Composite Event Recognition for Maritime Monitoring

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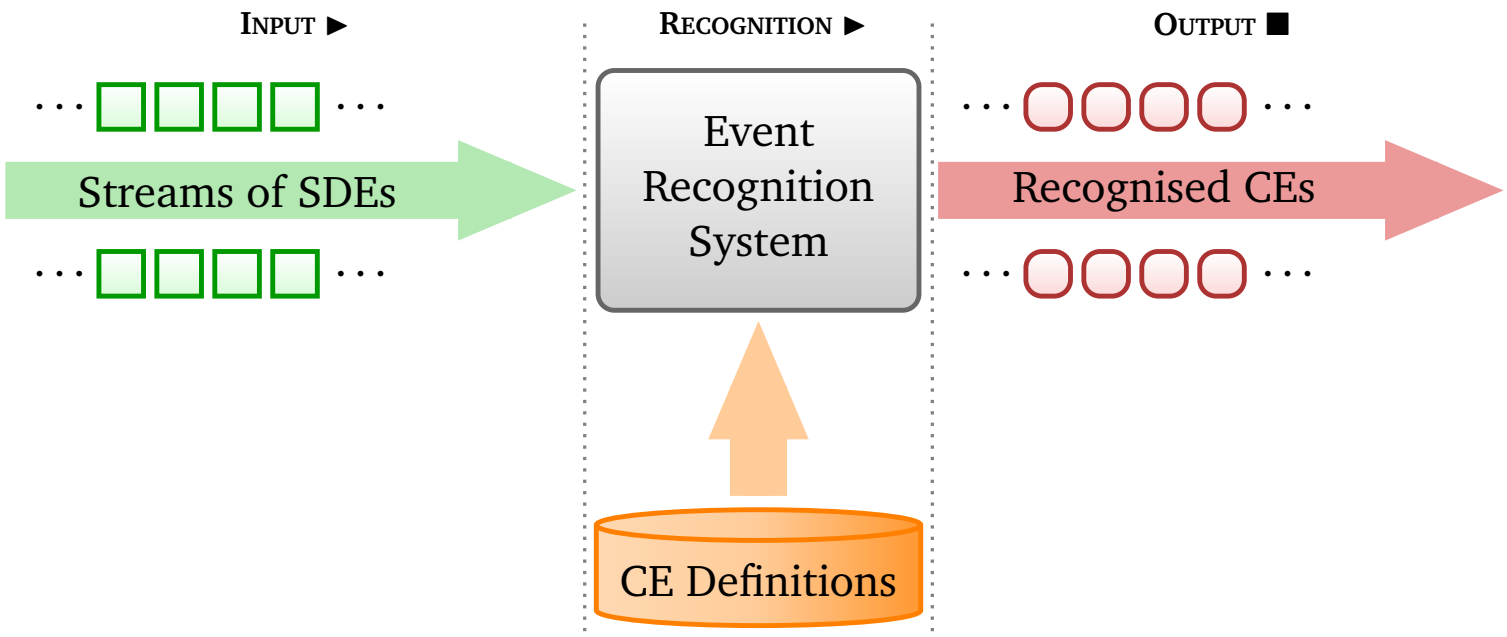
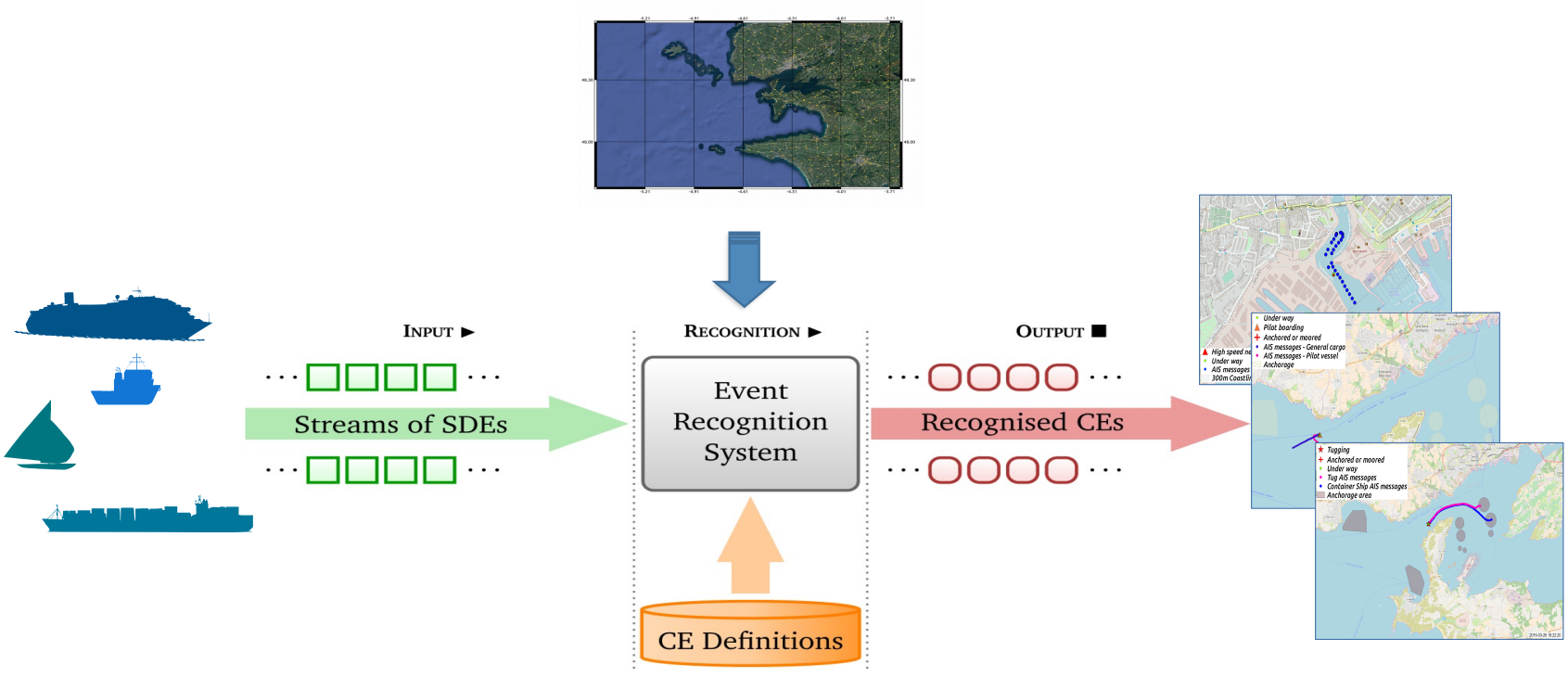
Composite Event Recognition



