Maritime Situational Awareness in the era of Large Language/Reasoning Models

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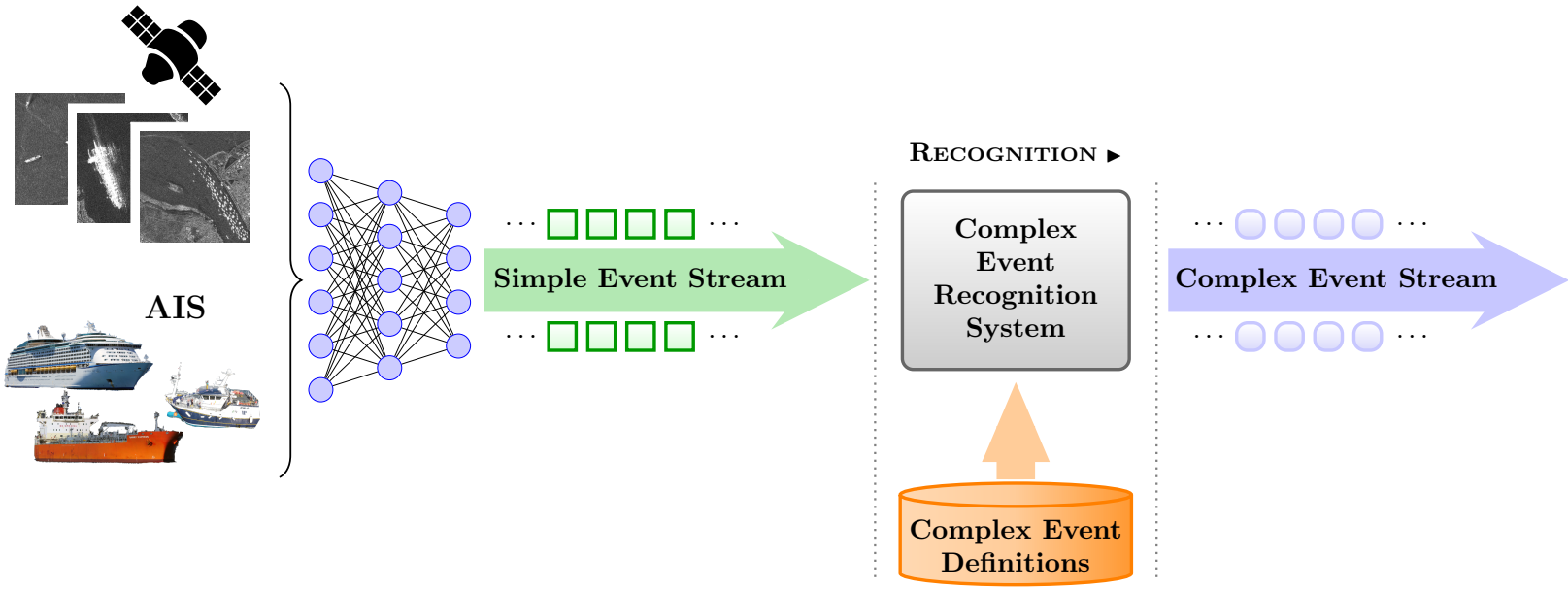
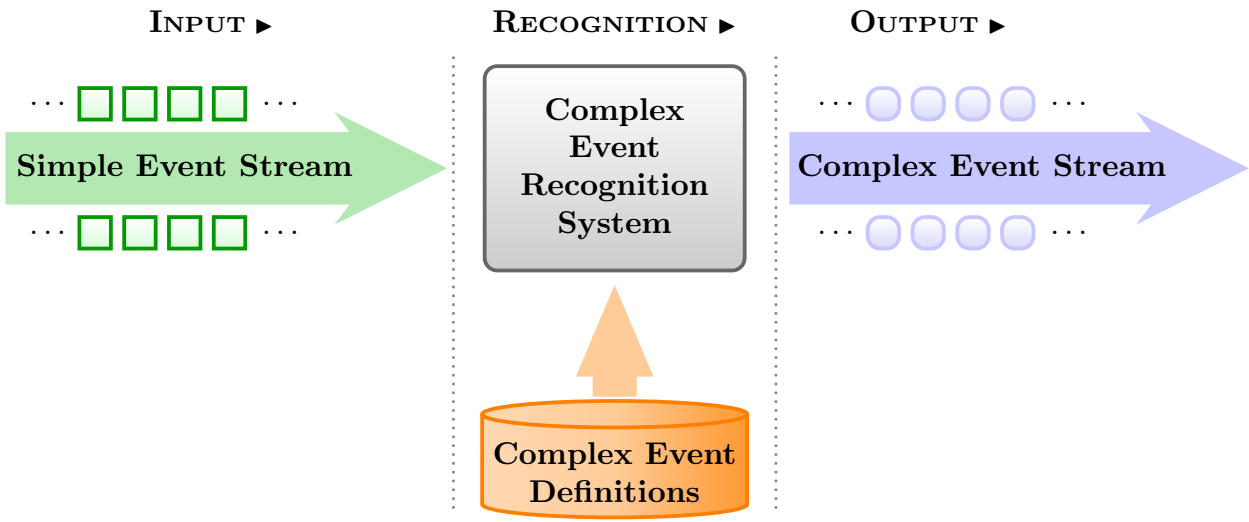
https://cer.iit.demokritos.gr

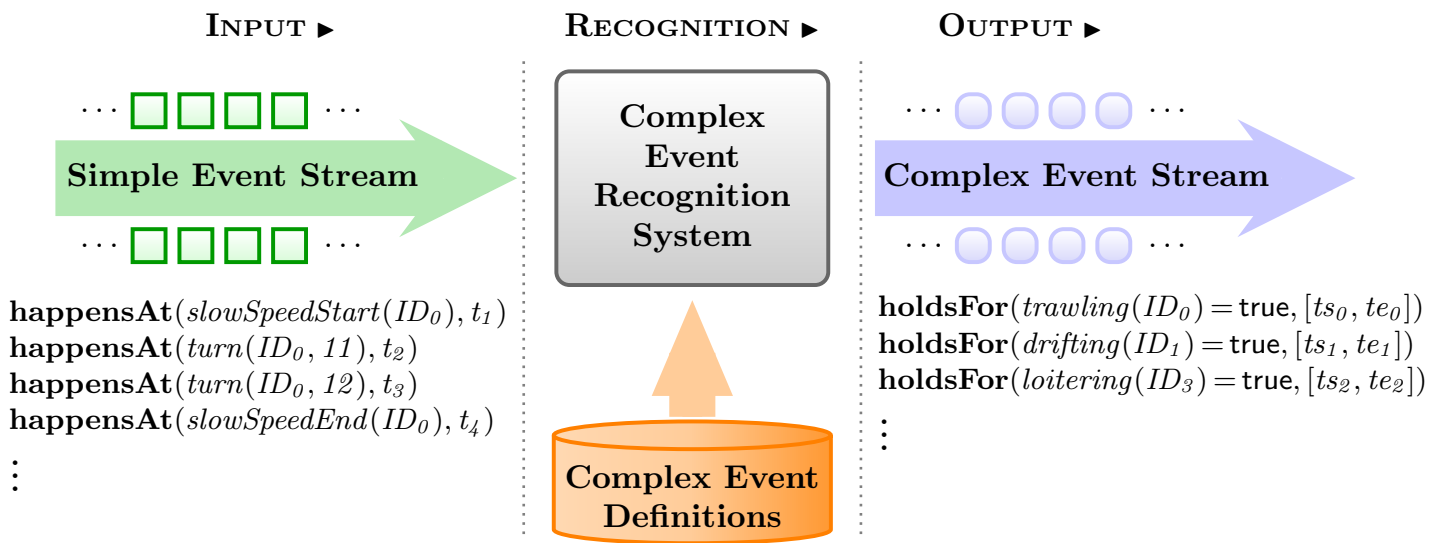
Complex Event Recognition



Complex Event Recognition



Complex Event Recognition



initiatedAt$(stopped(Vessel) = nearPorts, T) \leftarrow$
  happensAt$(stop\_start(Vessel), T)$,
  holdsAt$(withinArea(Vessel, nearPorts) = \mathsf{true}, T)$.

terminatedAt$(stopped(Vessel) = nearPorts, T) \leftarrow$
  happensAt$(stop\_end(Vessel), T)$.

⋮

holdsFor$(trawling(Vessel) = \mathsf{true}, I) \leftarrow$
  holdsFor$(trawlingMovement(Vessel) = \mathsf{true}, I_{tc})$,
  holdsFor$(trawlingSpeed(Vessel) = \mathsf{true}, I_t)$,
  intersect_all$([I_{tc}, I_t], I_i)$,
  $threshold(v_{trawl}, V_{trawl})$,
  $intDurGreater(I_i, V_{trawl}, I)$.

⋮

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.

