is related to a set of thematic layers as follows:

```
443
444 Class: ProfessionalFishingContext
445   SubClassOf: concerns value Fishery_zone
446               concerns value Fishing_ground
447               concerns value Fishing_facilities
448               concerns value RONIM_tide_gauges
449               concerns value Waves_height_and_direction
450               concerns value Depth_contour
451
452
```

Listing 2: Thematic layers associated to *ProfessionalFishingContext*.

```
453
454 Class: BadVisibilityContext
455   SubClassOf: concerns value Light
456               concerns value Fog_signal
457
```

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(<i>Bob</i>)	✓		
hasExpertise(<i>Bob</i> , <i>high</i>)	✓		
ProfessionalUser(<i>Bob</i>)		✓	(9)
Fishing(<i>a</i>)	✓		
engagedIn(<i>Bob</i> , <i>a</i>)	✓		
TemporalEntity(<i>t</i>)	✓		
Instant(<i>i</i>)	✓		
hasBeginning(<i>t</i> , <i>i</i>)	✓		
inTemporalPosition(<i>i</i> , <i>Tuesday</i>)	✓		
hasTime(<i>a</i> , <i>t</i>)	✓		
hasLocation(<i>a</i> , <i>l</i>)	✓		
Feature(<i>l</i>)	✓		
hasGeometry(<i>l</i> , <i>g</i>)	✓		
Context(<i>c1</i>)	✓		
hasContext(<i>a</i> , <i>c1</i>)	✓		
isTheContextOf(<i>c1</i> , <i>a</i>)		✓	hasContext ⁻¹
hasActor(<i>a</i> , <i>Bob</i>)		✓	engagedIn ⁻¹
ProfessionalFishingContext(<i>c1</i>)		✓	(16)
Resources(<i>layer1</i>)	✓		
concerns(<i>c1</i> , <i>layer1</i>)	✓		
maybeInterestedIn(<i>Bob</i> , <i>layer1</i>)		✓	Rule 1
PhysicalEnvironment(<i>e</i>)	✓		
hasEnvironment(<i>a</i> , <i>e</i>)	✓		
VisibilityDistance(<i>vd</i>)	✓		
hasVisibilityDistance(<i>vd</i> , 1.5)	✓		
hasConditions(<i>e</i> , <i>vd</i>)	✓		
Situation(<i>s</i>)	✓		
implies(<i>vd</i> , <i>s</i>)	✓		
causedBy(<i>s</i> , <i>vd</i>)		✓	implies ⁻¹
BadVisibility(<i>s</i>)		✓	(7)
Context(<i>c2</i>)	✓		
generates(<i>s</i> , <i>c2</i>)	✓		
generatedBy(<i>c2</i> , <i>s</i>)		✓	generates ⁻¹
BadVisibilityContext(<i>c2</i>)		✓	(8)
Resources(<i>layer2</i>)	✓		
concerns(<i>c2</i> , <i>layer2</i>)	✓		
maybeInterestedIn(<i>Bob</i> , <i>layer2</i>)		✓	Rule 3

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

465 Scenario 2

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

469

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

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

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(<i>Alice</i>)	✓		
hasExpertise(<i>Alice</i> , <i>medium</i>)	✓		
StandardUser(<i>Alice</i>)		✓	(10)
Sailing(<i>a</i>)	✓		
engagedIn(<i>Alice</i> , <i>a</i>)	✓		
hasLocation(<i>a</i> , <i>l</i>)	✓		
Feature(<i>l</i>)	✓		
hasGeometry(<i>l</i> , <i>g</i>)	✓		
Context(<i>c1</i>)	✓		
hasContext(<i>a</i> , <i>c1</i>)	✓		
SailingContext(<i>c1</i>)		✓	(20)
hasActor(<i>a</i> , <i>Alice</i>)		✓	engagedIn ⁻¹
isTheContextOf(<i>c1</i> , <i>a</i>)		✓	hasContext ⁻¹
Resources(<i>layer1</i>)	✓		
concerns(<i>c1</i> , <i>layer1</i>)	✓		
maybeInterestedIn(<i>Alice</i> , <i>layer1</i>)		✓	Rule 1
Night(<i>t</i>)	✓		
hasTime(<i>a</i> , <i>t</i>)	✓		
Situation(<i>s</i>)	✓		
implies(<i>t</i> , <i>s</i>)	✓		
causedBy(<i>s</i> , <i>t</i>)		✓	implies ⁻¹
BadVisibility(<i>s</i>)		✓	(7)
Context(<i>c2</i>)	✓		
generates(<i>s</i> , <i>c2</i>)	✓		
generatedBy(<i>c2</i> , <i>s</i>)		✓	generates ⁻¹
BadVisibilityContext(<i>c2</i>)		✓	(8)
Resources(<i>layer2</i>)	✓		
concerns(<i>c2</i> , <i>layer2</i>)	✓		
maybeInterestedIn(<i>Alice</i> , <i>layer2</i>)		✓	Rule 3

482 6. Conclusion and Discussion

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

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

503 the quality of the recommendations through a reasoning process that matches the user's
504 requirements to the relevant thematic layers.

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

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

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