

Making Sense of Streaming Data: Formal Models for CER

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Slides, Papers, Code & Data

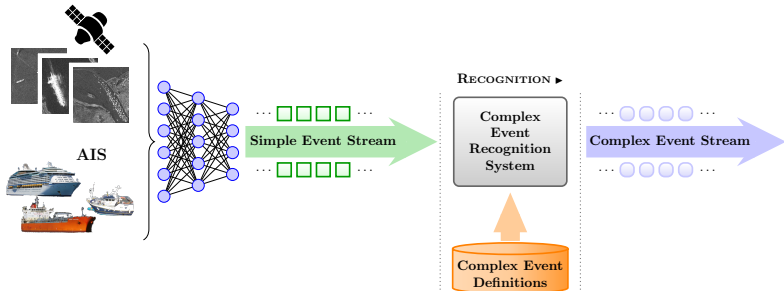


Making Sense of Streaming Data

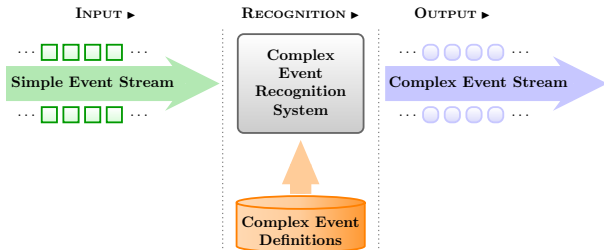


Complex Event Recognition lab

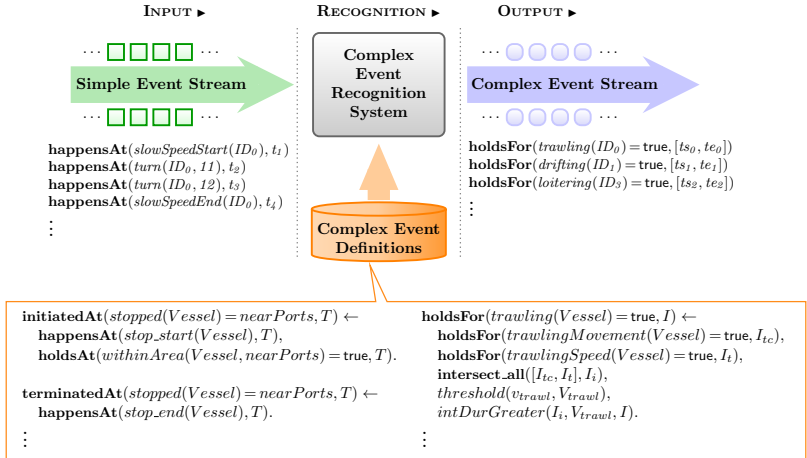
Complex Event Recognition



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Complex Event Recognition



Deductive Databases*: 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.

* Ramamohanarao and Harland. An Introduction to Deductive Database Languages and Systems. VLDB Journal, 1994.

[†] Kowalski and Sergot, A Logic-based Calculus of Events. New Generation Computing, 1986.

Deductive Databases*: 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.

*Ramamohanarao and Harland. An Introduction to Deductive Database Languages and Systems. VLDB Journal, 1994.

[†]Kowalski and Sergot, A Logic-based Calculus of Events. New Generation Computing, 1986.

Run-Time Event Calculus (RTEC)^{*,†}

initiatedAt($F = V, T$) $\leftarrow$
 happensAt(E_{In_1}, T),
 [conditions]

...

initiatedAt($F = V, T$) $\leftarrow$
 happensAt(E_{In_i}, T),
 [conditions]

terminatedAt($F = V, T$) $\leftarrow$
 happensAt(E_{T_1}, T),
 [conditions]

...

terminatedAt($F = V, T$) $\leftarrow$
 happensAt(E_{T_j}, T),
 [conditions]

where

conditions:
 $0-K$ **happensAt**(E_k, T),
 $0-M$ **holdsAt**($F_m = V_m, T$),
 $0-N$ atemporal-constraint _{n}

^{*} Artikis et al, An Event Calculus for Event Recognition. IEEE TKDE, 2015.

