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Spatio-Temporal Rule-based Analysis of Maritime Traffic

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Abstract. The maritime environment is diverse, open but partly ruled, and covers a large spectrum of ships from small sailing boats to tankers which generally exhibit type-related behaviours. Several real-time positioning systems have been designed for keeping track of ships movements. However data provided by these reporting systems are underutilized to help operators in charge of maritime safety and security. This paper introduces an information system relying on user-defined navigation rules and an inference engine to analyse maritime traffic and report abnormalities and suspicious behaviours to operators. The proposed approach improves existing ones by combining a spatio-temporal database and a rule-based inference engine.

1 INTRODUCTION

The maritime environment is a place where human activities (fishing, goods transportation...) continuously evolve and where traffic increases regularly. This ever increasing traffic leads to navigation difficulties and risks in coastal and crowded areas where numerous ships exhibit different movement objectives which can be conflicting (eg. sailing vs. fishing). The disasters and damages caused in the event of sea collisions can pose serious threats to the environment and human lives. The sea surveillance has therefore become a major concern in order to prevent disasters and damages but also to provide an answer to illegal immigration, drug smuggling, and terrorism. Consideration of this control issue by the International Maritime Organization (IMO) has partly evolved in the last decade from education, navigational rules to technical answers for traffic monitoring. Nowadays, ships are fitted out with real-time position report systems whose objective is to identify and locate vessels at distance (Automatic Identification System (AIS) for example). Combined with radar surveillance and others, real-time localisation of ships in coastal area (around 40 miles) is effective.

A real-time maritime surveillance system relies on tools for extracting several levels of information gathered from different sources (sensors, cartographic maps, databases) as well as a set of rules [Nilsson et al., 2008]. An example of such a rule is a pre-determined metric which defines the suspicious behaviour according to the deviation of a vessel from the expected (or declared) route. Any new information has the potential of generating an update on dangerous or suspicious context; as a consequence, decision

supports must be included in a perpetual process performing data storage, management and analysis. To describe rules, a surveillance system needs to include mechanisms from which operators can define the contextual situations he wants to be detected as suspicious, dangerous or abnormal. This mechanism can rely on a rule-based engine approach allowing to formalise rules and to ensure the link between the conceptual specification of a situation and its implementation [Vandecasteele and Napoli, 2012], [Idiri and Napoli, 2012], [Morel and Claisse, 2010]. This approach entails a challenging combination of the cartographic context, position reports from ships and behavioural analysis into the inference engine for further processing.

Several studies addressed spatial ontology to describe maritime traffic and identify dangerous and/or suspicious behaviours [Roy, 2008], [Vandecasteele and Napoli, 2012]. Related to these behaviours, researches proposed solutions for anomaly detection from supervised approaches. They used set of recorded trajectories and situations, to define a panel of typical abnormal behaviours from statistical analysis [Devogele *et al.*, 2013], [Brax, 2011], [Riveiro *et al.*, 2008]. Mentioning the abnormal behaviours typology, surveillance systems with rule-based reasoning [Popovich *et al.*, 2009], [Idiri and Napoli, 2012], [Roy, 2010] have been proposed. Nevertheless, although geo-based situational contexts are described in these works, integration of spatial analysis and geo-based database queries are not implemented and still requires improvements.

The information system presented in this paper aims to address this improvement. It presents an approach to implement decision support system for sea surveillance, combining analysis of static and dynamic geo-maritime information with a rule-based inference engine (Drools). It follows the “situation awareness” concept defined as “the perception of the elements in the environment within a volume of time and space, the comprehension of their meaning and the projection of their status in the near future” [Endsley, 2000]. Based on a spatio-temporal database model, the system includes traffic data records (AIS) and Electronic Navigational Charts (S-57). The spatio-temporal database approach allows to manage short and long term events and to extract information and knowledge about maritime traffic from spatial-temporal analysis.

