Stream Reasoning for Complex Event Recognition

Alexander Artikis

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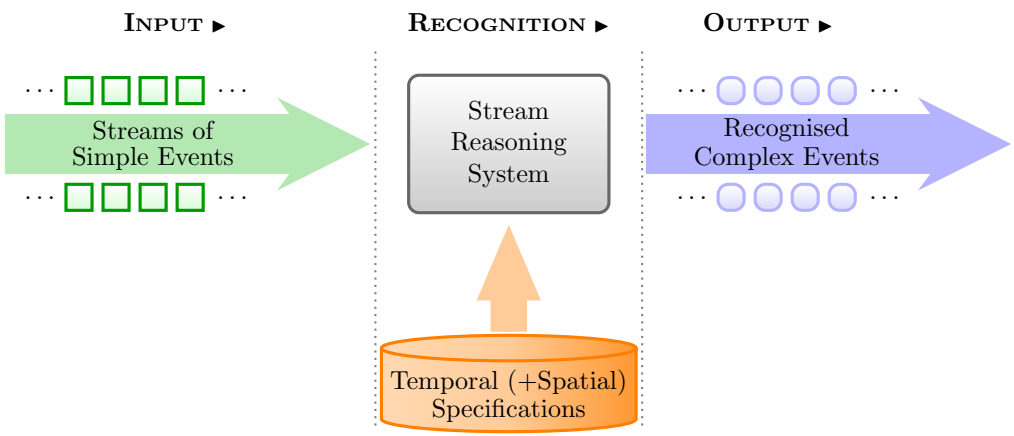
https://cer.iit.demokritos.gr

Complex Event Recognition (Event Pattern Matching)[*,†,‡]



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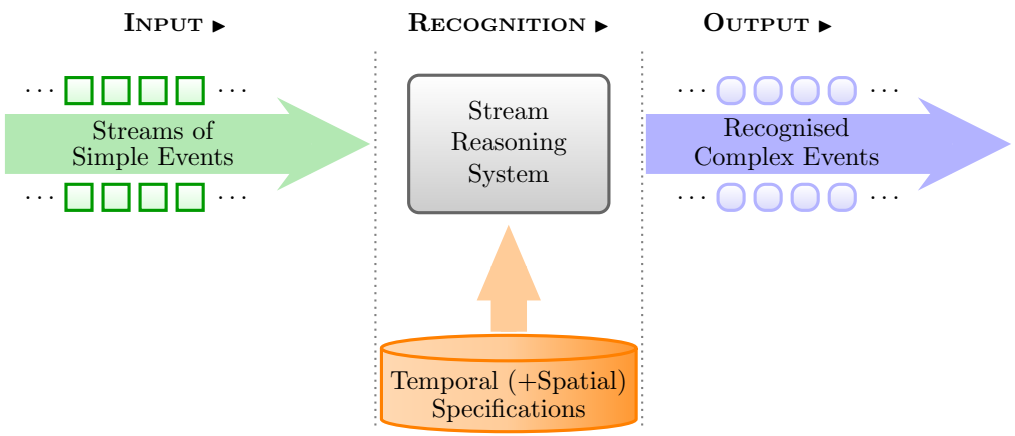

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Event Calculus*

- 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.

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

Event Calculus*

- A logic programming language for representing and reasoning about events and their effects.
- Key components:
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  - 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.

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

Run-Time Event Calculus (RTEC)*

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

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

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

*Artikis et al, An Event Calculus for Event Recognition. IEEE TKDE, 2015.
https://github.com/aartikis/RTEC

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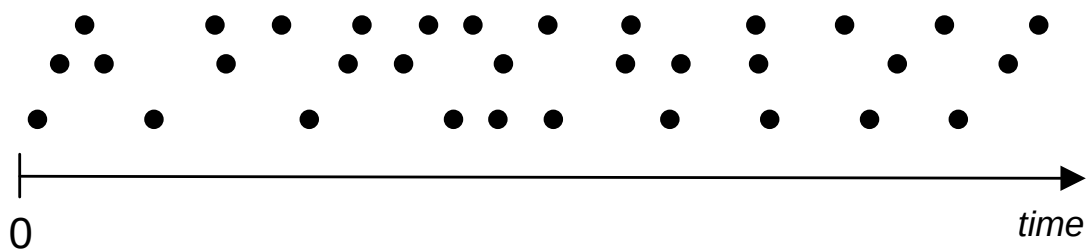