Composite Event Recognition for Maritime Monitoring



Composite Event Recognition Engine

Run-Time Event Calculus (RTEC):

- Guides data-driven reasoning using domain-knowledge.
- High-level language facilitating interaction with domain experts.
- Built-in rules for temporal reasoning.
- Formal, declarative semantics.
- Scalable to high-velocity data streams.
- Direct routes to machine learning.

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 (RTEC)

Predicate	Meaning
happensAt(E, T)	Event E occurs at time T
initiatedAt$(F = V, T)$	At time T a period of time for which $F = V$ is initiated
terminatedAt$(F = V, T)$	At time T a period of time for which $F = V$ is terminated
holdsFor$(F = V, I)$	I is the list of the maximal intervals for which $F = V$ holds continuously
holdsAt$(F = V, T)$	The value of fluent F is V at time T
union_all$([J_1, \ldots, J_n], I)$	$I = (J_1 \cup \ldots \cup J_n)$
intersect_all$([J_1, \ldots, J_n], I)$	$I = (J_1 \cap \ldots \cap J_n)$
relative_complement_all $(I', [J_1, \ldots, J_n], I)$	$I = I' \setminus (J_1 \cup \ldots \cup J_n)$
deadline[UE]$(F = V, T)$	$F = V$ is terminated after T timepoints (Unless Extended)

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CE Definitions in the RTEC

CE definition:

$$\textbf{initiatedAt}(CE,\ T) \leftarrow \textbf{happensAt}(E_{In_1},\ T), [\text{conditions}]$$
$$\ldots$$
$$\textbf{initiatedAt}(CE,\ T) \leftarrow \textbf{happensAt}(E_{In_i},\ T), [\text{conditions}]$$

$$\textbf{terminatedAt}(CE,\ T) \leftarrow \textbf{happensAt}(E_{T_1},\ T), [\text{conditions}]$$
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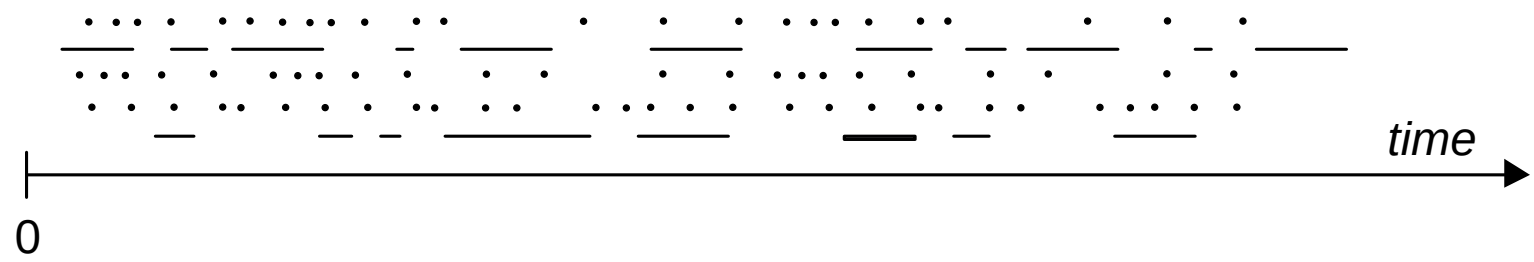
CE recognition:



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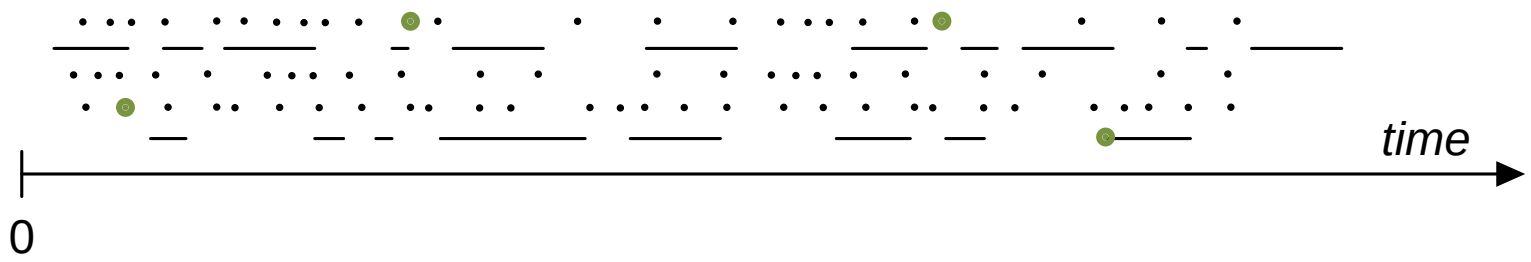

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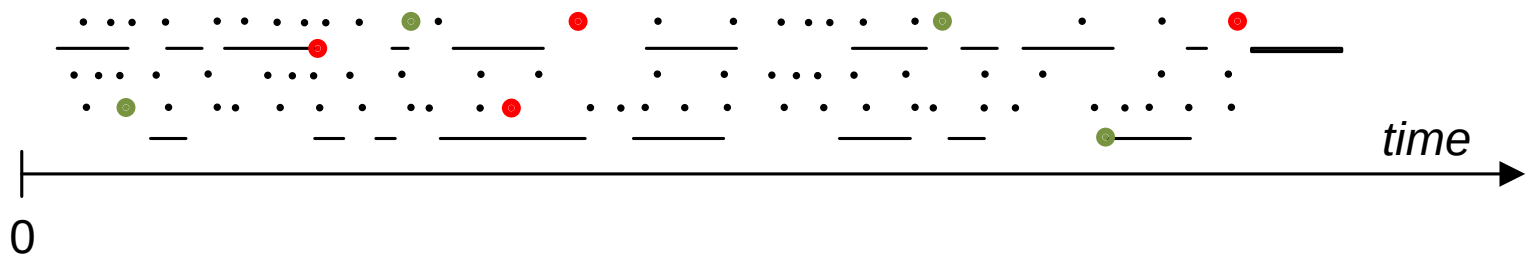

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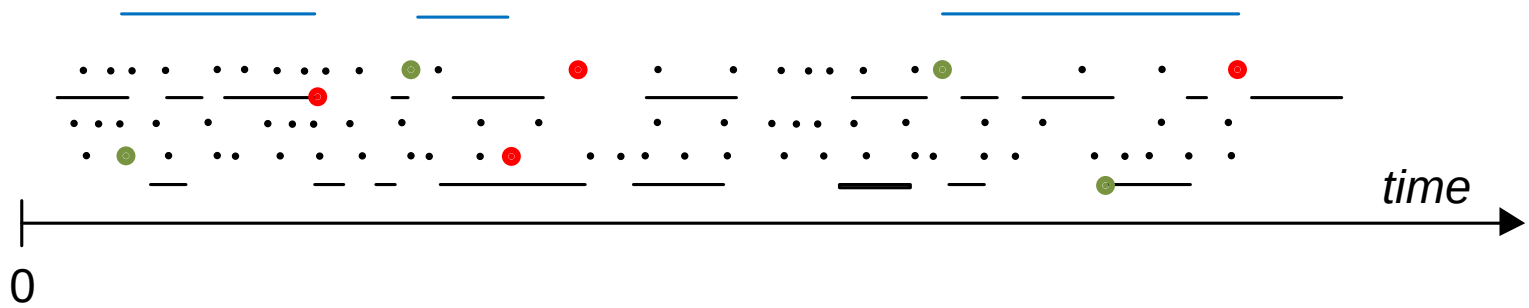
CE recognition: $\textbf{holdsFor}(CE,\ I)$