The remainder of this paper is organized as follows. Section 2 motivates the proposed approach and explains the architectural design of the information system. Section 3 gives implementation details and provides examples of spatio-temporal rules. Finally, Section 4 draws some conclusions and outlines future work.

2 A RULE-BASED REASONING APPROACH

Different strategies have been examined to address a computer-based detection of abnormal ship behaviours. A first approach relies on the automatic characterization of ship trajectories. It uses statistical analyses (clustering, aggregation, etc.) of historical data to generate, for instance, prototypes of typical paths [Devogele *et al.*, 2013]. Another approach relies on a semi-automatic characterization of ship trajectories [Riveiro *et al.*, 2008] which uses “supervised machine-learning techniques” to generate and refine the typical paths. Both approaches are essentially ascendant, meaning the surveillance rules are derived from data analyses.

2.1 Motivation

The design of a highly flexible surveillance system, where the business logic might have to be re-configured by a surveillance operator, requires different approaches than conventional location-based systems. Changing the business logic of an application requires a two-step process. Firstly, a domain expert, often a non-technical person, adjusts or amends the requirements. Then, a computer programmer encodes those requirements within the existing business logic. This two-steps process is pernicious. Firstly, the logic is hidden within the code, incapacitating the expert to verify whether his requirements have been properly understood. Secondly, frequent additions or modifications of requirements may result in the production of so-called spaghetti code, noticeable by their numerous imbrications of conditional statement and overloads of design-patterns.

Rule-based reasoning appears as particularly well suited for developing expert systems [Sottara *et al.*, 2008]. An expert system may be defined as a computer program able to reason over the knowledge of some domain expert in order to assist in the decision making process. Rule engines such as DROOLS (JBoss), JRules BRMS (IBM), Haley BRMS (Oracle), can help to overcome such a situation by keeping the business logic isolated from the rest of the application.

Production rules are pieces of knowledge represented under a condition-action format. A condition is often referred as a pattern (possibly spatial and/or temporal). Production rules are so-called because they generate behaviours. [Browne, 2009] defines production rules as any fragments of knowledge that can be expressed in the format: “WHEN conditions are verified THEN perform some actions”, where the WHEN part is referred to as the “left-hand side”, and the THEN part as the “right-hand side”. This format allows an expert to express his knowledge in a straightforward way, without computing any Java or Python code; hence, removing the need for a computer programmer to assist the expert in encoding his knowledge.

2.2 Architecture

A computing architecture has been designed for the real-time monitoring and analysis of maritime traffic with an original combination of spatio-temporal databases and expert system. The platform developed is a Java-based software with a multi-tiers architecture, and organised through a distributed data and processing model (Figure 1).

The persistence layer relies on PostgreSQL database management system for data manipulation and storage. The PostGIS spatial extension is used to define and handle geographic data types and functions (e.g. distance or intersection between geometries). This layer comprises several database schemas. One has been defined for user-defined geographic information (e.g. a line ships should not cross) and one for each official nautical chart (Fig. 1, geographic data). A schema is used for positioning data (Fig. 1, real-time data) and another one has been defined for historical positioning data (Fig. 1, historical data). The temporal extent of the content can be parameterized by the user (typically 5 to 30 min). Finally editable rules defining maritime events to be detected are packaged and stored as files.

