A Semantic Approach to Detecting Maritime Anomalous Situations

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Introduction

For surveillance of maritime areas, various sensors are used to collect relevant data that need to be fused to support situational awareness, in which detection of maritime anomalies is a major concern.

Examples of such anomalies are terrorism, drug and gun traffic, espionage, piracy, illegal fishing, smuggling, illegal military operations, and territorial violation.
Introduction

Approaches to detect anomalies in a maritime setting are based on the analysis of the kinematics and behavior of the involved agents by means of formal knowledge representation.

However, occasionally such representations do not take into consideration important aspects of agents and settings.

We developed a semantic approach to represent and allow inferences about vessel kinematics and behavior to detect anomalous situations in maritime scenarios, based on semantic annotations of vessels’ trajectories.
Background

The approach presented in this work is extensively based on the notion of ontology and Semantic Web standard languages and tools.

The standard languages used are the Web Ontology Language (OWL), Resource Description Framework (RDF), Resource Description Framework Schema (RDFS), and SPARQL.
Background

An ontology is a representational artifact composed of a combination of universals, defined classes and relationships between them.

The major structural aspect of ontologies is a taxonomy, which is a hierarchy of universals and defined classes linked by subtype relations.

The ontological view is in accordance with the ontological realism, which is based on an Aristotelian view that there must always be particulars that ground the existence of universals.

Background

Resource Description Framework (RDF) is a format that allows describing a binary relationship as a triple: subject, property and object.

The key idea of the schema in RDF is that it should help provide some sense of meaning to the data.
Web Ontology Language (OWL) is a Semantic Web language designed to represent rich and complex knowledge about things, groups of things, and relations between things.

OWL is a computational logic-based language such that knowledge expressed in OWL can be reasoned with by computer programs either to verify the consistency of that knowledge or to make implicit knowledge explicit.
Related Works

Frameworks for maritime anomaly detection, for instance to detecting anomalous behavior from navigation rules (GARCIA et al., 2011)

Use of interactive graphical interface to support better visualization for detecting maritime anomalies (RIVEIRO et al., 2008; RIVEIRO et al., 2009)

BRAX and NIKLASSON (2009) proposed an approach for maritime anomaly detection based on intelligent agents. Each agent was in charge of detecting a specific type of anomaly within both static and dynamic data sets for the created scenarios
Related Works

ROY (2008) and (ROY; DAVENPORT, 2009): taxonomy of anomalies and anomalous situation rules; description of maritime areas, such as fishing and anchorage area; types of activities performed by vessels, such as fishing and smuggling

SPACCAPIETRA et al. (2008): Conceptual model for trajectories representation in terms of stop and move episodes

YAN (2011): approach for trajectory analysis aiming at facilitating the understanding the behavior of moving objects
Approach for Detecting Maritime Anomalies

The purpose of the approach is to offer a way to represent and allow inferences about vessel kinematics and behavior to detect anomalous situations in a maritime scenario.
Approach for Detecting Maritime Anomalies – Semantic Module

The Semantic Model is composed of three interconnected ontologies
Approach for Detecting Maritime Anomalies – Semantic Module: Maritime Domain Ontology

Represents knowledge about vessels’ categories and properties, and concepts related to the maritime environment.

Anomalous situations:
- Smuggling
- Illegal fishing
- Piracy

Vessels:
- FishingVessel
- ForeignVessel
- MerchantVessel

Class hierarchy: EmbarcacaoNacional

Represented concepts:
- EmbarcacaoAIS
- EmbarcacaoAltaVelocidade
- EmbarcacaoAutorizadaTrafegarEmAJB
- EmbarcacaoDePesca
- EmbarcacaoDePesquisa
- EmbarcacaoEmpregadaEmViagensInternacionais
- EmbarcacaoEmpregadaEmViagensNacionais
- EmbarcacaoEsporteRecreio
- EmbarcacaoEspera
- EmbarcacaoIrregular
- EmbarcacaoMercante
- EmbarcacaoMiuda
- EmbarcacaoNacional
- EmbarcacaoSOLAS
- EmbarcacaoSuspeita
- NavioDeCarga
- NavioDeEstado
Approach for Detecting Maritime Anomalies – Semantic Module: Trajectory Ontology

The trajectory ontology specifies relevant aspects related to vessels’ trajectories, such as origin and destination ports, time and geographic information.
Approach for Detecting Maritime Anomalies – Semantic Module: Simple Event Model Ontology

The simple event model ontology supports the representation of stop-move episodes; Used to check two types of events: Vessels encounter and navigation through an area.

HAGE et al., 2011; HAGE et al., 2009
Experiments and Results

The Query Module uses SPARQL for querying the Triple Store about anomalous situations of interest.

To test the feasibility of this approach, we carried out experiments using synthetic data translated to Resource Description Framework (RDF) format to compose data sets depicting several distinct abnormal situations.

To build the synthetic data sets, we used two mechanisms. The first one was a multiagent-based simulation, and the second was an algorithm to generate RDF triples directly from a random Markov chain that controls trajectory state changes.
Experiments and Results – Agent-based Simulation

For the agent-based simulation experiments we used the Library MASON

We simulated fishing vessels departing from the Port of Santos, going through and stopping in prohibited fishing areas, then coming back to the port.
Experiments and Results – Agent-based Simulation: Triple representation

ex:stop1_ag5
   trj:hasInterval
      [ trj:hasFirstInstant ex:t101 ;
      trj:hasLastInstant ex:t211
      ] ;
   trj:hasPoint ex:p186 .

ex:move3_ag5
   trj:from ex:stop2_ag5 ;
   trj:to ex:stop3_ag5 .

ex:p186
   georss:point "-46.17698146769451 -24.27022964080674" ;
   mar:estaDentroDeArea
      ex:area_1 .

