Composite Event Patterns for Maritime Monitoring

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Composite Event Recognition

INPUT ▶ RECOGNITION ▶ OUTPUT ■

Streams of SDEs

Event Recognition System

CE Definitions

Recognised CEs
Maritime Monitoring
The Automatic Identification System is an extensively used autonomous tracking system that allows transmission of dynamic and static vessel information.

Transmitted Data:

- **Dynamic information**: MMSI, timestamp, position, speed, heading, course over ground, rate of turn
- **Static & Voyage related information**: IMO, name, type, dimensions, destination, ETA, draught
Tugging operation

- Two vessels, close in distance...
- one of them is a tug boat...
- and they are moving with same speed and direction at the same time.
Rendezvous

- Two vessels are close in distance...
- and they are stopped or sailing with low speed...
- for a period of time.
Fishing

- A fishing vessel in a fishing area...
- sailing with trawling speed...
- and its course is “erratic”.

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Event Calculus

- A **logic programming language** for representing and reasoning about events and their effects.

- Key components:
  - event (typically instantaneous).
  - fluent: a property that may have different values at different points in time.

- Built-in representation of **inertia**:
  - \( F = V \) holds at a particular time-point if \( F = V \) has been *initiated* by an event at some earlier time-point, and not *terminated* by another event in the meantime.
## Run-Time Event Calculus: Predicates

<table>
<thead>
<tr>
<th>Predicate</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td><code>happensAt(E, T)</code></td>
<td>Event $E$ occurs at time $T$</td>
</tr>
<tr>
<td><code>initiatedAt(F = V, T)</code></td>
<td>At time $T$ a period of time for which $F = V$ is initiated</td>
</tr>
<tr>
<td><code>terminatedAt(F = V, T)</code></td>
<td>At time $T$ a period of time for which $F = V$ is terminated</td>
</tr>
<tr>
<td><code>holdsFor(F = V, I)</code></td>
<td>$I$ is the list of the maximal intervals for which $F = V$ holds continuously</td>
</tr>
<tr>
<td><code>holdsAt(F = V, T)</code></td>
<td>The value of fluent $F$ is $V$ at time $T$</td>
</tr>
<tr>
<td><code>union_all([J₁, ..., Jₙ], I)</code></td>
<td>$I = (J₁ \cup ... \cup Jₙ)$</td>
</tr>
<tr>
<td><code>intersect_all([J₁, ..., Jₙ], I)</code></td>
<td>$I = (J₁ \cap ... \cap Jₙ)$</td>
</tr>
<tr>
<td><code>relative_complement_all (I', [J₁, ..., Jₙ], I)</code></td>
<td>$I = I' \setminus (J₁ \cup ... \cup Jₙ)$</td>
</tr>
</tbody>
</table>
Run-Time Event Calculus: Windows

[Diagram showing a timeline with events labeled Q177 to Q182 and working memory changes indicated with arrows and dots.]

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**Patterns: Rendezvous**

holdsFor(\textit{rendezVous}(\textit{Vessel1}, \textit{Vessel2}), I) \leftarrow
\text{holdsFor}(\textit{proximity}(\textit{Vessel1}, \textit{Vessel2}), I_p),
\text{holdsFor}(\textit{lowSpeed}(\textit{Vessel1}), I_{l1}),
\text{holdsFor}(\textit{lowSpeed}(\textit{Vessel2}), I_{l2}),
\text{holdsFor}(\textit{stopped}(\textit{Vessel1}) = \textit{farFromPorts}, I_{s1}),
\text{holdsFor}(\textit{stopped}(\textit{Vessel2}) = \textit{farFromPorts}, I_{s2}),
\text{holdsFor}(\textit{tugging}(\textit{Vessel1}, \textit{Vessel2}), I_{tug}),
I_1 = I_{l1} \cup I_{s1},
I_2 = I_{l2} \cup I_{s2},
I = (I_1 \cap I_2 \cap I_p) \setminus I_{tug},
I > R_{V_time}.