[†] Mantenoglou et al, Stream Reasoning with Cycles. KR, 2022. <https://github.com/aartikis/RTEC>

Run-Time Event Calculus (RTEC)

initiatedAt($F = V$, T) $\leftarrow$
 happensAt(E_{In_1} , T),
 [conditions]

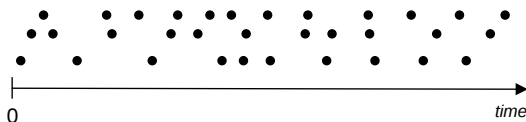
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 happensAt(E_{In_i} , T),
 [conditions]

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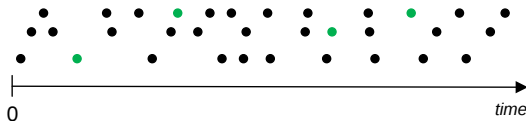
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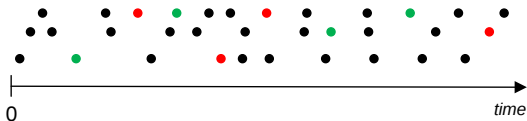
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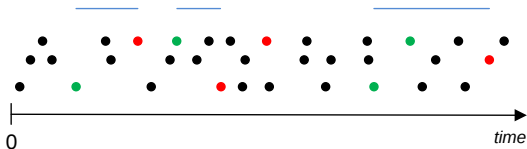
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[conditions]

holdsFor($F = V$, I)



High Speed Near Coast

initiatedAt(*highSpeedNC*(*Vessel*) = true, *T*) $\leftarrow$
 happensAt(*velocity*(*Vessel*, *Speed*, *_CoG*, *_TrueHeading*), *T*),
 holdsAt(*withinArea*(*Vessel*, *nearCoast*) = true, *T*),
 threshold(*v_{hs}*, *V*), *Speed* > *V*.

High Speed Near Coast

initiatedAt($highSpeedNC(Vessel) = true, T$) $\leftarrow$
 happensAt($velocity(Vessel, Speed, _CoG, _TrueHeading), T$),
 holdsAt($withinArea(Vessel, nearCoast) = true, T$),
 $threshold(v_{hs}, V), Speed > V$.

terminatedAt($highSpeedNC(Vessel) = true, T$) $\leftarrow$
 happensAt($velocity(Vessel, Speed), T$),
 $threshold(v_{hs}, V), Speed \leq V$.

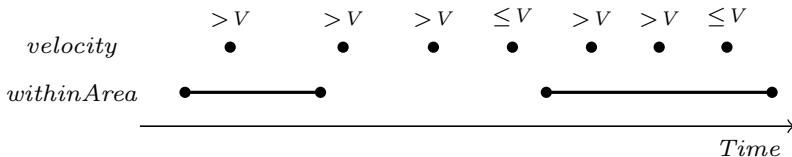
terminatedAt($highSpeedNC(Vessel) = true, T$) $\leftarrow$
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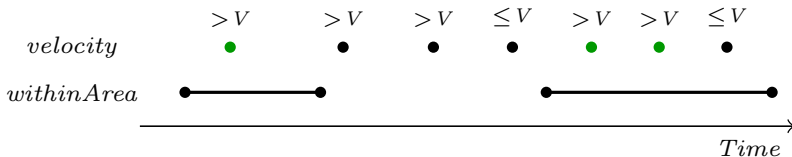


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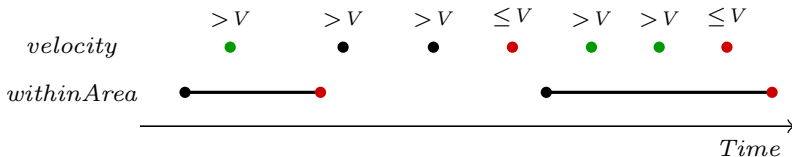


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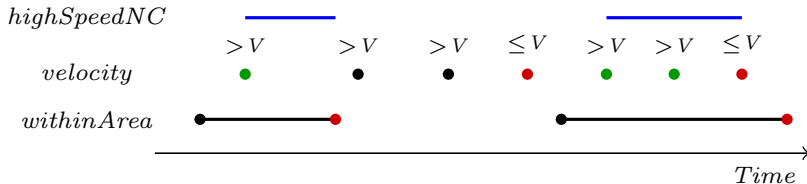


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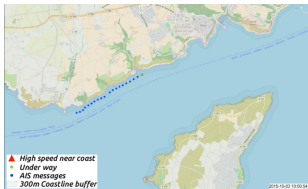


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<https://cer.iit.demokritos.gr> (high speed near coast (a))



<https://cer.iit.demokritos.gr> (high speed near coast (b))