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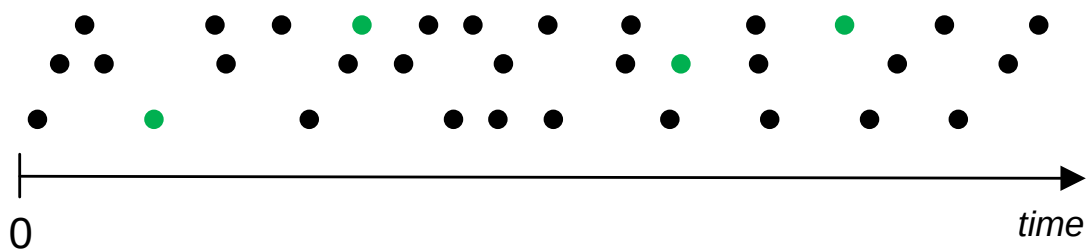

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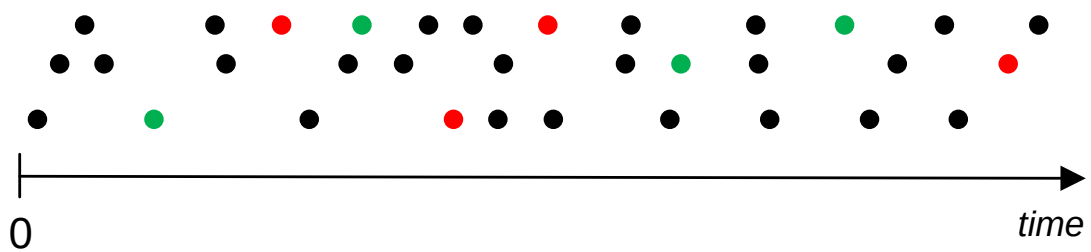

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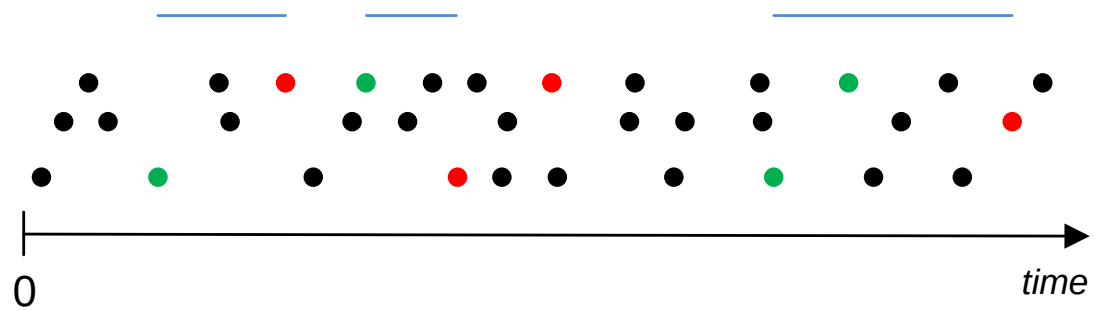
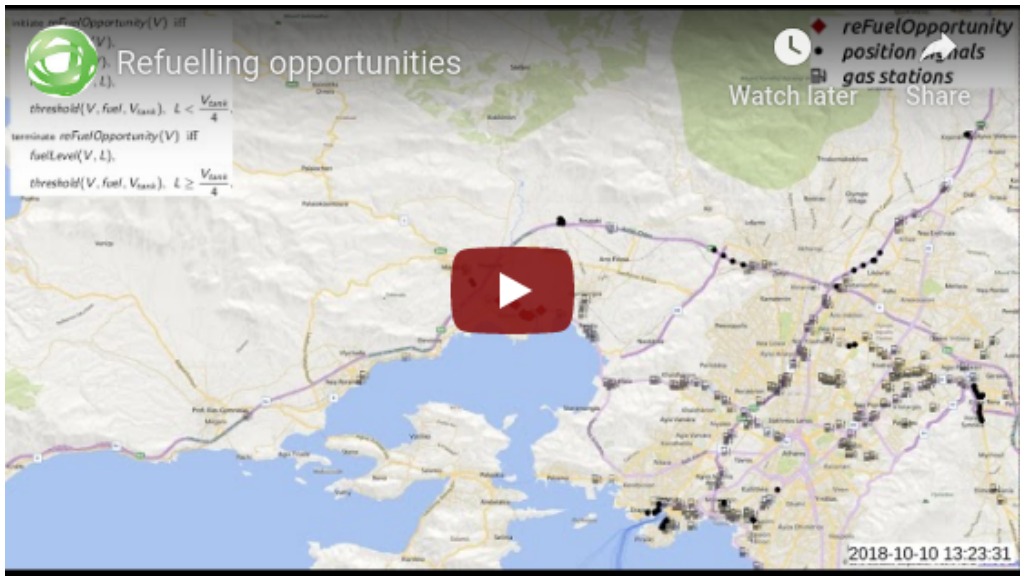
$\textbf{holdsFor}(F = V,\ I)$