<table>
<thead>
<tr>
<th>Classe</th>
<th>A-Box 1</th>
<th>A-Box 2</th>
<th>A-Box 3</th>
</tr>
</thead>
<tbody>
<tr>
<td>mar:Embarcacao</td>
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<td>50</td>
<td>500</td>
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<td>mar:Area</td>
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<tr>
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<td>50</td>
<td>500</td>
</tr>
<tr>
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<td>50</td>
<td>500</td>
</tr>
<tr>
<td>trj:Begin</td>
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<td>50</td>
<td>500</td>
</tr>
<tr>
<td>trj:Stop</td>
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<td>192</td>
<td>2205</td>
</tr>
<tr>
<td>trj:Move</td>
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<td>243</td>
<td>2706</td>
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<tr>
<td>trj:TimePoint</td>
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<td>103</td>
<td>1003</td>
</tr>
<tr>
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<tr>
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<tr>
<td>trj:Point</td>
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<td>13979</td>
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</table>
Experiments and Results – Agent-based Simulation: SPARQL query and result

```
Which Vessels Stopped in Prohibited Fishing Areas?

SELECT DISTINCT ?e ?a
WHERE {
  ?e trj:hasTrajectory ?t.
  ?t trj:hasStop ?s.
  ?s trj:hasPoint ?p.
  ?a a mar:AreaDePescaProhibida.
}
```

<table>
<thead>
<tr>
<th>Agent</th>
<th>Area</th>
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<tbody>
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<td>ex:agent4</td>
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<td>ex:agent3</td>
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</tr>
<tr>
<td>ex:agent0</td>
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<tr>
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</tr>
<tr>
<td>ex:agent2</td>
<td>ex:area_1</td>
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</tbody>
</table>
Experiments and Results – Strait RDF Triple Generation

Markov chain to generate trajectory episodes in terms of begin, move, stop, and end

<table>
<thead>
<tr>
<th>Classe</th>
<th>A-Box 4</th>
<th>A-Box 5</th>
<th>A-Box 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>mar:Embarcacao</td>
<td>20</td>
<td>30</td>
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<tr>
<td>mar:Area</td>
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<td>129</td>
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<tr>
<td>trj:End</td>
<td>13</td>
<td>24</td>
<td>100</td>
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<tr>
<td>trj:Trajectory</td>
<td>20</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>trj:Begin</td>
<td>20</td>
<td>30</td>
<td>100</td>
</tr>
<tr>
<td>trj:Stop</td>
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<td>315</td>
<td>1266</td>
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<tr>
<td>trj:Move</td>
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<td>343</td>
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<td>trj:TimePoint</td>
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<td>12291</td>
</tr>
<tr>
<td>trj:Interval</td>
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<td>3945</td>
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<td>965</td>
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<tr>
<td>trj:Geo</td>
<td>1999</td>
<td>3077</td>
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<tr>
<td>sem:Event</td>
<td>873</td>
<td>1289</td>
<td>2679</td>
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</tbody>
</table>
Experiments and Results – Strait RDF Triple Generation – Possible smuggling situation

Which vessels ran into another for a period of time, in which one of them is a merchant vessel coming from a foreign port, the other is coming from a small port, the meeting point is in a suspicious smuggling area, and the stop duration is longer than 30 units of time?
Experiments and Results – Strait RDF Triple Generation

```sql
WHERE {
  ?emb1 trj:hasTrajectory/trj:hasStop ?stop1 ;
    mar:temPortoDeOrigem/a mar:PortoPequeno .
  ?emb2 trj:hasTrajectory/trj:hasStop ?stop2 ;
    mar:temPortoDeOrigem/a mar:PortoEstrangeiro ;
    a mar:NavioDeCarga .
  ?evt sem:hasActor ?emb1, ?emb2 ;
      sem:hasPlace ?place ;
      trj:hasInterval ?int_evt ;
      sem:eventType mar:encontroDeEmbarcacoes .
  ?int_evt trj:hasFirstInstant/rdf:value ?t_inicio
    trj:hasLastInstant/rdf:value ?t_fim .
  ?place a mar:AreaSuspeitaDeContrabando .
  FILTER (?emb1 != ?emb2)
  FILTER (?t_fim - ?t_inicio > 30)
}
```

<table>
<thead>
<tr>
<th>evt</th>
<th>move</th>
<th>stop</th>
</tr>
</thead>
<tbody>
<tr>
<td>:emb26</td>
<td>:move298</td>
<td>:stop278</td>
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<td>:move246</td>
<td>:stop222</td>
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<td>:stop216</td>
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<td>:emb26</td>
<td>:move120</td>
<td>:stop185</td>
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<td>:emb26</td>
<td>:move271</td>
<td>:stop249</td>
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<tr>
<td>:emb26</td>
<td>:move227</td>
<td>:stop204</td>
</tr>
<tr>
<td>:emb23</td>
<td>:move131</td>
<td>:stop111</td>
</tr>
<tr>
<td>:emb23</td>
<td>:move32</td>
<td>:stop29</td>
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</table>
Conclusion

Though more experiment be necessary to stress the approach, the proposed approach allowed making inferences about anomalies in a reasonable way.

As future work, we intend to refine the approach by taking into account other practical aspects. Another intention is to refine the approach to allow reasoning about what will happen according to present and historical situations.

We intend to adapt the approach to other contexts, such as:
- UAV trajectory analysis, taking into account geographical, meteorological and demographic data
- Aeronautical accident investigation from aircraft trajectories data, and geographical and other aircraft flight data
Thank you!

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