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Run-Time Event Calculus (RTEC)*,†

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

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

where

$$\text{conditions:} \quad {}^{0-K}\textbf{happensAt}(E_k,\ T),\ {}^{0-M}\textbf{holdsAt}(F_m = V_m,\ T),\ {}^{0-N}\text{atemporal-constraint}_n$$

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*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)

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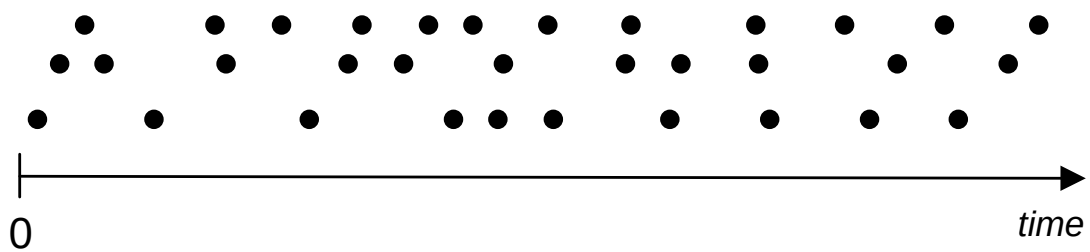

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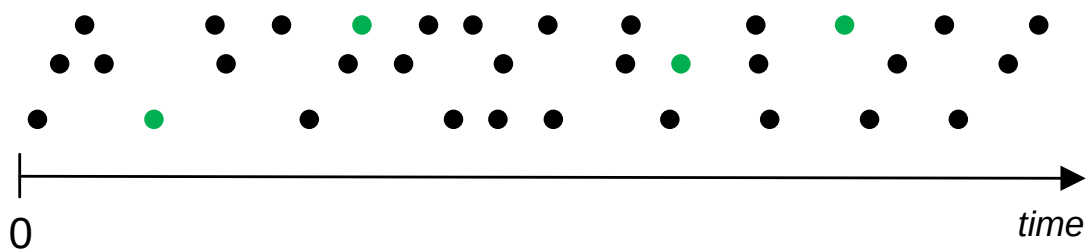

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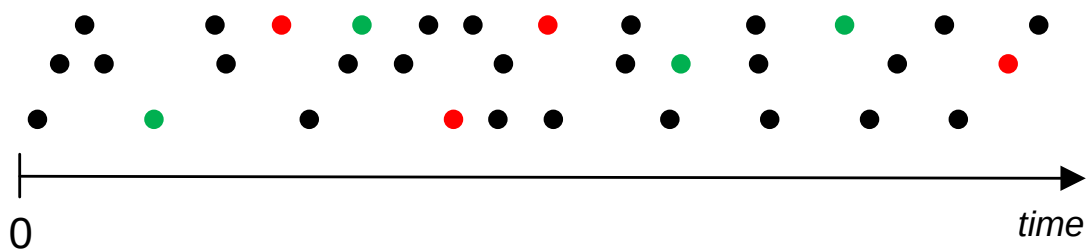

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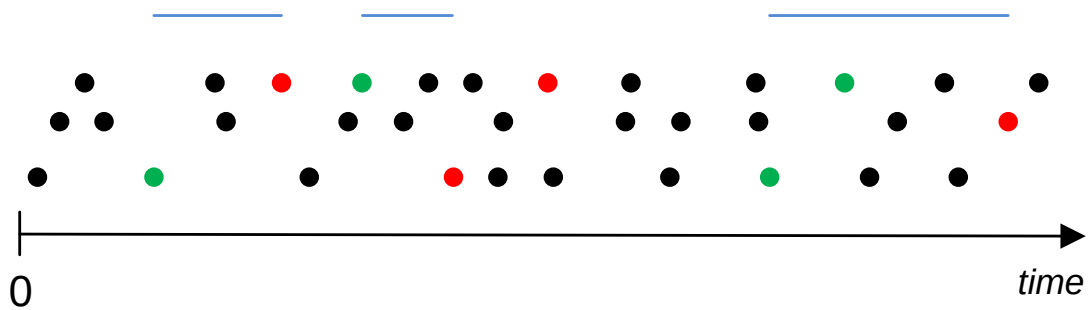
$\textbf{holdsFor}(F = V,\ I)$



High Speed Near Coast

$$\textbf{initiatedAt}(\mathit{highSpeedNC}(\mathit{Vessel}) = \text{true}, T) \leftarrow$$
$$\quad \textbf{happensAt}(\mathit{velocity}(\mathit{Vessel}, \mathit{Speed}, \_\mathit{CoG}, \_\mathit{TrueHeading}), T),$$
$$\quad \textbf{holdsAt}(\mathit{withinArea}(\mathit{Vessel}, \mathit{nearCoast}) = \text{true}, T),$$
$$\quad \mathit{threshold}(v_{hs}, V), \mathit{Speed} > V.$$

High Speed Near Coast

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

$$\textbf{terminatedAt}(\mathit{highSpeedNC}(\mathit{Vessel}) = \text{true}, T) \leftarrow$$
$$\quad \textbf{happensAt}(\mathit{end}(\mathit{withinArea}(\mathit{Vessel}, \mathit{nearCoast}) = \text{true}), T).$$

High Speed Near Coast

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

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

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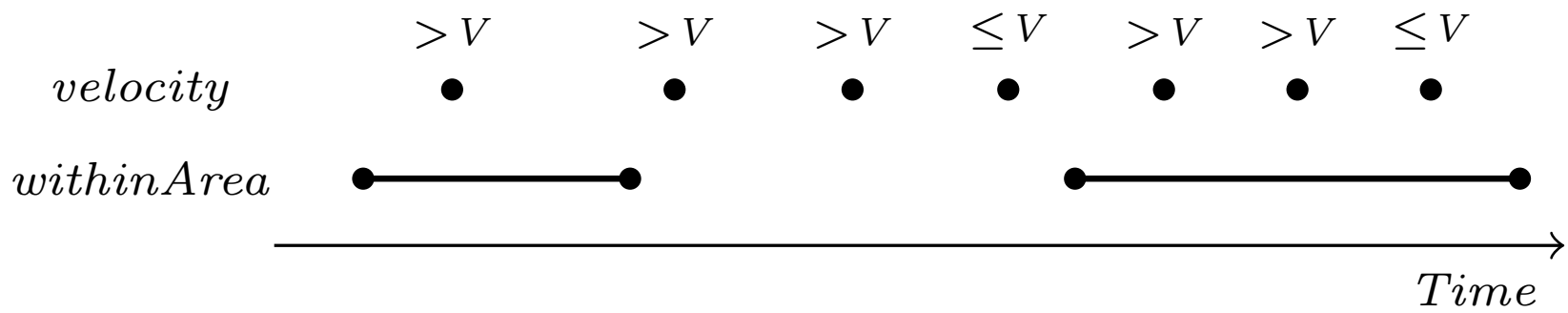

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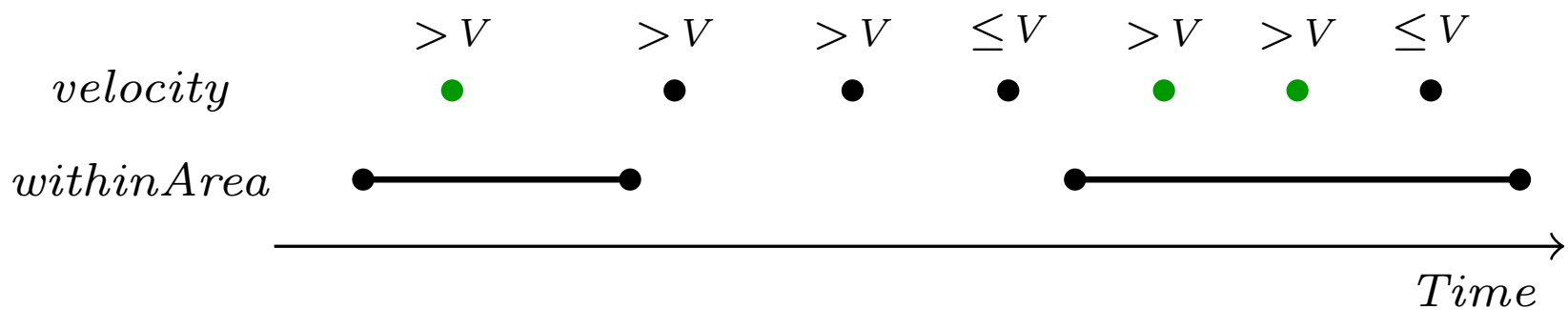

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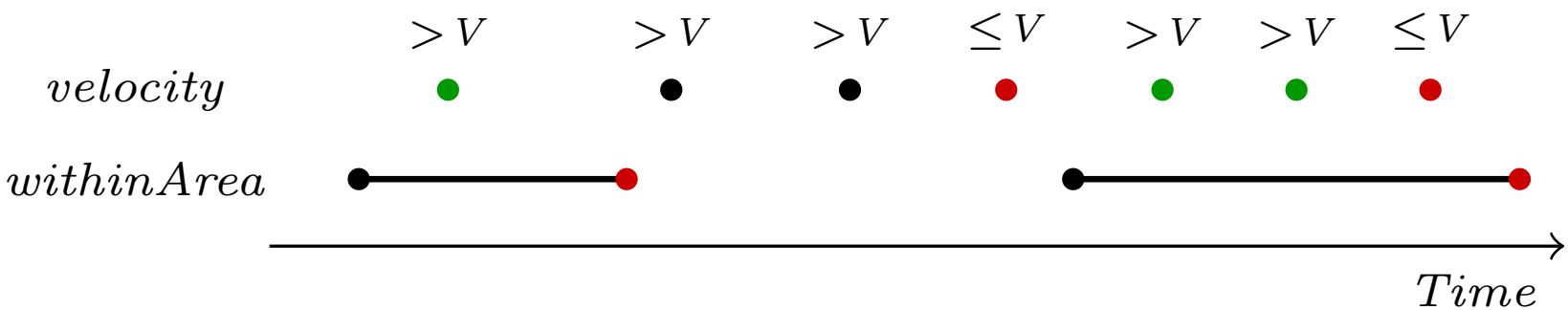