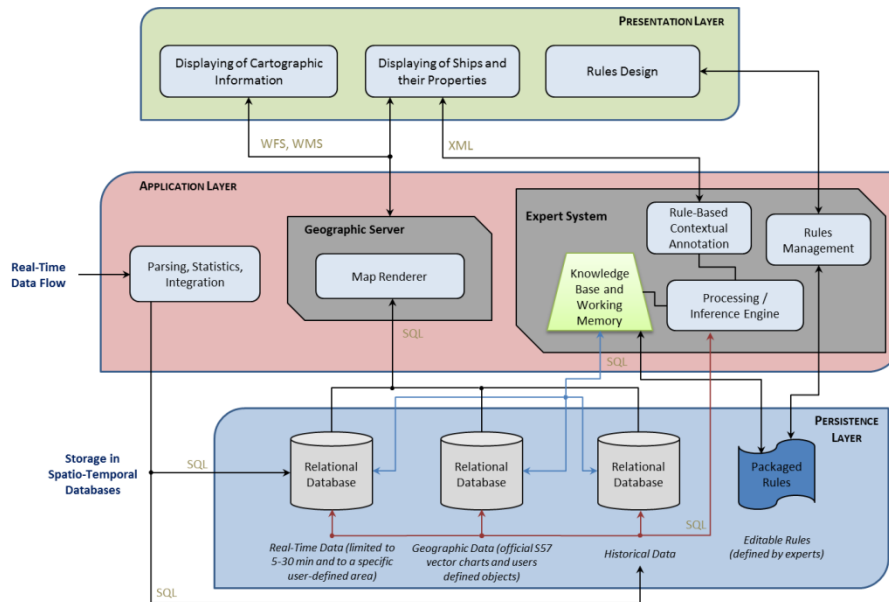


Fig. 1. Architecture

The application tier allows for real-time integration of positioning information and spatio-temporal analysis and inference of ship behaviours. It comprises three different middleware. The first middleware includes parsers dedicated to the integration of positioning data coming from the AIS and to the integration of official S-57 nautical charts. The first program is a Java software, the latter is a script based on GDAL and OGR allowing for integration of vector charts. The second middleware uses Geoserver to exchange data between the databases and the end-user (presentation layer).

The third middleware relies on the Drools expert system. This rule-based system is composed of three parts: a working memory filled with facts, a knowledge base filled with rules, and a rule engine matching facts with rules conditions, a process known as pattern-matching. It uses a "Data Driven" approach, meaning that rules are triggered by injection of data into the working memory. Drools continuously evaluates rules using geospatial data, the result is a set of activated rules having their conditions fully matched. The rule-based contextual annotation and associated XML-based exchange language aim to provide meta information to the presentation layer. For instance, a ship detected in a restricted area will be notified with an XML element containing the ship id, the rule(s) that triggered the notification, and the associated parameters. The presentation layer can then accommodate the visualisation of the maritime situation accordingly.

The graphic user interface (GUI) displays on a single screen all the data presently visualized on many different monitors [Rouxel *et al.*, 2012]. The GUI is implemented (by Mines-Telecom Institute) so as to be operated with a touch table (Diamond Touch). Thence, behavioural surveillance rules can be edited directly on the visualization interface using gestures.

3 EXPERT SYSTEM IMPLEMENTATION

The main objective of the expert system (based on Drools) implemented is to continuously evaluate spatial rules using geospatial data. The following section presents processes taking place in the expert system that connect geographical information data-flows and the rule-based memory management of Drools.

3.1 Implementing the system core

Figure 2 provides a representation of the main processes taking place in the expert system developed. From a user perspective (top-down approach), the surveillance operator defines rules using specific gesture on the touch table (Fig. 2-a). Then, the rules are compiled and inserted into a knowledge base (Fig. 2-b), which produces a Rete graph for Drools.