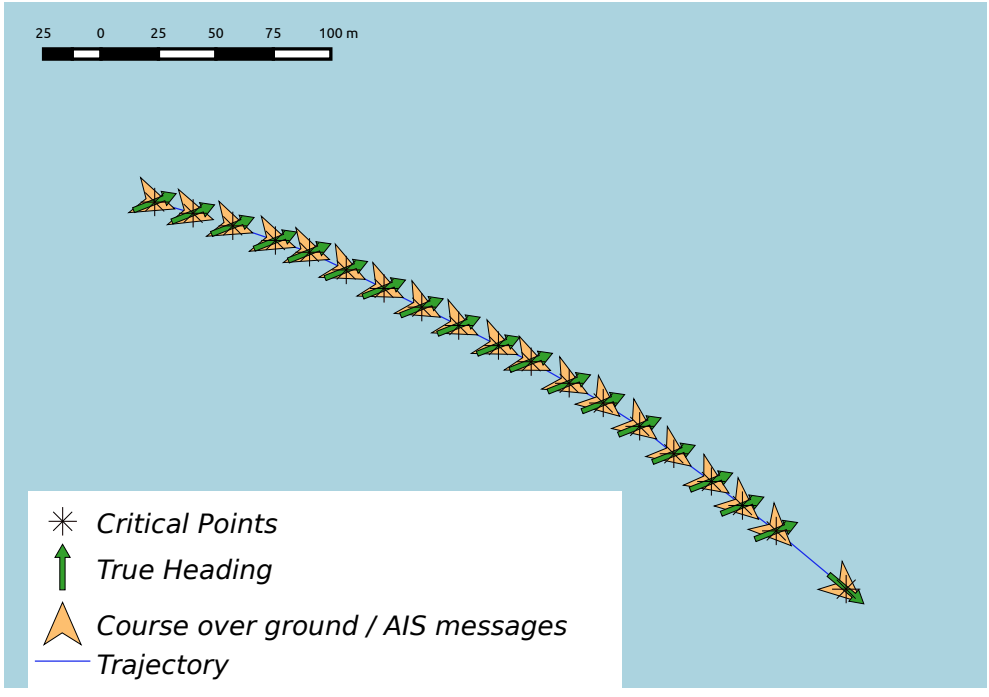


Maritime Patterns: Drifting

initiatedAt$(drifting(Vessel), T) \leftarrow$
happensAt$(velocity(Vessel, \_, CoG, TrHd), T)$,
$angleDiff(CoG, TrHd, Ad)$,
$threshold(v_{ad}, V_{ad})$, $\quad Ad > V_{ad}$,
holdsAt$(underWay(Vessel), T)$.

terminatedAt$(drifting(Vessel), T) \leftarrow$
happensAt$(velocity(Vessel, \_, CoG, TrHd), T)$,
$angleDiff(CoG, TrHd, Ad)$,
$threshold(v_{ad}, V_{ad})$, $\quad Ad \leq V_{ad}$.

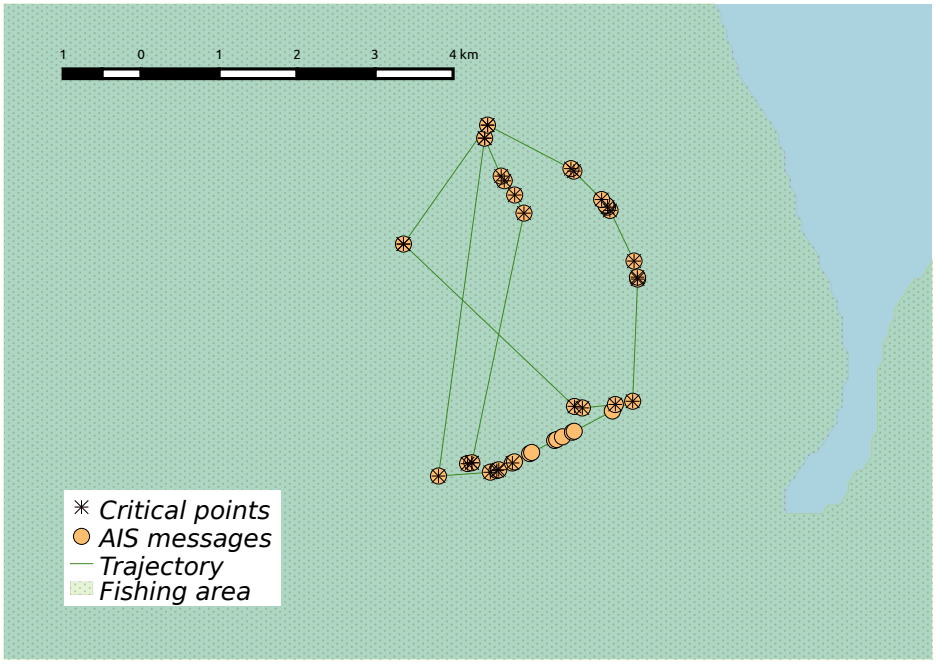
terminatedAt$(drifting(Vessel), T) \leftarrow$
happensAt$(\text{end}(underWay(Vessel)), T)$.