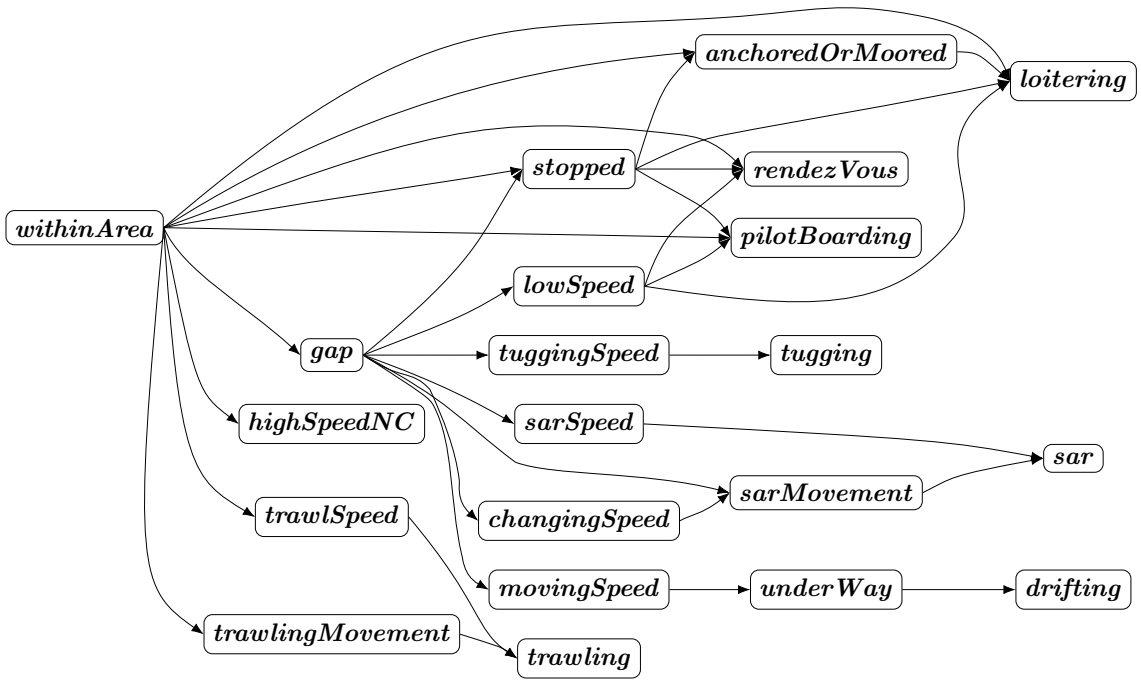


Fleet Management

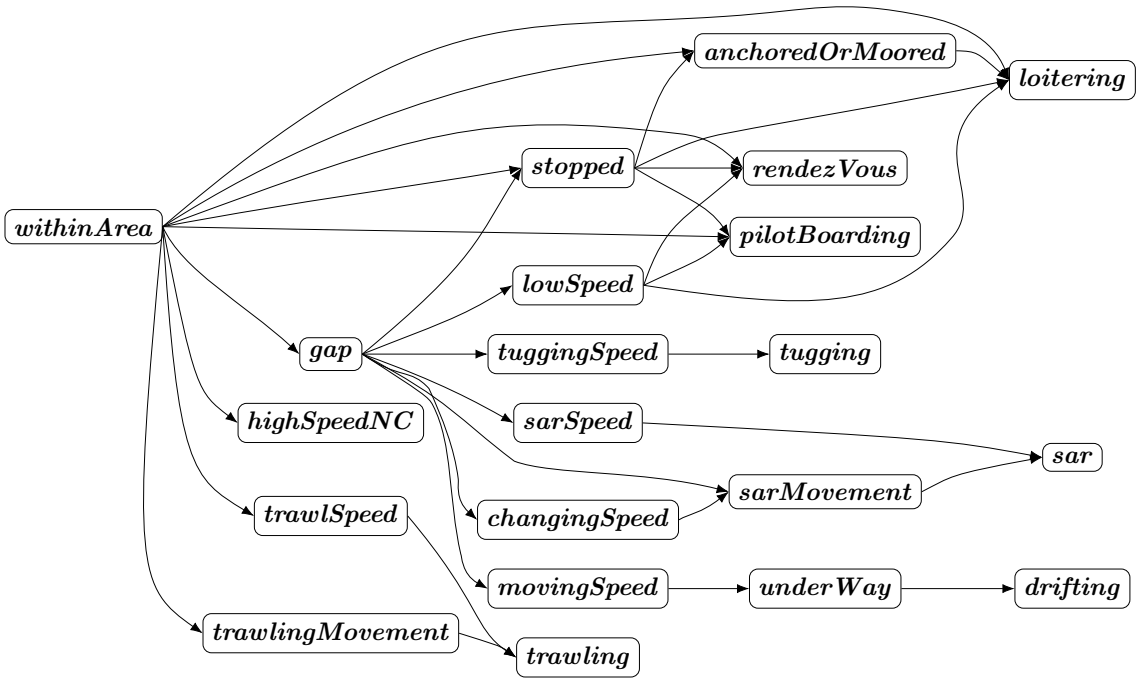


https://cer.iit.demokritos.gr (fleet management)