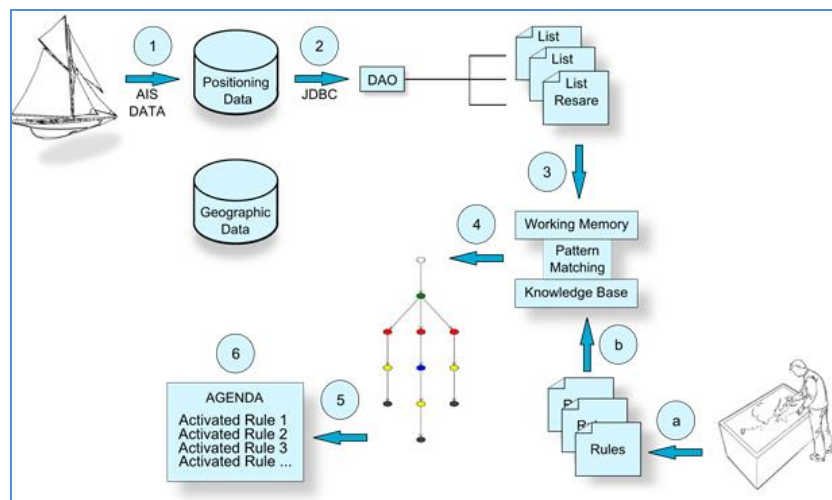


Fig. 2. Main processes involved in the system

From a data flow perspective, the AIS data received are parsed and stored in the positioning database (Fig. 2-1). The integration of spatio-temporal data within Drools memory is a two-step process. Data are firstly retrieved from the spatio-temporal database upon regular basis, and inserted into typed lists (Fig. 2-2). The mechanism has been implemented using the Java Database Connectivity (JDBC) driver. A Data Access Object (DAO) is implemented for each objects manipulated in rules (position, trajectory, coastline...). This fetching process considers two types of objects: stationary objects (S-57 data or user-defined geometries), and dynamic objects (positions and trajectories, etc.). These two types have been differentiated based on their update rates. A DAO thread regularly asks all dynamic DAO objects to check the database for the arrival of new data (every 15 seconds for AIS data). When new records are found, they are transferred into the aforementioned typed list. In a second step, a *Rule Engine Runner* is started and objects are pushed into the working memory of Drools (Fig. 2-3).

Finally, a pattern matching is performed between the facts and rules, using the Rete graph (Fig. 2-4). The facts injected into the working memory propagate along the graph. Ultimately, the facts that reach a leaf activate the affiliated rule (Fig. 2-5). This rule is placed into the Drools agenda. At this stage, a conflict resolution strategy is adopted by the rule engine to choose which rule to execute first (Fig. 2-6).

3.2 Implementing spatial rules

Two approaches have been successfully implemented and tested to execute spatial rules with our expert system. These spatial rules rely several object classes. Objects represent dynamic (e.g. ship position or trajectory) or static inputs (IHO S-57 nautical spatial objects especially restricted area, or operator-defined geometric objects: points and polylines).

The first approach relies on Java Topology Suite library (JTS) which provides many different spatial operators implementing the OpenGIS Simple Features Specification. When evaluated by the inference engine, rules “call” such spatial functions and operators. The following rule (Fig. 3) illustrates that approach using JTS.

```
rule "Rule 7"
salience 20
when
  $resare : Resare()
  $trajectory : AisTrajectory()
  eval($trajectory.getGeom().
intersects($resare.getWkb_geometry()))
then
  logger.logMessage("");
end
```



Fig. 3. Calling a spatial operation using Java Topology Suite

The rule checks whether a boat has crossed a restricted area. The left-hand side of the rule (the WHEN part) is composed of 3 conditions. Firstly, the *Resare()* pattern considers all the object instances of type “Resare” inside the working memory. Secondly, the *AisTrajectory()* pattern considers all the object instances of type *AisTrajectory* inside the working memory. Finally, the *eval* statement evaluates a boolean. Therefore the procedure called inside the parentheses must return a boolean. Here, a call is made to the “intersects” operator of JTS Topology Suite. It checks whether a polyline (*\$trajectory*) has intersected a polygon (*\$resare*). The right-hand side of the rule (the THEN part) logs a message each time the left-hand side is fully matched. The salience attribute represent the rule priority. The higher the salience is, the higher is the rule priority.

The second approach consists in calling spatial SQL procedures which are executed remotely into PostGIS. The following rule (Figure 4) illustrates this method. The rule checks whether a point of interest (here defined by a *UDG_Point*, typically a ship position) is located at less than 5km from a user defined line geometry (*UDG_Line*). The

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