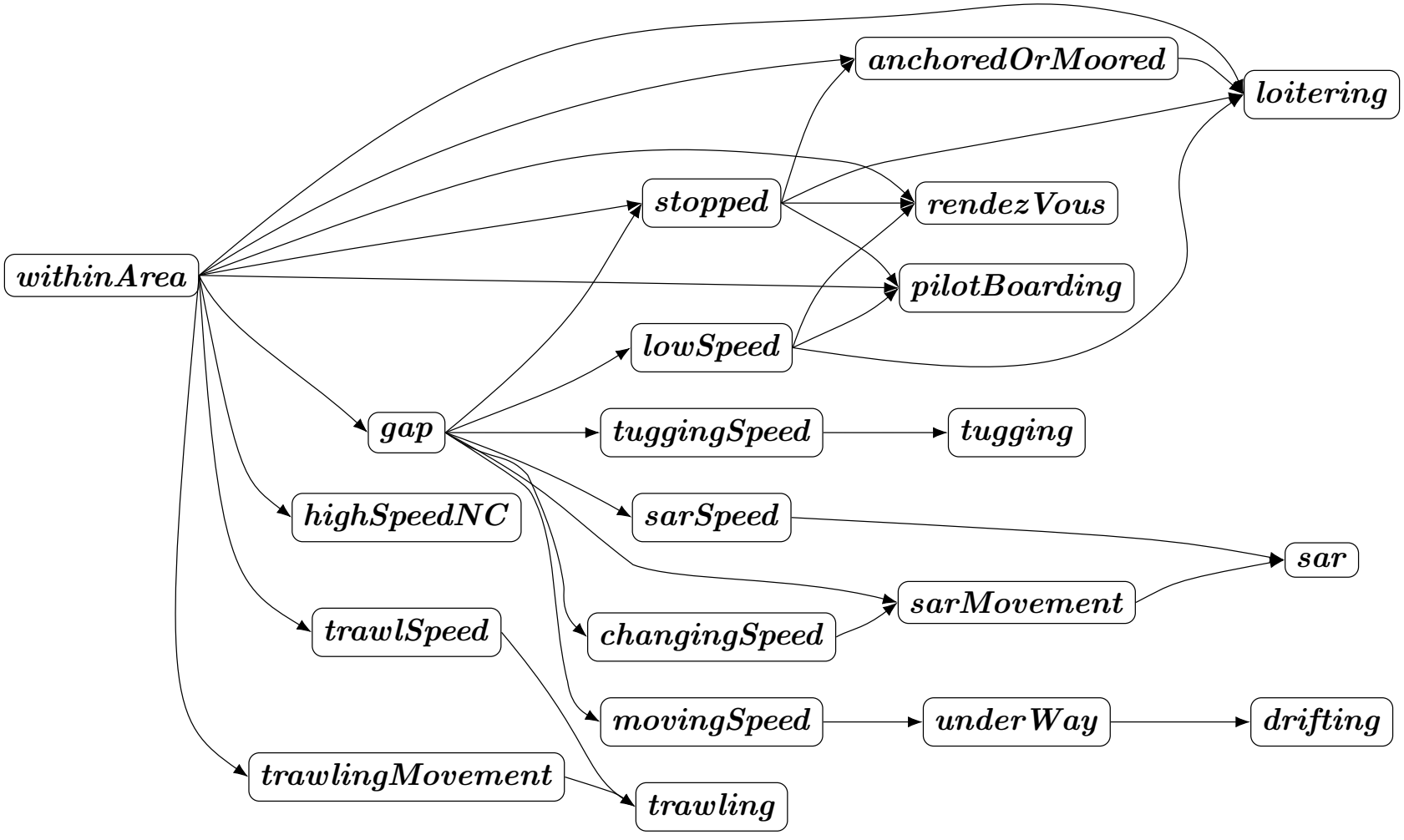
Maritime Patterns: Trawling

initiatedAt($trawlingMovement(Vessel)$, T) $\leftarrow$
  happensAt($change\_in\_heading(Vessel)$, T),
  $vesselType(Vessel, fishing)$,
  holdsAt($withinArea(Vessel, fishing)$, T).
deadlineUE($trawlingMovement(Vessel)$, $MinT$).

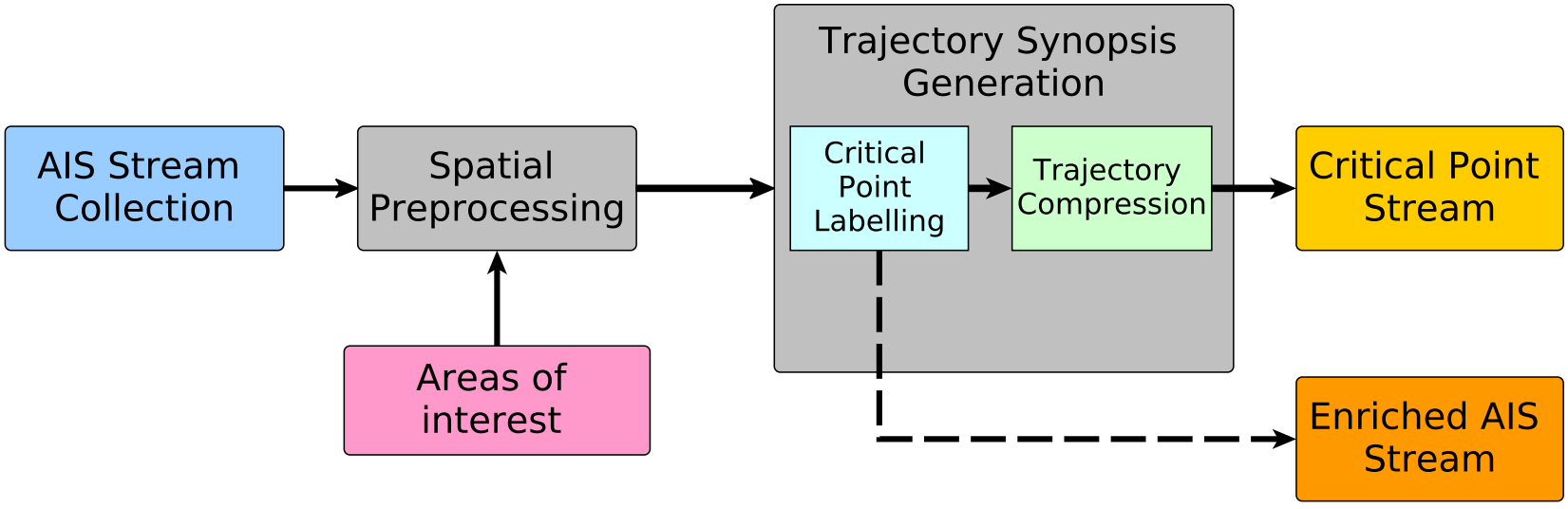
holdsFor($trawling(Vessel)$, I) $\leftarrow$
  holdsFor($trawlingMovement(Vessel)$, Itc),
  holdsFor($trawlSpeed(Vessel)$, It),
  intersect_all($[It, Itc], I_i$),
  $threshold(v_{trawl}, V_{trawl})$,
  $intDurGreater(I_i, V_{trawl}, I)$.