High Speed Near Coast

initiatedAt($highSpeedNC(Vessel) = \text{true}, T$) $\leftarrow$
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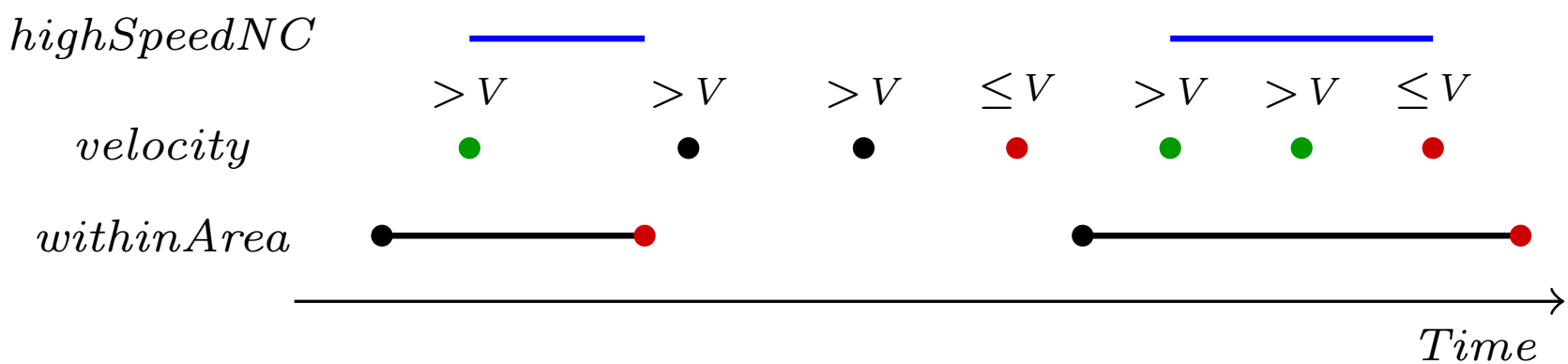

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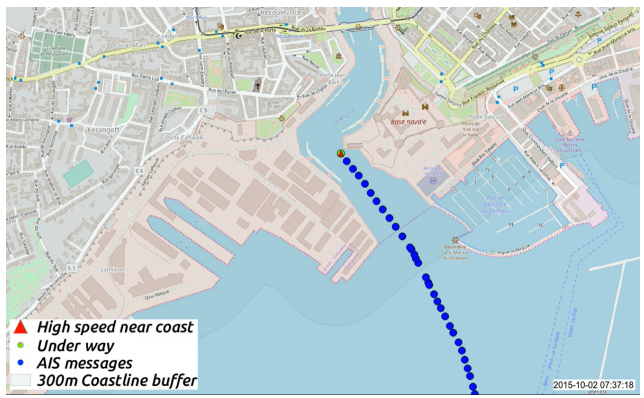
$$\textbf{terminatedAt}(\mathit{highSpeedNC}(\mathit{Vessel}) = \text{true}, T) \leftarrow$$
$$\textbf{happensAt}(\mathit{end}(\mathit{withinArea}(\mathit{Vessel}, \mathit{nearCoast}) = \text{true}), T).$$

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



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

RTEC: Interval-based Reasoning

$$\begin{aligned}
&\textbf{holdsFor}(\mathit{anchoredOrMoored}(\mathit{Vessel}) = \text{true},\ I) \leftarrow \\
&\quad \textbf{holdsFor}(\mathit{stopped}(\mathit{Vessel}) = \mathit{farFromPorts},\ I_{sf}), \\
&\quad \textbf{holdsFor}(\mathit{withinArea}(\mathit{Vessel}, \mathit{anchorage}) = \mathit{true},\ I_{wa}), \\
&\quad \textbf{intersect_all}([I_{sf}, I_{wa}],\ I_{sa}), \\
&\quad \textbf{holdsFor}(\mathit{stopped}(\mathit{Vessel}) = \mathit{nearPorts},\ I_{sn}), \\
&\quad \textbf{union_all}([I_{sa}, I_{sn}],\ I).
\end{aligned}$$

RTEC: Interval-based Reasoning

$$\begin{aligned}
&\textbf{holdsFor}(\mathit{anchoredOrMoored}(\mathit{Vessel}) = \text{true},\ I) \leftarrow \\
&\quad \textbf{holdsFor}(\mathit{stopped}(\mathit{Vessel}) = \mathit{farFromPorts},\ I_{sf}), \\
&\quad \textbf{holdsFor}(\mathit{withinArea}(\mathit{Vessel}, \mathit{anchorage}) = \mathit{true},\ I_{wa}), \\
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&\quad \textbf{holdsFor}(\mathit{stopped}(\mathit{Vessel}) = \mathit{nearPorts},\ I_{sn}), \\
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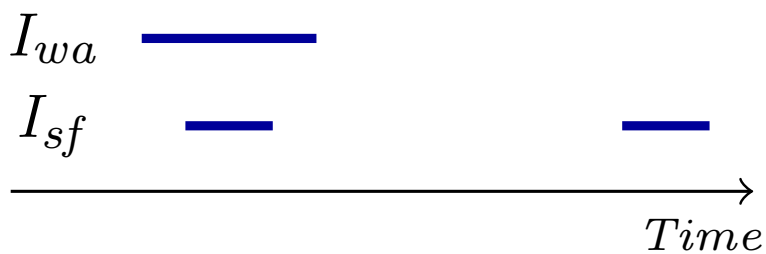
\end{aligned}$$



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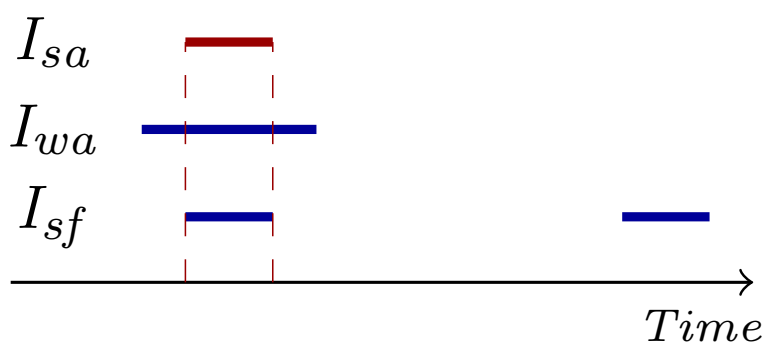
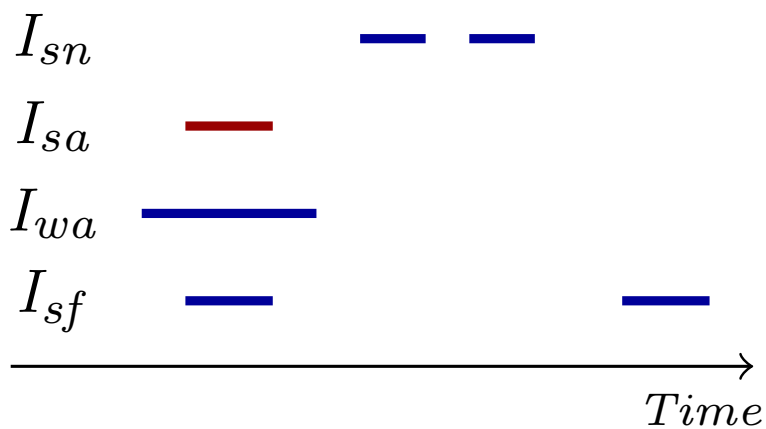
$$\textbf{intersect\_all}([I_{sf}, I_{wa}],\ I_{sa}),$$
$$\textbf{holdsFor}(\mathit{stopped}(\mathit{Vessel}) = \mathit{nearPorts},\ I_{sn}),$$
$$\textbf{union\_all}([I_{sa}, I_{sn}],\ I).$$



RTEC: Interval-based Reasoning

holdsFor$(anchoredOrMoored(Vessel) = \text{true},\ I) \leftarrow$
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$([I_{sa}, I_{sn}],\ I).$



RTEC: Interval-based Reasoning

holdsFor$(anchoredOrMoored(Vessel) = \text{true},\ I) \leftarrow$
holdsFor$(stopped(Vessel) = farFromPorts,\ I_{sf})$,
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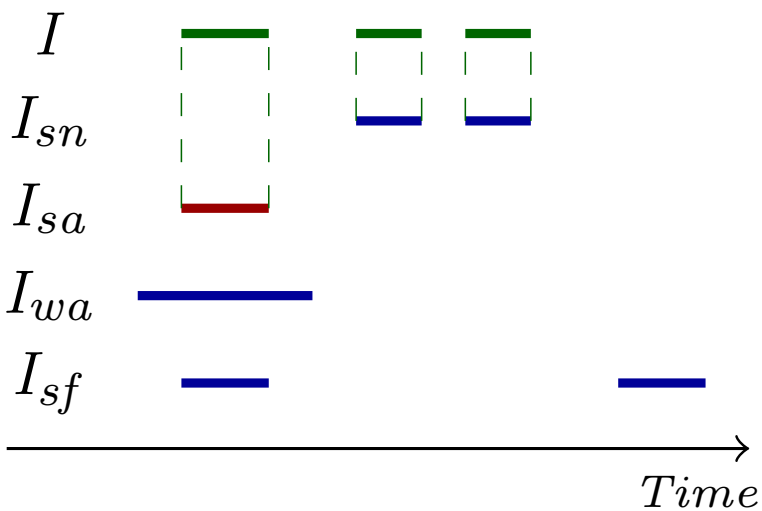