High Speed Near Coast: Quiz

initiatedAt(*highSpeedNC*(*Vessel*) = true, *T*) $\leftarrow$
happensAt(*velocity*(*Vessel*, *Speed*, *_CoG*, *_TrueHeading*), *T*),
holdsAt(*withinArea*(*Vessel*, *nearCoast*) = true, *T*),
threshold(*v_{hs}*, *V*), *Speed* > *V*.

happensAt(*velocity*(*v1*, 7.5, 124, 130), 13),
happensAt(*velocity*(*v1*, 5.2, 180, 178), 24),
happensAt(*velocity*(*v1*, 5.1, 212, 212), 32),
happensAt(*velocity*(*v1*, 4, 210, 212), 36),
happensAt(*velocity*(*v1*, 6, 200, 199), 52),
happensAt(*velocity*(*v1*, 4, 189, 189), 56).

Which are the initiation points of
highSpeedNC(*v1*) = true ?

** *withinArea*(*v1*, *nearCoast*) = true holds continuously in the intervals [10,21) and [40,61) and the threshold for *v_{hs}* is 5 knots.

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Initiations: 13 and 52

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High Speed Near Coast: Quiz

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Which are the termination points
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Terminations : 20, 36, 56 and 60

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Initiations: 13 and 52

Terminations : 20, 36, 56 and 60

What are the maximal intervals of *highSpeedNC*(*v1*) = true ?

High Speed Near Coast: Quiz

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Initiations: 13 and 52

Terminations : 20, 36, 56 and 60

What are the maximal intervals of $highSpeedNC(v1) = true$?

Answer: [14, 21) and [53, 57)

RTEC: Interval-based Reasoning

holdsFor(*anchoredOrMoored*(*Vessel*) = true, *I*) $\leftarrow$
 holdsFor(*stopped*(*Vessel*) = *farFromPorts*, *I_{sf}*),
 holdsFor(*withinArea*(*Vessel*, *anchorage*) = true, *I_{wa}*),
 intersect_all([*I_{sf}*, *I_{wa}*], *I_{sa}*),
 holdsFor(*stopped*(*Vessel*) = *nearPorts*, *I_{sn}*),
 union_all([*I_{sa}*, *I_{sn}*], *I*).

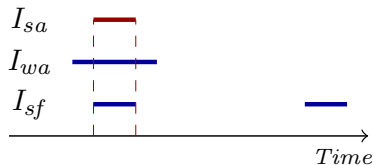
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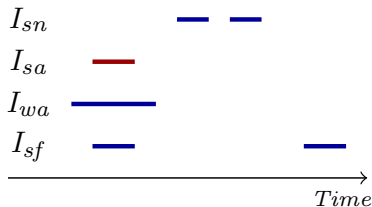
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 intersect_all($[I_{sf}, I_{wa}]$, I_{sa}),
 holdsFor(*stopped*(*Vessel*) = *nearPorts*, I_{sn}),
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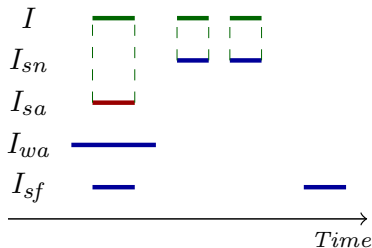
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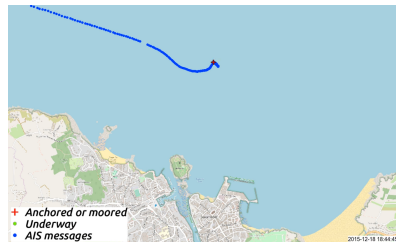
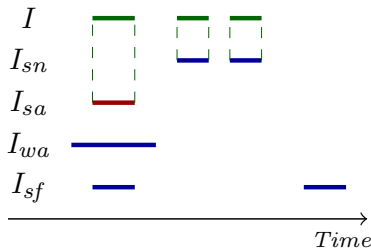
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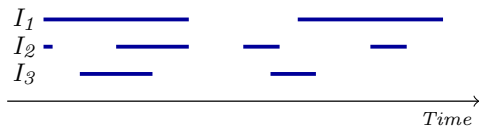
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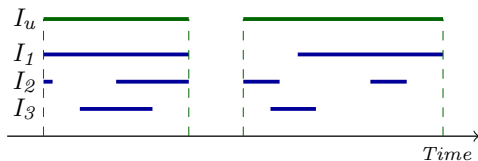
<https://cer.iit.demokritos.gr> (anchored or moored)