Maritime Pattern Hierarchy

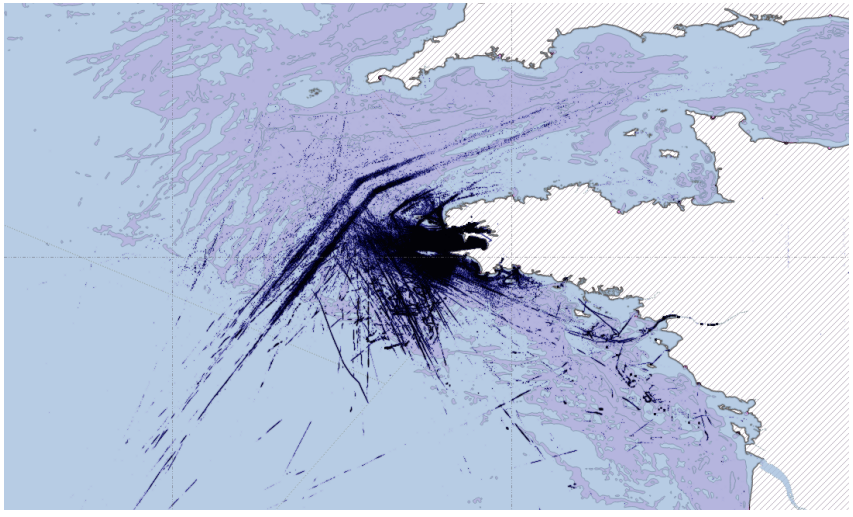


Empirical Evaluation



Empirical Evaluation

Attribute	**Brest, France**	Europe
Period (months)	6	1
Vessels	5K	34K
AIS signals	18M	55M
Critical points	4.6M	17M
Fishing areas	263	1K
Natura 2000 areas	1K	6K
Ports	222	2201
Spatio-temporal events	811K	7M



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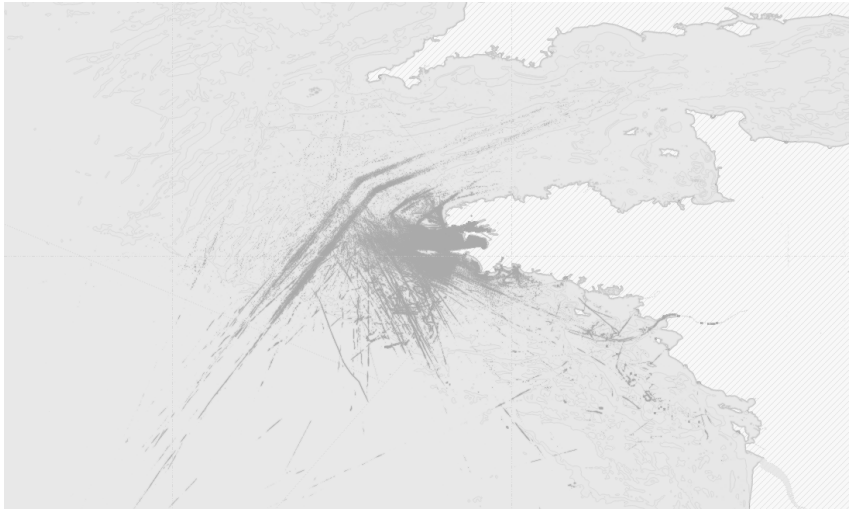
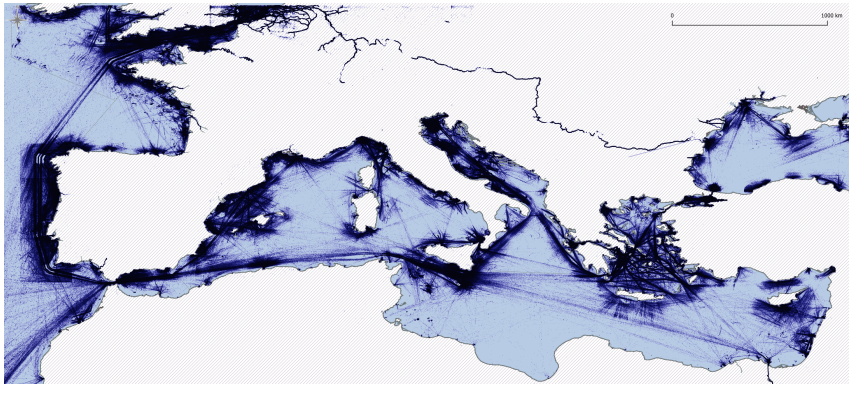