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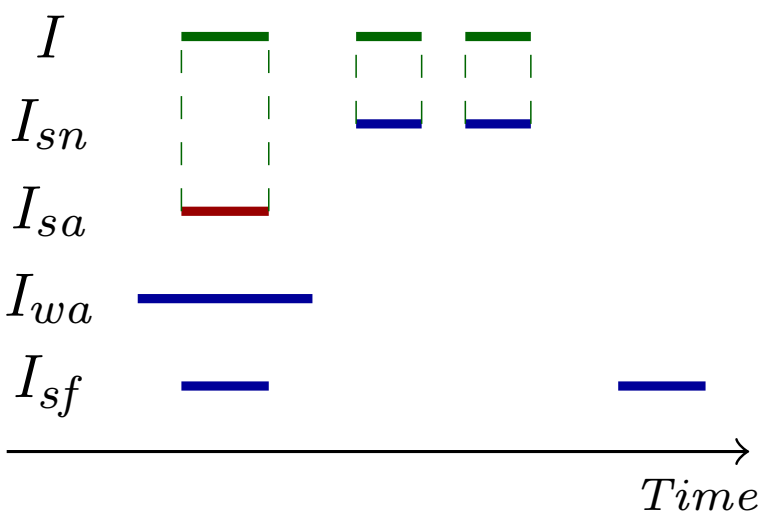
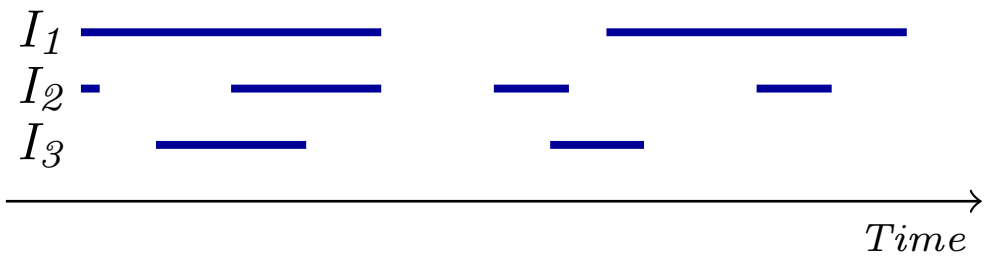


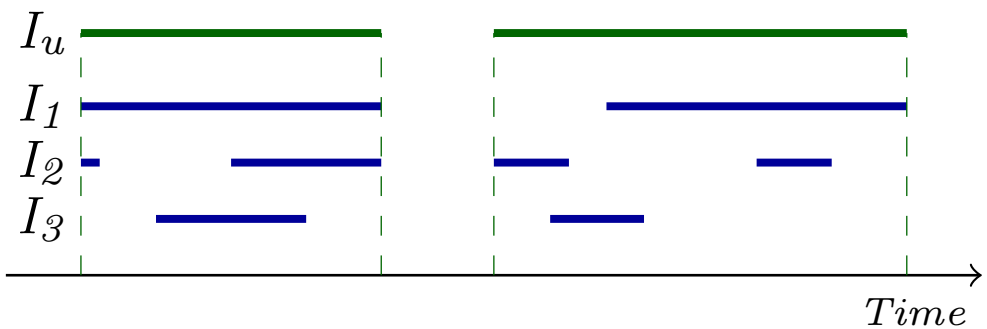
https://cer.iit.demokritos.gr (anchored or moored)

RTEC: Interval-based Reasoning



RTEC: Interval-based Reasoning

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



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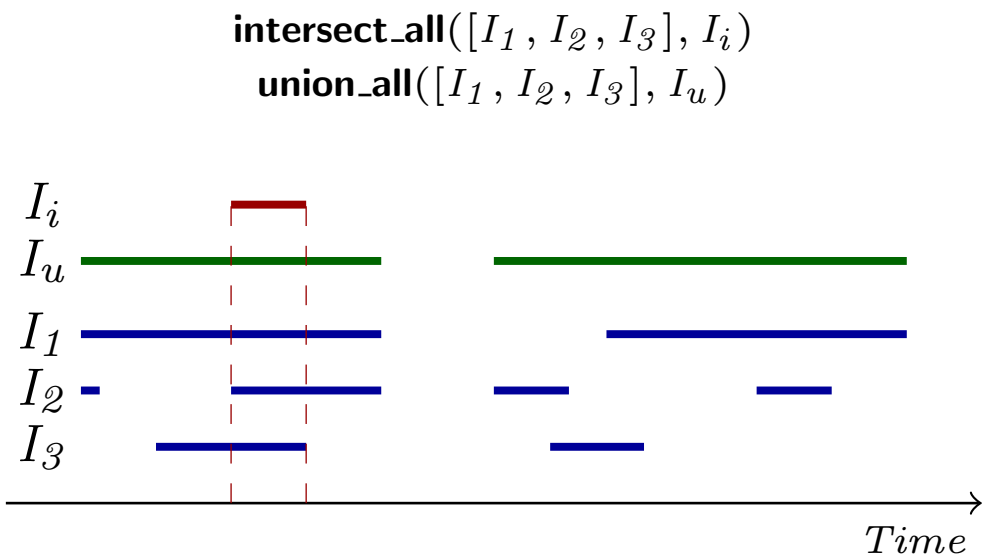

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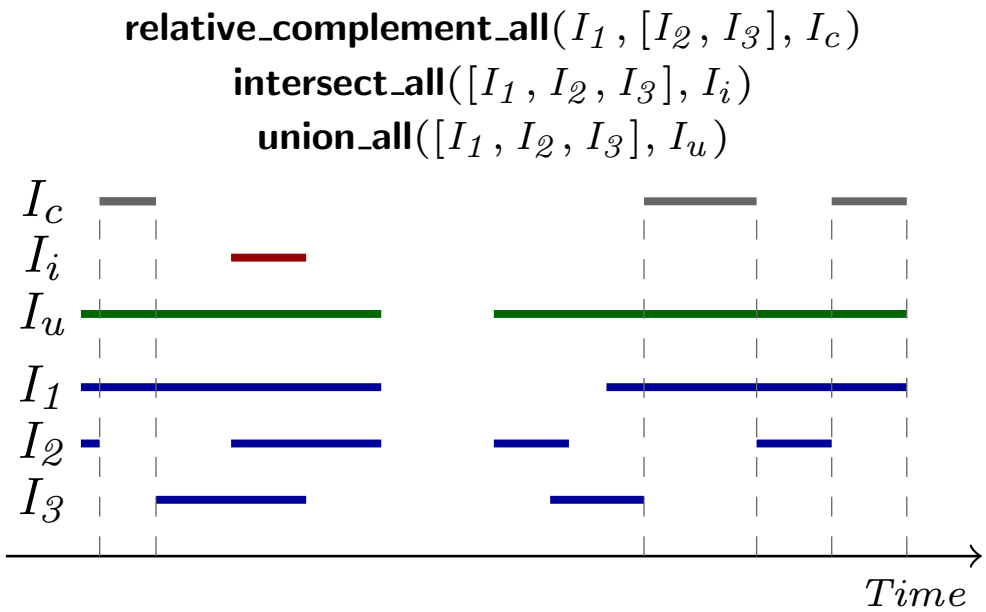
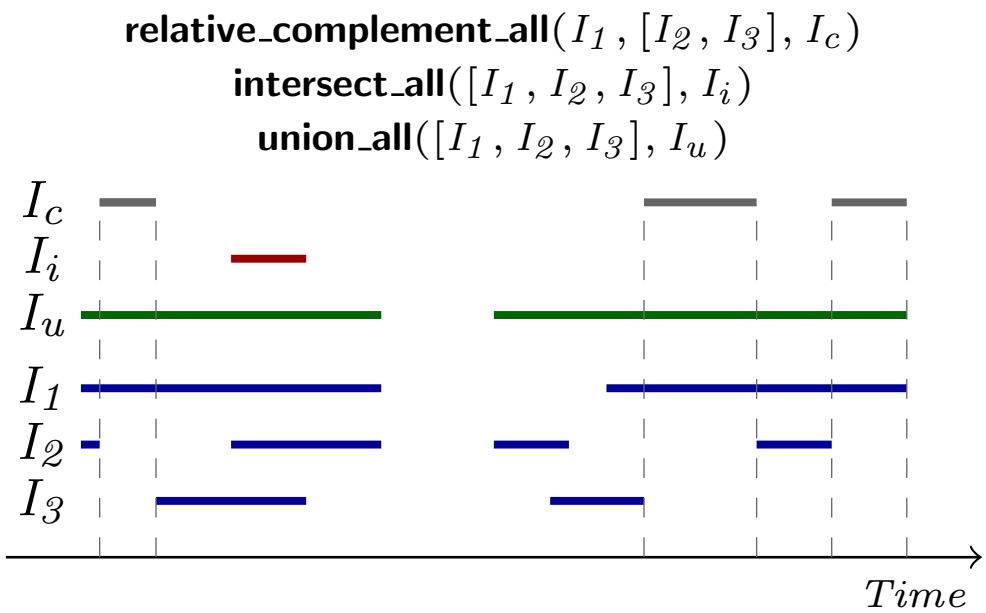
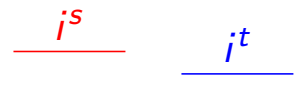
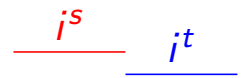
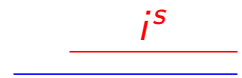
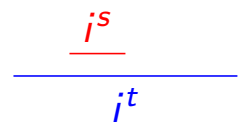
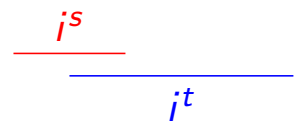
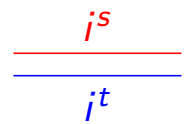


RTEC: Interval-based Reasoning & Allen Relations*



Relation	Illustration
before(i^s, i^t)	
meets(i^s, i^t)	
starts(i^s, i^t)	
finishes(i^s, i^t)	
during(i^s, i^t)	
overlaps(i^s, i^t)	
equal(i^s, i^t)	