RTEC: Interval-based Reasoning



RTEC: Interval-based Reasoning

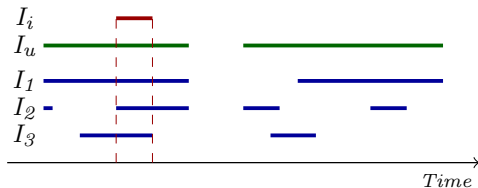
union_all($[I_1, I_2, I_3], I_u$)



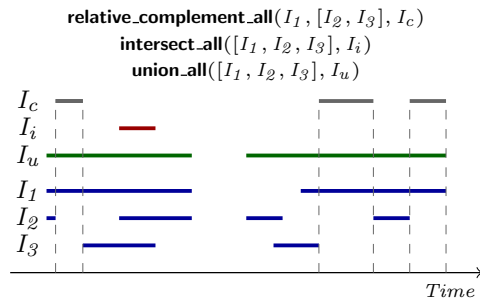
RTEC: Interval-based Reasoning

intersect_all($[I_1, I_2, I_3], I_i$)

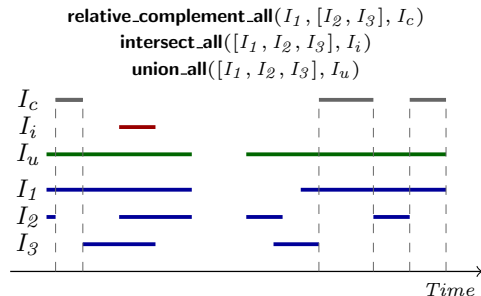
union_all($[I_1, I_2, I_3], I_u$)



RTEC: Interval-based Reasoning



RTEC: Interval-based Reasoning & Allen Relations*



Relation	Illustration
$\text{before}(i^s, i^t)$	
$\text{meets}(i^s, i^t)$	
$\text{starts}(i^s, i^t)$	
$\text{finishes}(i^s, i^t)$	
$\text{during}(i^s, i^t)$	
$\text{overlaps}(i^s, i^t)$	
$\text{equal}(i^s, i^t)$	

* Mantenoglou et al, Complex Event Recognition with Allen Relations. KR, 2023.

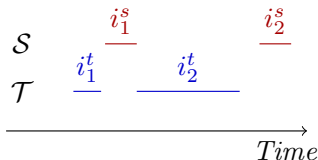
RTEC: Interval-based Reasoning & Allen Relations*

holdsFor(*disappearedInArea*(*Vessel*, *AreaType*) = true, *I*) $\leftarrow$
 holdsFor(*withinArea*(*Vessel*, *AreaType*) = true, *S*),
 holdsFor(*gap*(*Vessel*) = *farFromPorts*, *T*),
 allen(meets, *S*, *T*, target, *I*).

* Mantenoglou et al, Complex Event Recognition with Allen Relations. KR 2023.

RTEC: Interval-based Reasoning & Allen Relations*

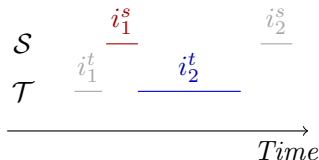
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* Mantenoglou et al, Complex Event Recognition with Allen Relations. KR 2023.

RTEC: Interval-based Reasoning & Allen Relations*

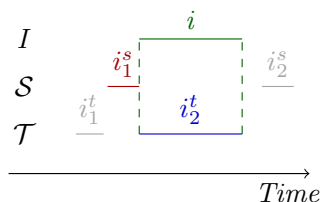
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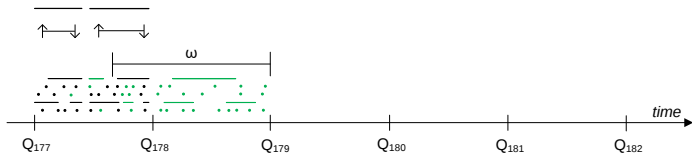
RTEC: Interval-based Reasoning & Allen Relations*

holdsFor(*disappearedInArea*(*Vessel*, *AreaType*) = true, *I*) $\leftarrow$
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holdsFor(*gap*(*Vessel*) = *farFromPorts*, $\mathcal{T}$),
allen(meets, $\mathcal{S}$, $\mathcal{T}$, target, *I*).