Precision based on expert feedback

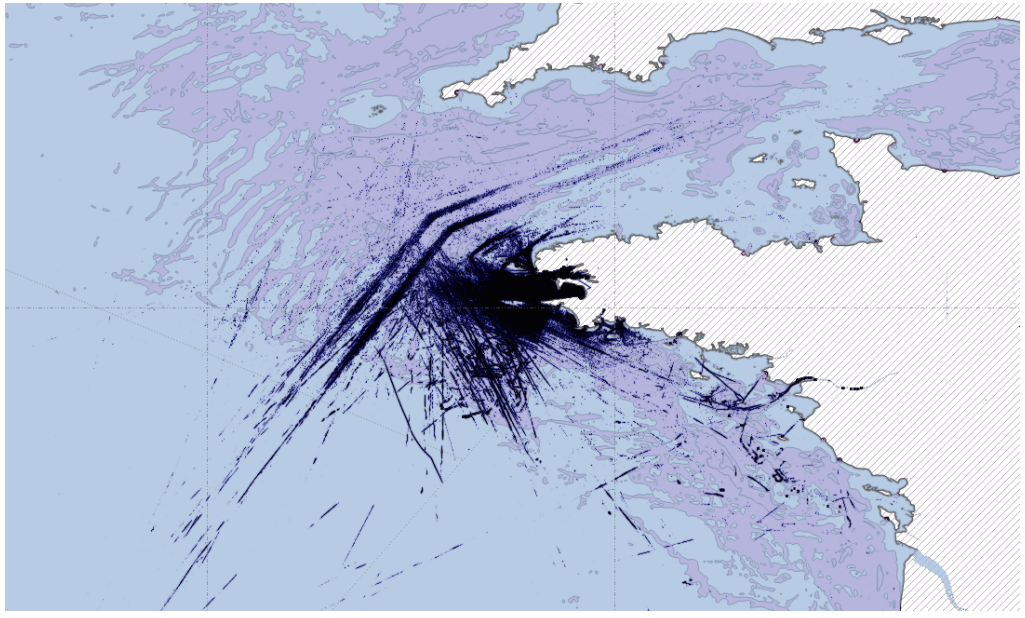
Composite Event	**TP**	**FP**	**Precision**
anchoredOrMoored(*Vessel*)	3067	4	0.999
trawling(*Vessel*)	29	0	**1.000**
tugging(*Vessel*)	117	0	**1.000**
pilotBoarding($Vessel_1$, $Vessel_2$)	80	0	**1.000**
rendezVous($Vessel_1$, $Vessel_2$)	52	2	0.963

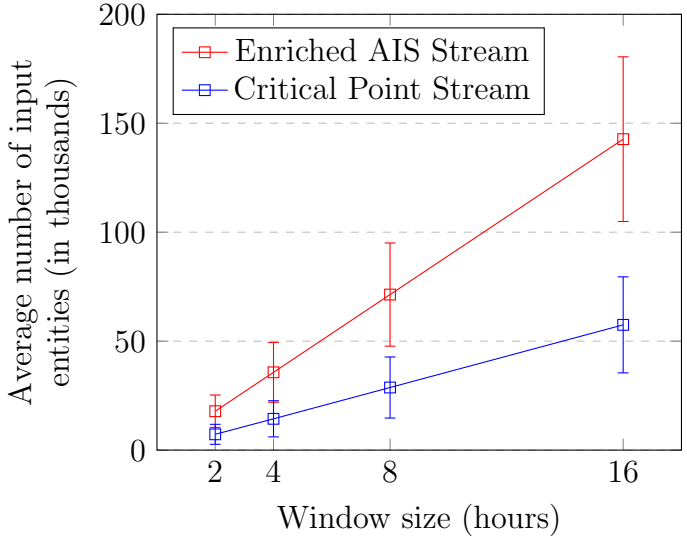
One month of the Brest dataset.

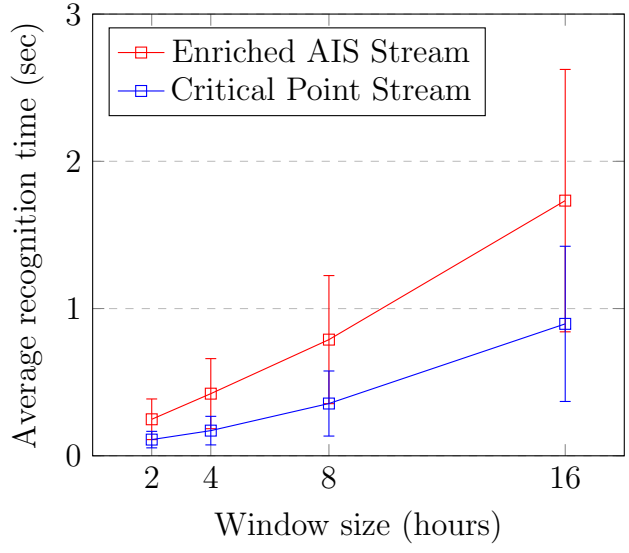
Compression effects on accuracy

Composite Event	**Brest** F_1**-Score**	**Europe** F_1**-Score**
highSpeedNC(*Vessel*)	0.989	0.989
anchoredOrMoored(*Vessel*)	**1.000**	**1.000**
drifting(*Vessel*)	0.999	-
trawling(*Vessel*)	0.994	0.998
tugging($Vessel_1$, $Vesssel_2$)	0.994	0.951
pilotBoarding($Vessel_1$, $Vessel_2$)	**1.000**	**1.000**
rendezVous($Vessel_1$, $Vessel_2$)	**1.000**	**1.000**
loitering(*Vessel*)	**1.000**	**1.000**
sar(*Vessel*)	0.998	0.988