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

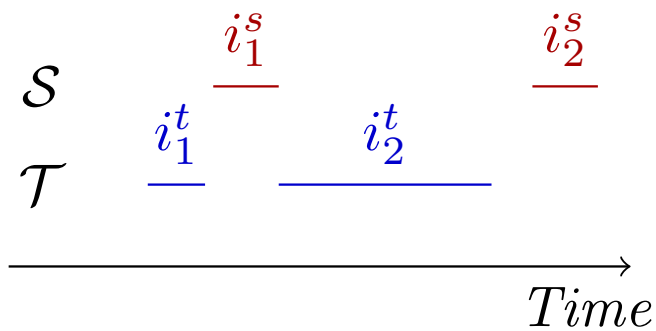
RTEC: Interval-based Reasoning & Allen Relations*

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

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

RTEC: Interval-based Reasoning & Allen Relations*

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



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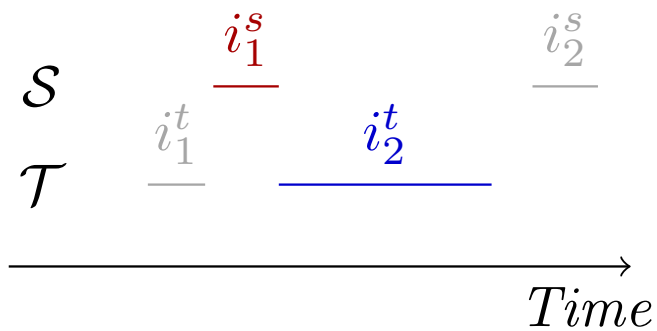
holdsFor($disappearedInArea(Vessel, AreaType) = \text{true}, I$) $\leftarrow$
  holdsFor($withinArea(Vessel, AreaType) = \text{true}, \mathcal{S}$),
  holdsFor($gap(Vessel) = farFromPorts, \mathcal{T}$),
  allen(meets, $\mathcal{S}, \mathcal{T}$, target, I).



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holdsFor($\mathit{disappearedInArea}(\mathit{Vessel}, \mathit{AreaType}) = \text{true}, I$) $\leftarrow$
  holdsFor($\mathit{withinArea}(\mathit{Vessel}, \mathit{AreaType}) = \text{true}, \mathcal{S}$),
  holdsFor($\mathit{gap}(\mathit{Vessel}) = \mathit{farFromPorts}, \mathcal{T}$),
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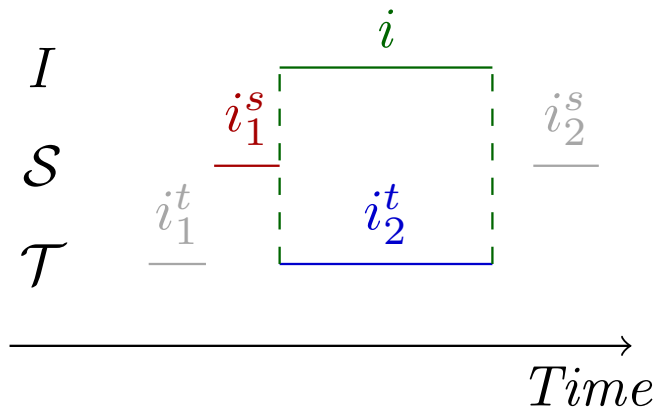

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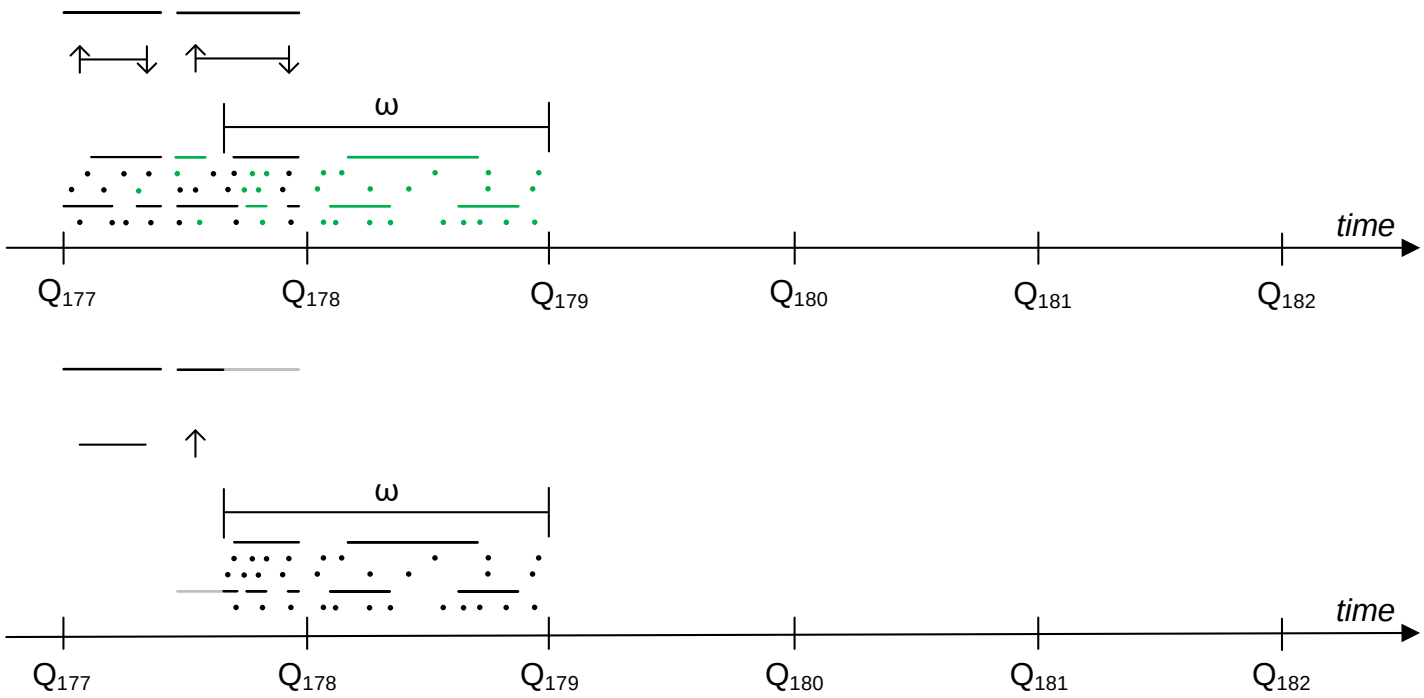
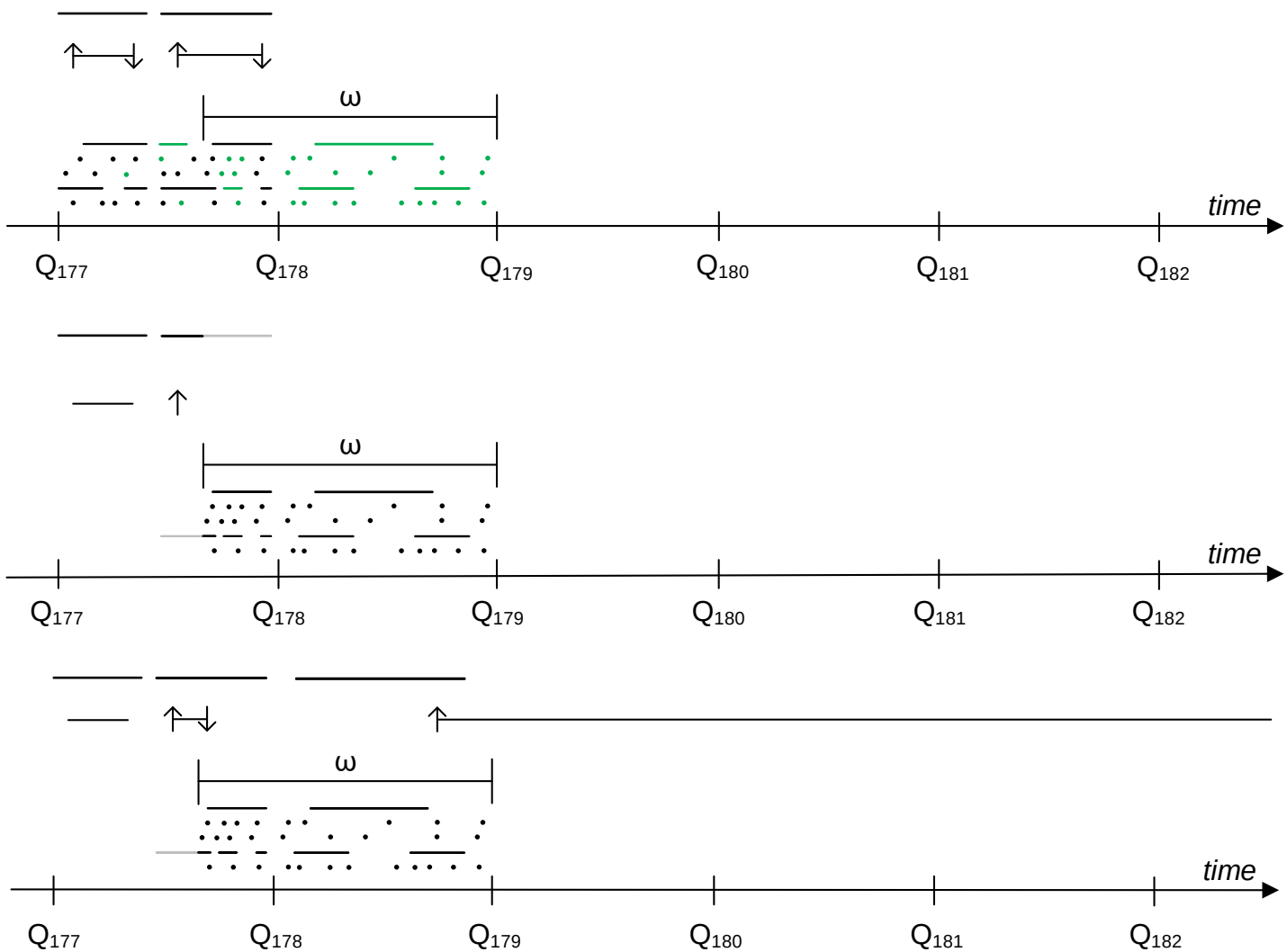
Windowing