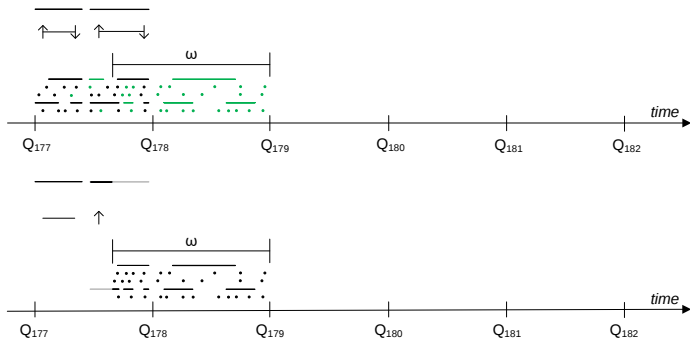


* Mantenoglou et al, Complex Event Recognition with Allen Relations. KR 2023.

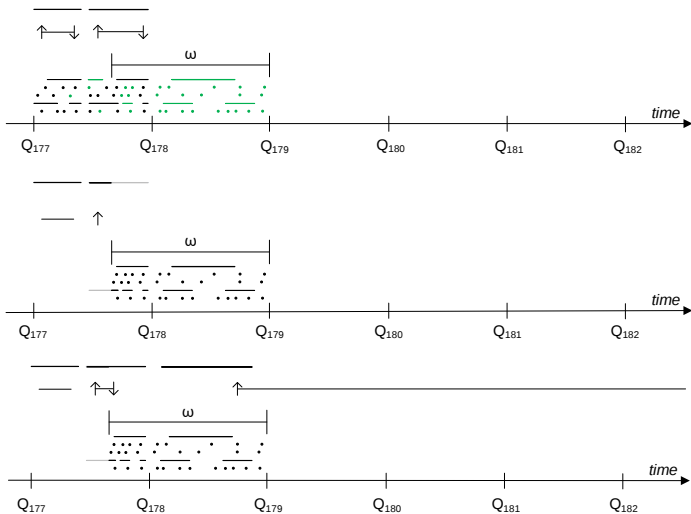
Windowing



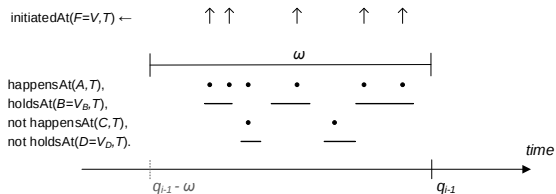
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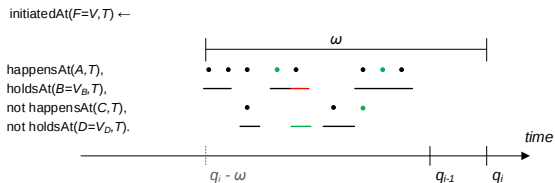
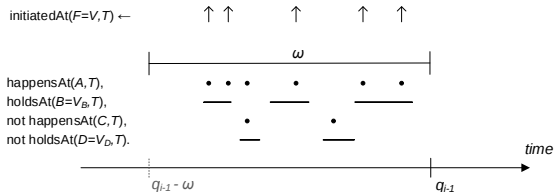
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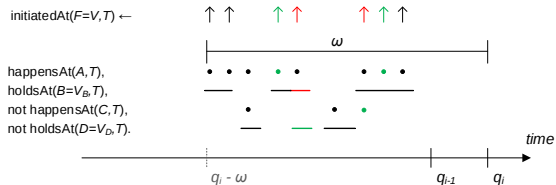
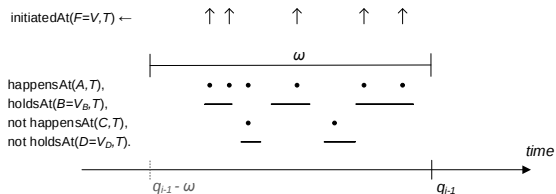
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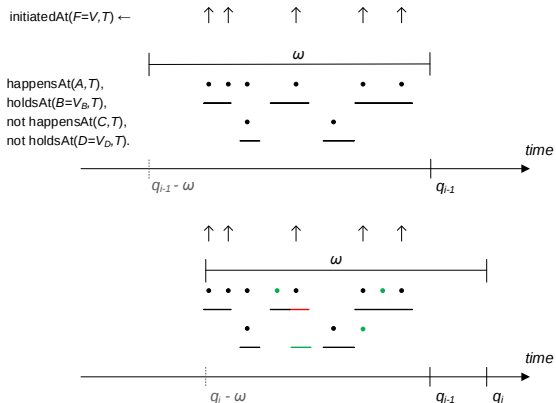
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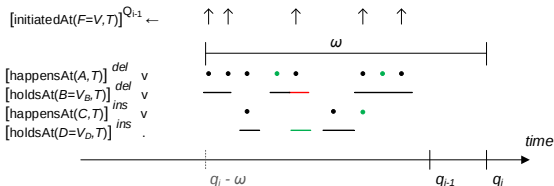
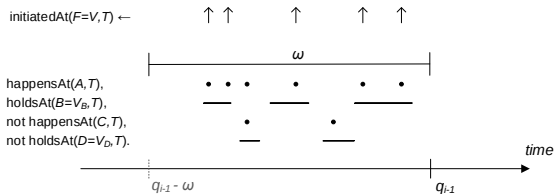