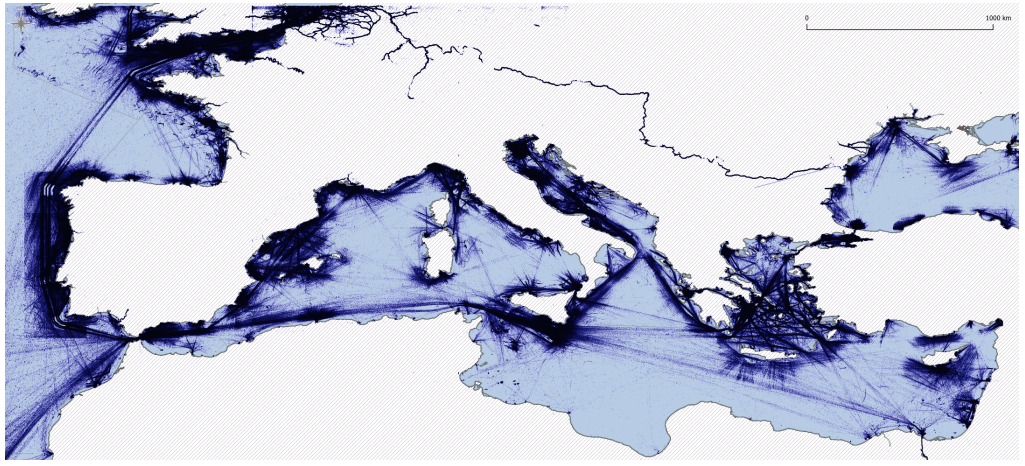
Performance Evaluation: Brest, France

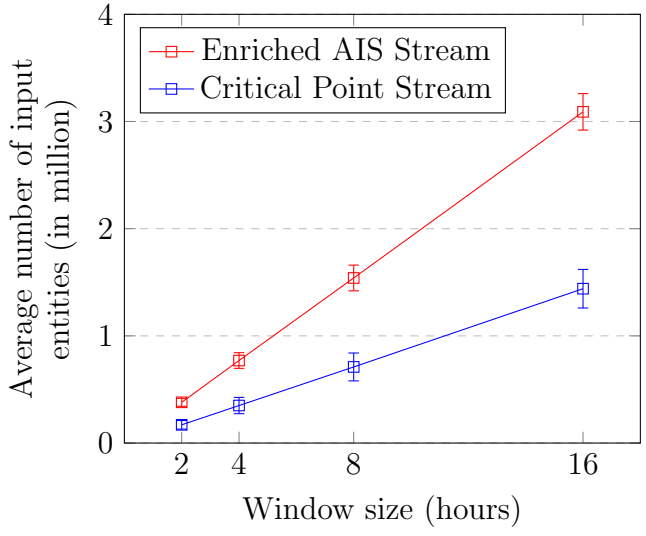


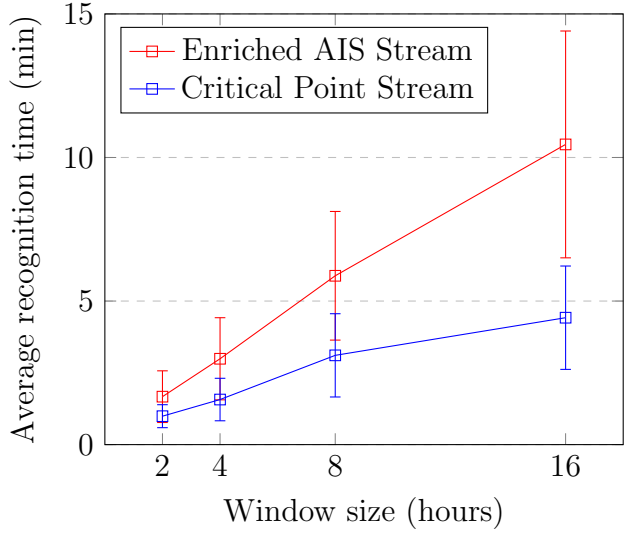




Performance Evaluation: Europe







Summary

Composite Event Recognition system for maritime monitoring:

- with formal specifications of effective maritime patterns,
- evaluated by domain experts using real data,
- and proven to be capable of real-time CER.

Current work:

- data fusion (AIS in conjuction with SAR images, radar etc),
- and detection of dark targets.

The dataset of recognised composite events is available here:
`https://zenodo.org/record/2557290`

Join us in the demo session or visit our site below:
`https://cer.iit.demokritos.gr/cermm`