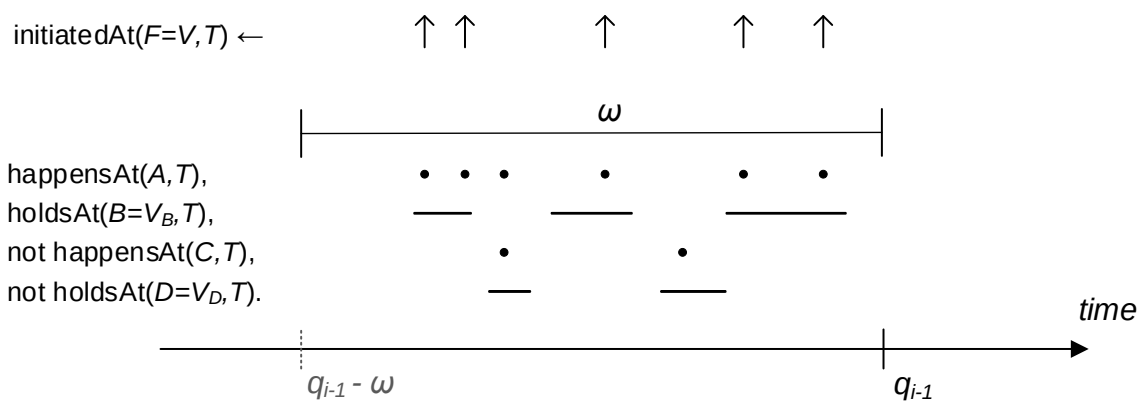
Windowing


ω
time
Q177
Q178
Q179
Q180
Q181
Q182
ω
time
Q177
Q178
Q179
Q180
Q181
Q182

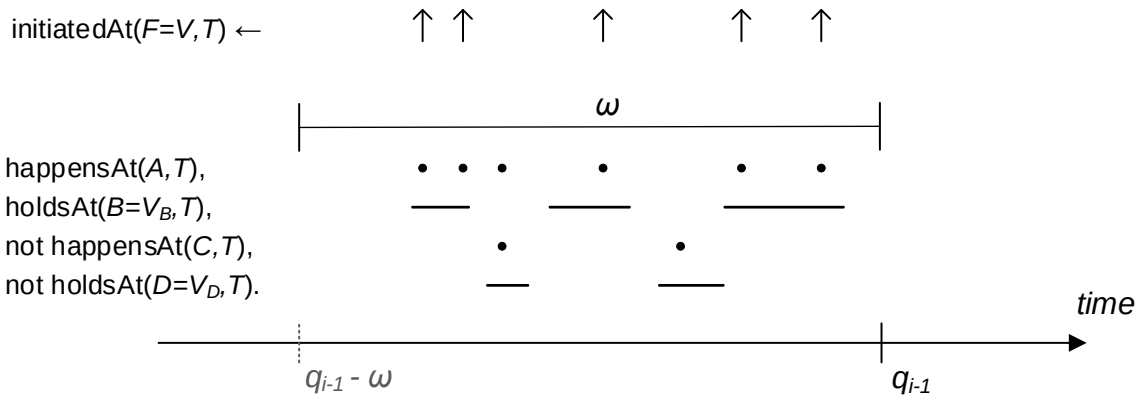
Windowing

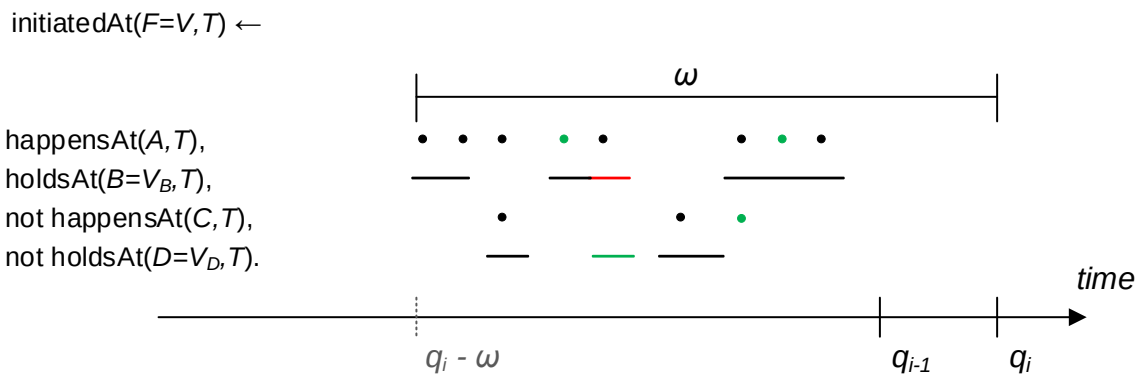

ω
time
Q_{177}
Q_{178}
Q_{179}
Q_{180}
Q_{181}
Q_{182}
ω
time
Q_{177}
Q_{178}
Q_{179}
Q_{180}
Q_{181}
Q_{182}
ω
time
Q_{177}
Q_{178}
Q_{179}
Q_{180}
Q_{181}
Q_{182}

Windowing

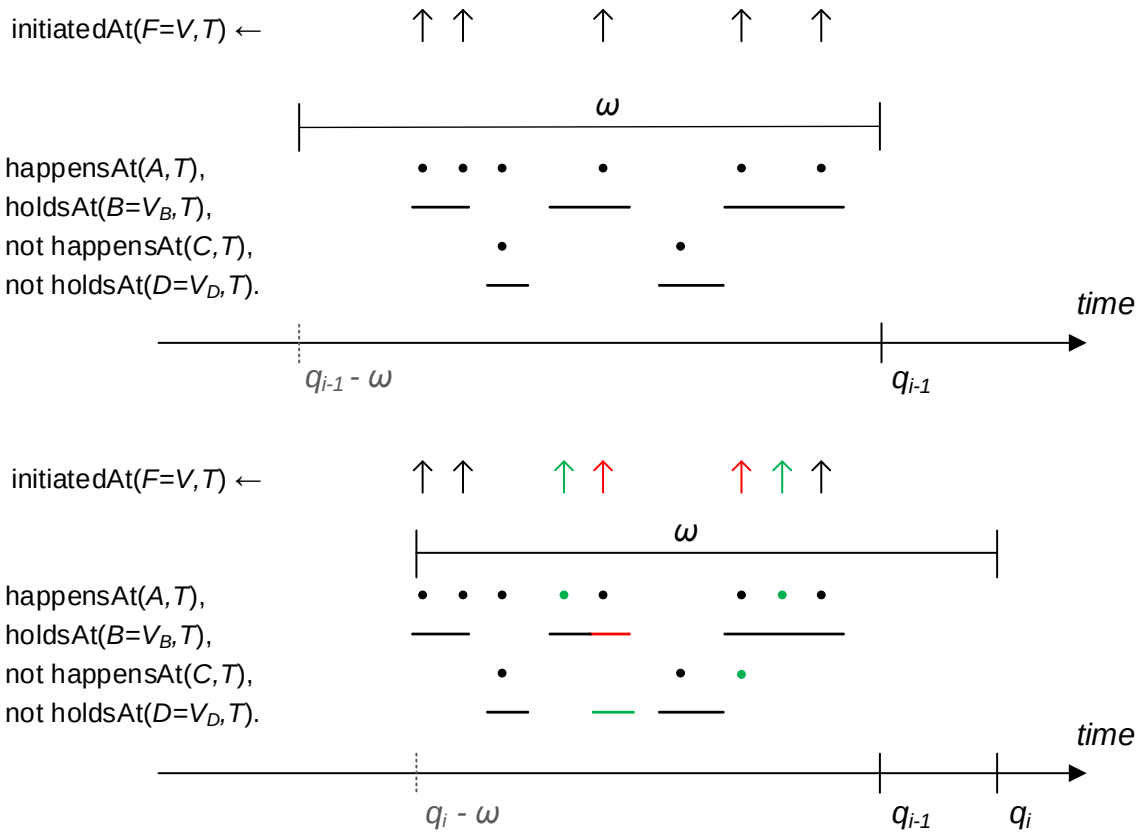

initiatedAt(F=V,T) ←
ω
happensAt(A,T),
holdsAt(B=V_B,T),
not happensAt(C,T),
not holdsAt(D=V_D,T).
time
q_{i-1} - ω
q_{i-1}

Windowing


initiatedAt(F=V,T) ←
ω
happensAt(A,T),
holdsAt(B=V_B,T),
not happensAt(C,T),
not holdsAt(D=V_D,T).
time
q_{i-1} - ω
q_{i-1}


initiatedAt(F=V,T) ←
ω
happensAt(A,T),
holdsAt(B=V_B,T),
not happensAt(C,T),
not holdsAt(D=V_D,T).
time
q_i - ω
q_{i-1}
q_i