Incremental Reasoning: Deletion Phase*



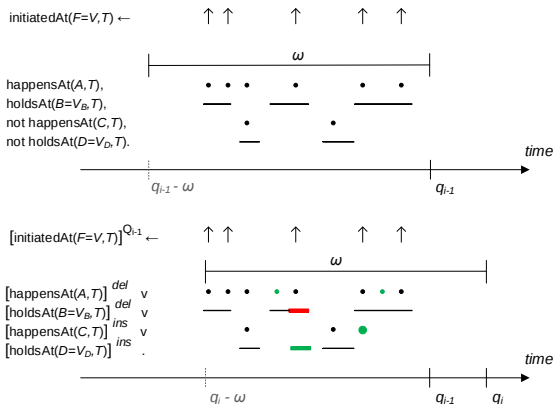
*Tsilionis et al, Incremental Event Calculus for Run-Time Reasoning. Journal of AI Research (JAIR), 2022.

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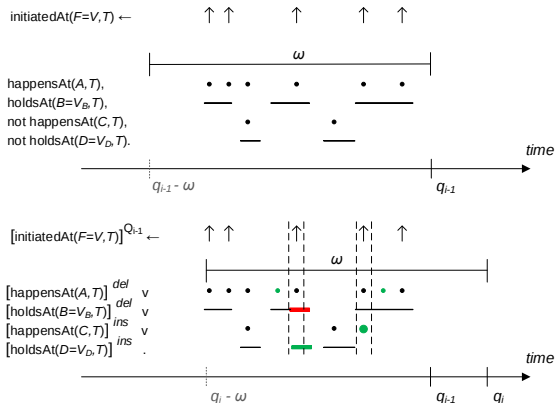
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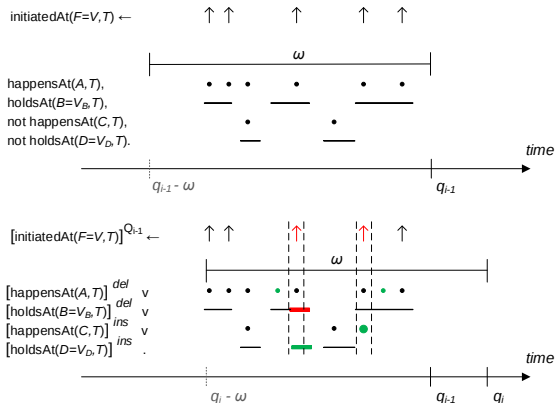
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RTEC: Correctness and Complexity

Correctness

RTEC computes all maximal intervals of a fluent, and no other interval, provided that interval delays/retractions, if any, are tolerated by the window size.

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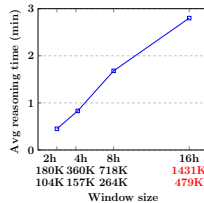
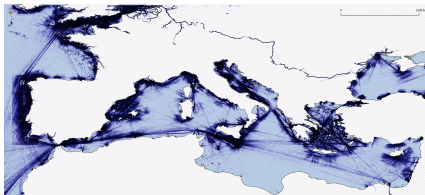
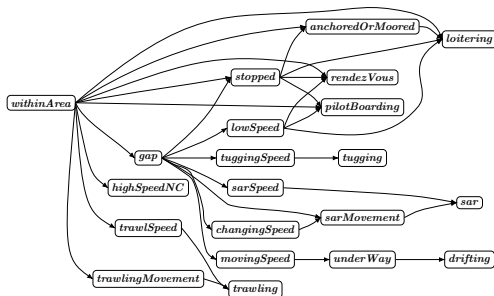
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Complexity

The time to compute the maximal intervals of a fluent is linear to the window size.

Performance: Indicative Results



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* Mantenoglou et al, Complex Event Recognition with Allen Relations. KR, 2023.

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- ▶ Tensor-based CER.
- ▶ Topics not covered.