Rendezvous between two fishing vessels.
Patterns: Engaged in fishing

\[
\text{initiatedAt}(\text{trawlingMovement}(Vessel), T) \leftarrow \\
\text{happensAt}(\text{change\_in\_heading}(Vessel), T), \\
\text{holdsAt}(\text{withinArea}(Vessel, fishing), T). \\
\text{deadlineUE}(\text{trawlingMovement}(Vessel), TrawlingMDtime). \\
\text{holdsFor}(\text{trawling}(Vessel), I) \leftarrow \\
\text{Vessel}: \text{fishing}, \\
\text{holdsFor}(\text{trawlSpeed}(Vessel), It), \\
\text{holdsFor}(\text{withinArea}(Vessel, fishing), Iw), \\
\text{holdsFor}(\text{trawlingMovement}(Vessel), Itc), \\
I = It \cap Iw \cap Itc, \\
I > TrawlingDuration.
\]

A fishing vessel during trawling activity.
Experimental Setup: Dataset

Brest, France  

<table>
<thead>
<tr>
<th>Data</th>
<th>#</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vessels</td>
<td>5K</td>
</tr>
<tr>
<td>Position signals</td>
<td>18M</td>
</tr>
<tr>
<td>Critical position signals</td>
<td>4.6M</td>
</tr>
<tr>
<td>Spatio-temporal events</td>
<td>811K</td>
</tr>
</tbody>
</table>
Experimental Setup: Streams

- AIS Stream Collection
- Spatial Preprocessing
- Trajectory Synopsis Generation
  - Critical Point Labelling
  - Trajectory Compression
- Critical Point Stream
- Enriched AIS Stream
Experimental Results: Accuracy

<table>
<thead>
<tr>
<th>Event</th>
<th>$F_1$-Score</th>
</tr>
</thead>
<tbody>
<tr>
<td>Speed not compatible with area</td>
<td>1.000</td>
</tr>
<tr>
<td>Anchored</td>
<td>1.000</td>
</tr>
<tr>
<td>Moored</td>
<td>1.000</td>
</tr>
<tr>
<td>Aground</td>
<td>1.000</td>
</tr>
<tr>
<td>Loitering</td>
<td>1.000</td>
</tr>
<tr>
<td>Rendezvous</td>
<td>1.000</td>
</tr>
<tr>
<td>Under way</td>
<td>0.997</td>
</tr>
<tr>
<td>Movement ability affected</td>
<td>0.964</td>
</tr>
<tr>
<td>Trawling speed</td>
<td>0.961</td>
</tr>
<tr>
<td>Engaged in fishing</td>
<td>0.961</td>
</tr>
<tr>
<td>Speed not compatible with vessel type</td>
<td>0.937</td>
</tr>
<tr>
<td>Tugging</td>
<td>0.915</td>
</tr>
<tr>
<td>Dead in water, drifting</td>
<td>0.838</td>
</tr>
</tbody>
</table>
Experimental Results: False Positives/Negatives

Critical Points

Raw AIS messages

Critical Points

Raw AIS messages

(0,0.0012)

(4,0.0054)

(11,0.001)

(13,0.0053)

(18,0.0017)

(23,0.0014)

(21,0.0056)

(27,0.0041)
Average recognition time: all events

Step = 2 hours

Average recognition times.

Average Recognition Time (sec)

Window size (hours)

Enriched AIS Stream
Critical Point Stream
Average recognition time: per composite event (part A)

Enriched AIS stream

Critical point stream
Average recognition time: per composite event (part B)

Enriched AIS stream

Critical point stream
Average recognition time: per composite event (part C)

Enriched AIS stream

Critical point stream
Average recognition time: per composite event (part D)

Enriched AIS stream

Critical point stream
• Slides, complex event recognition software, datasets: http://cer.iit.demokritos.gr
• Brest dataset: https://zenodo.org/record/1167595
Any questions?