Windowing


initiatedAt(F=V,T) ←
ω
happensAt(A,T),
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time
q_{i-1} - ω
q_{i-1}
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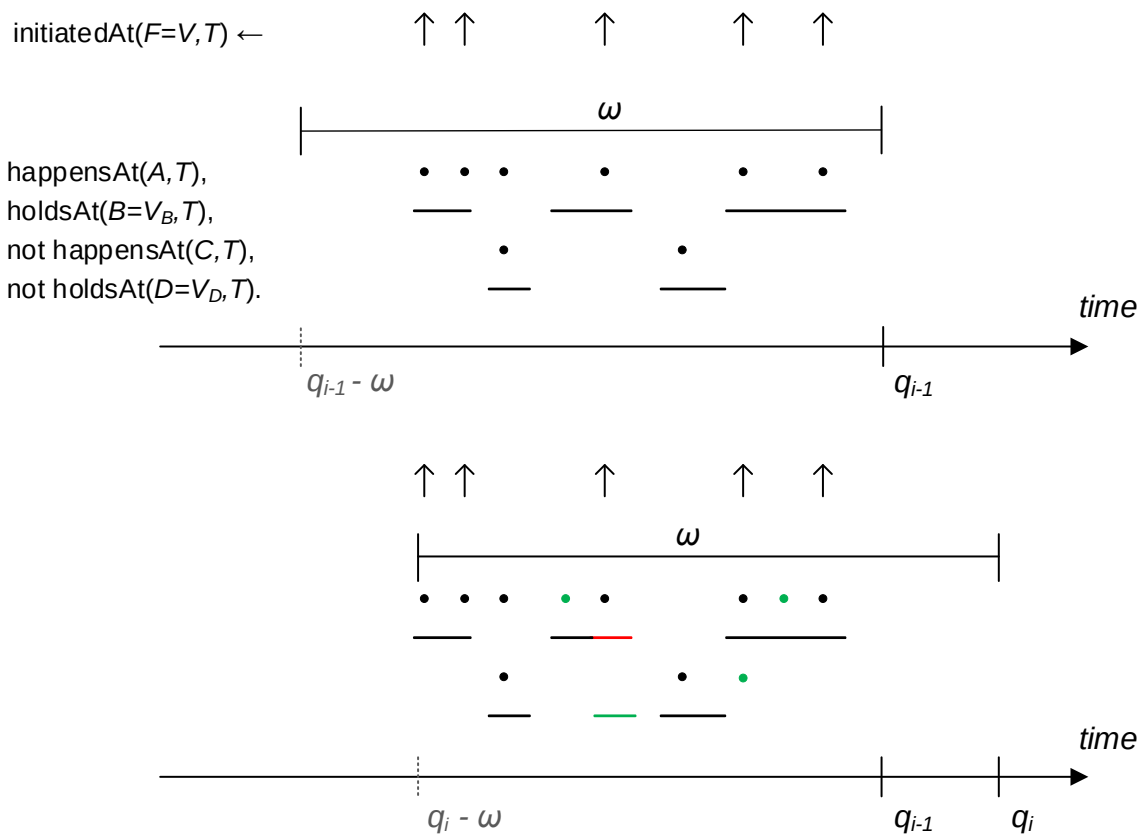
time
q_i - ω
q_{i-1}
q_i

Incremental Reasoning: Deletion Phase*



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

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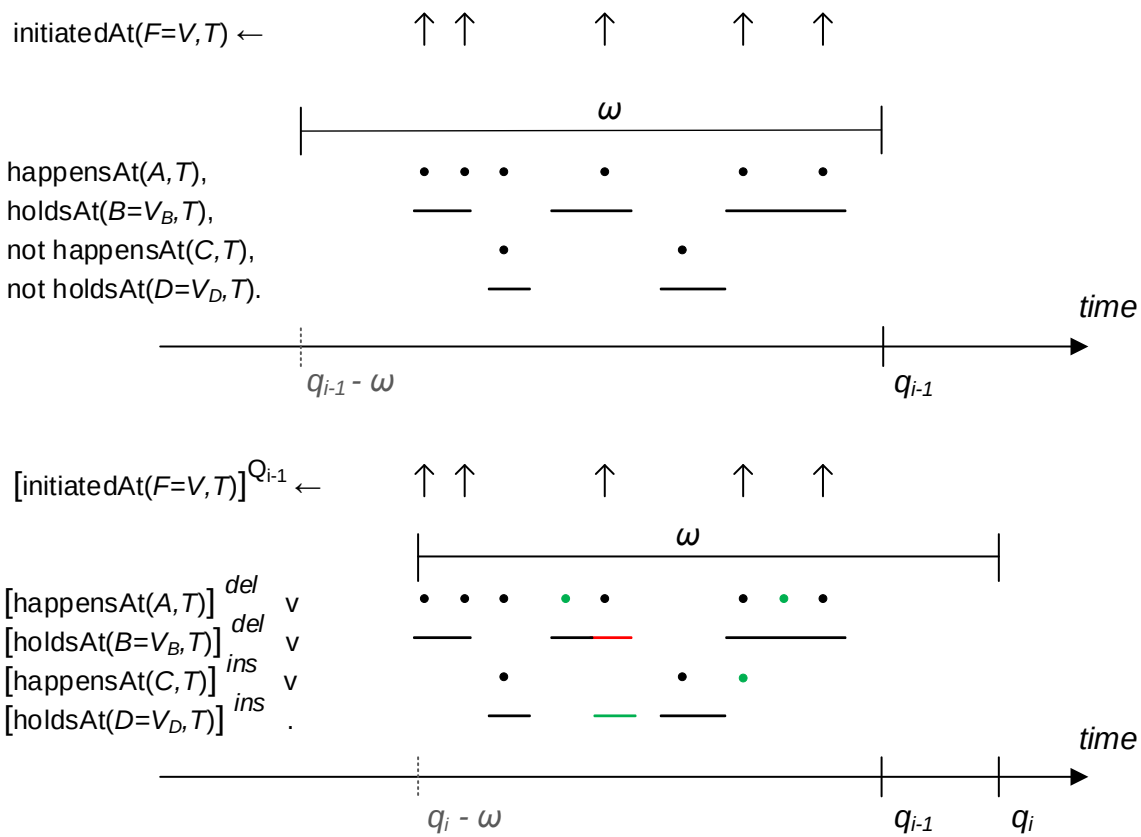

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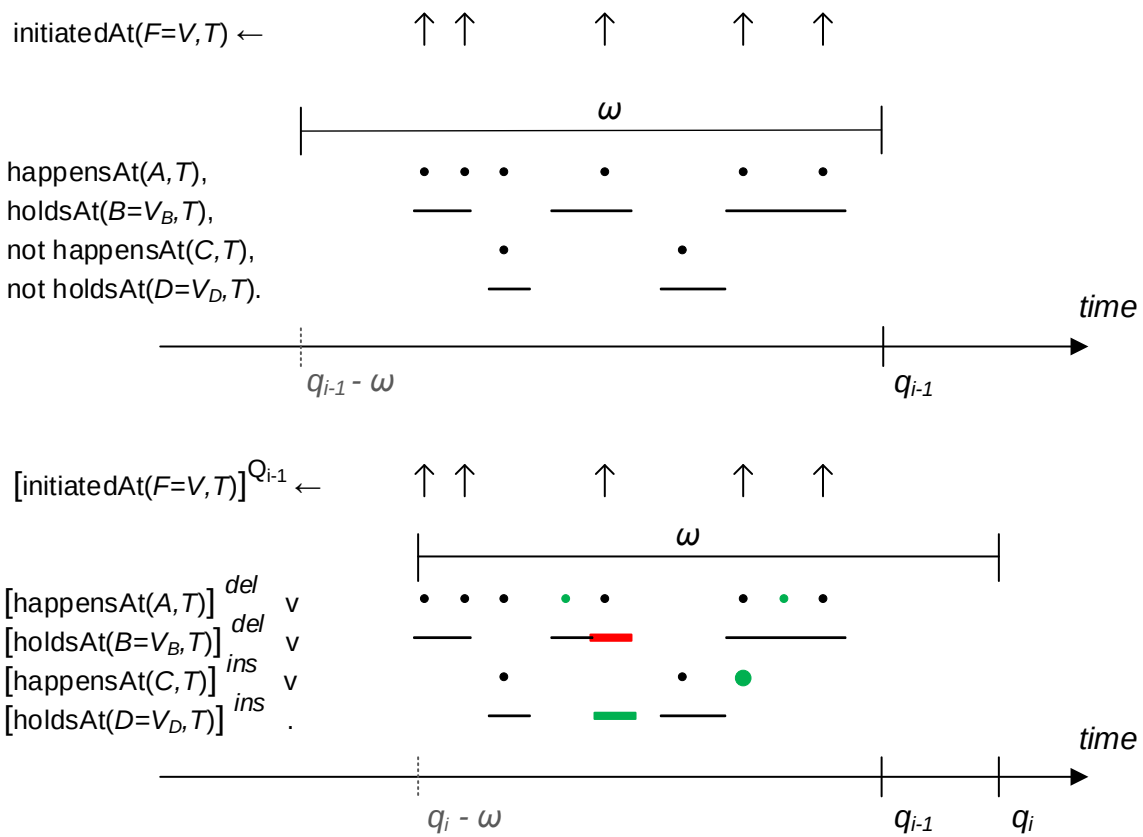

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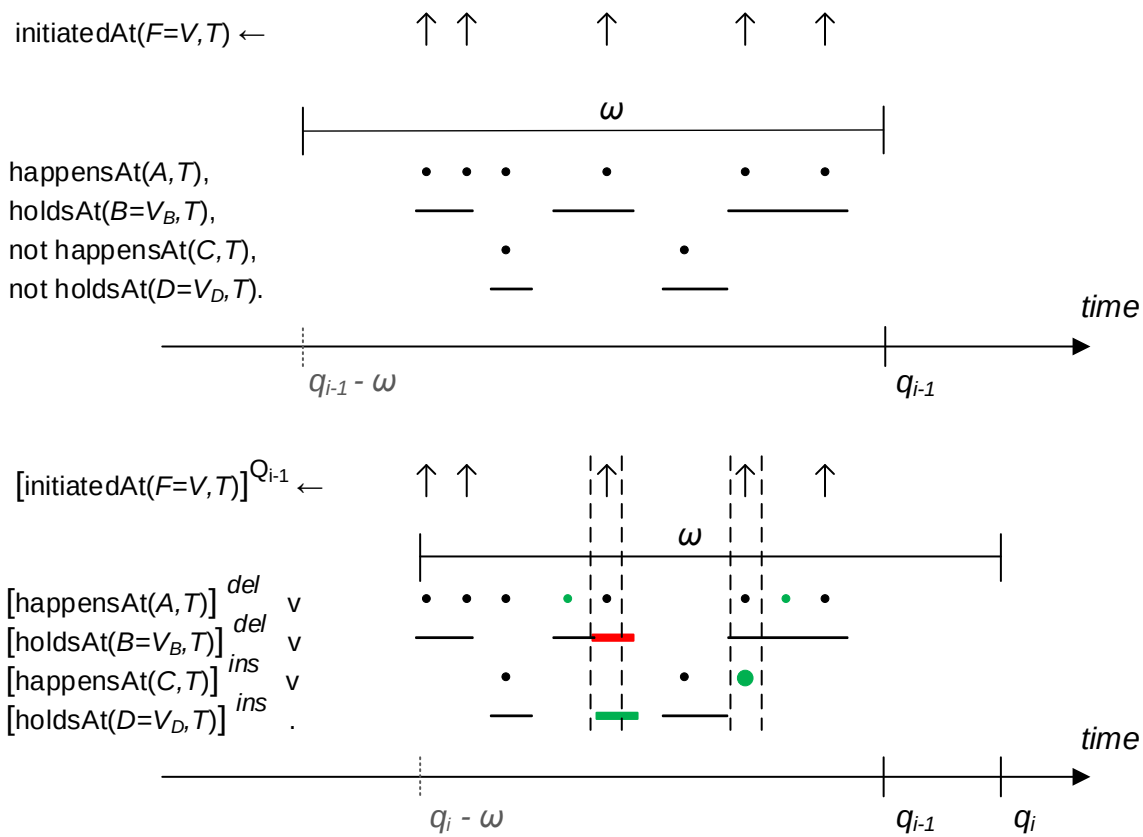

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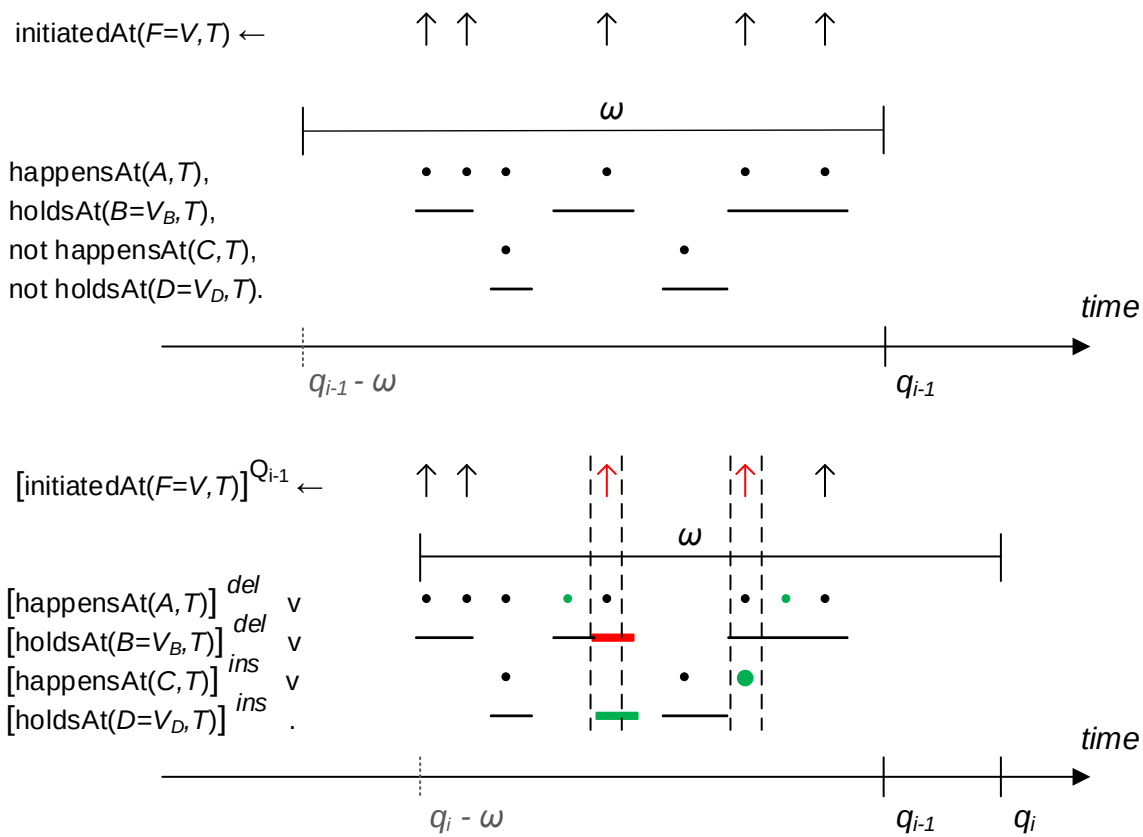

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RTEC: Correctness and Complexity

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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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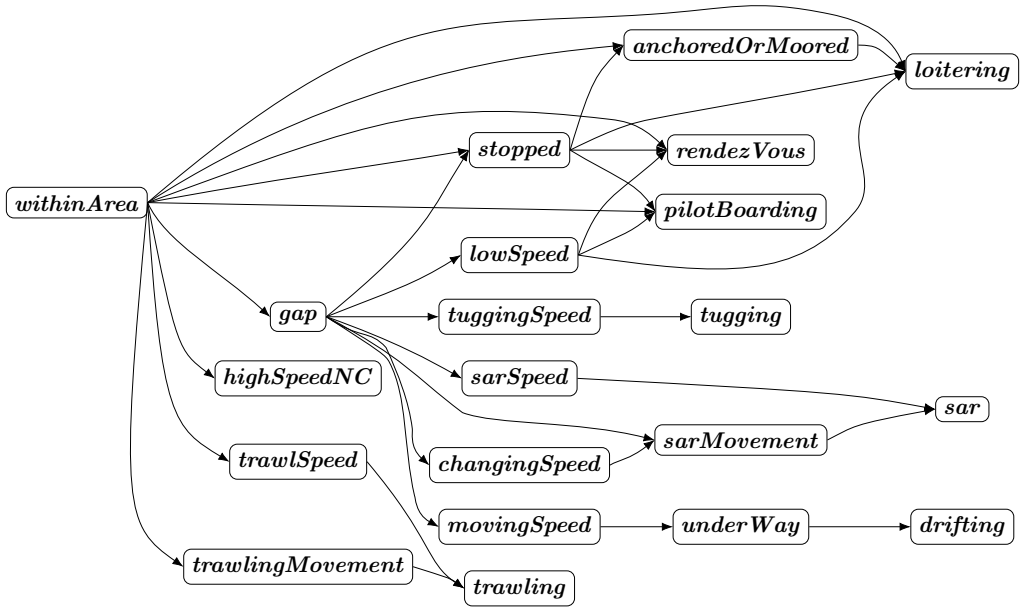
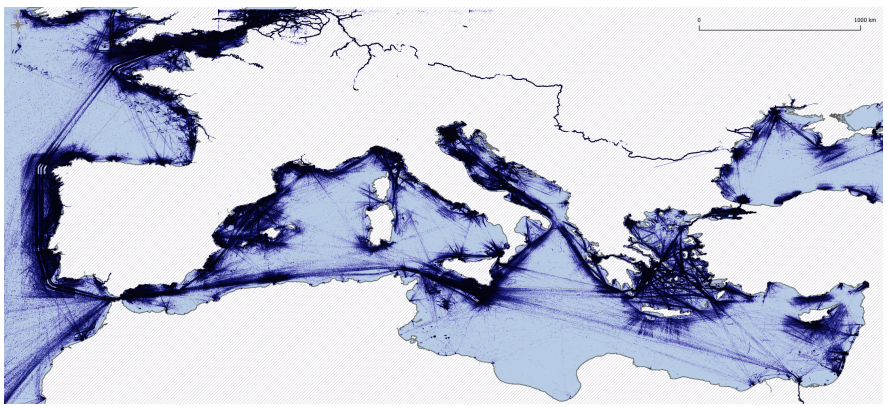
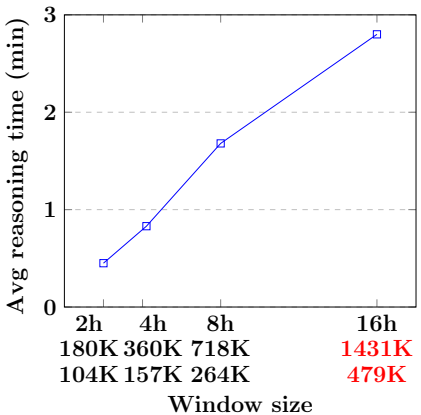
Complexity

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

Performance: Indicative Results







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Next: RTEC program generation with LLMs/LRMs.

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