Semantics


anchoredOrMoored
loitering
stopped
rendezVous
withinArea
pilotBoarding
lowSpeed
gap
tuggingSpeed
tugging
highSpeedNC
sarSpeed
sar
sarMovement
trawlSpeed
changingSpeed
movingSpeed
underWay
drifting
trawlingMovement
trawling

Semantics


withinArea
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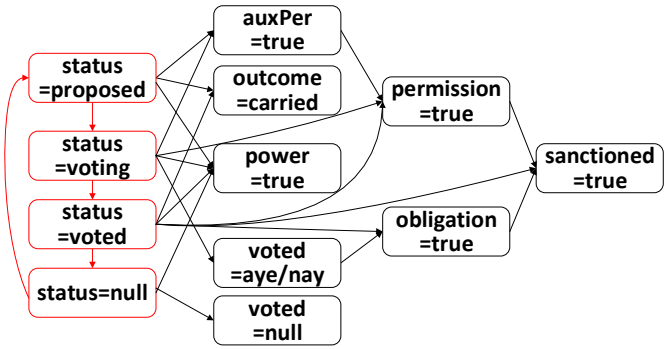
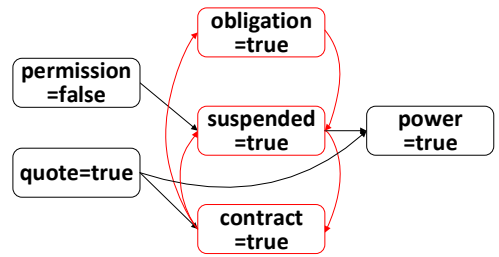
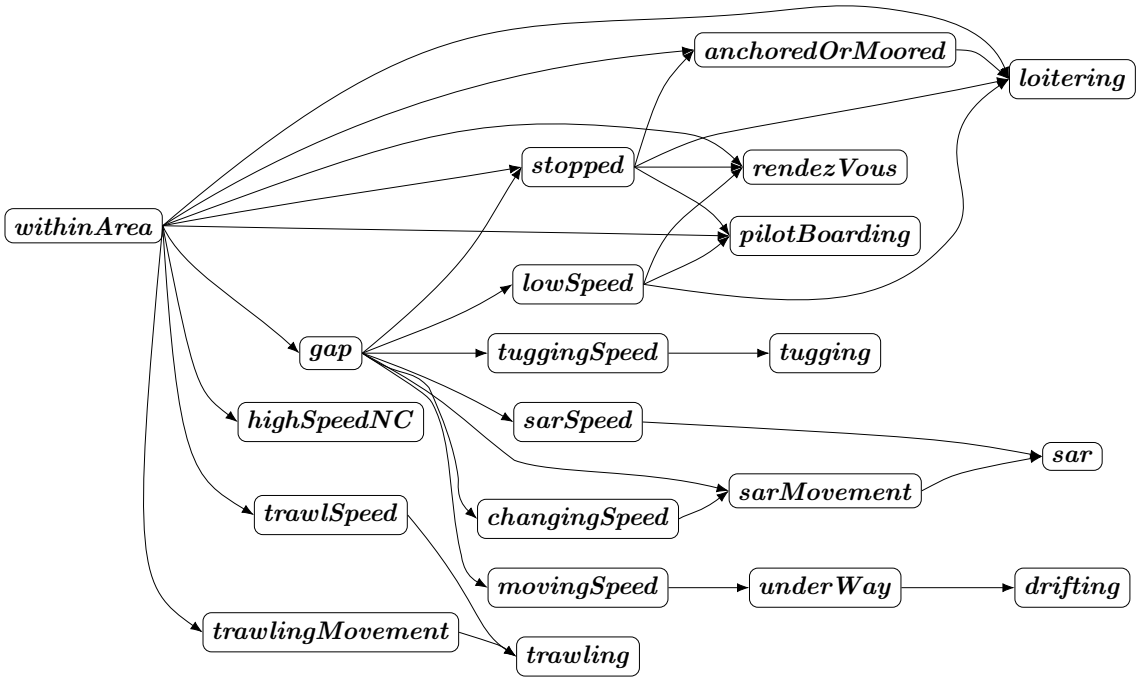
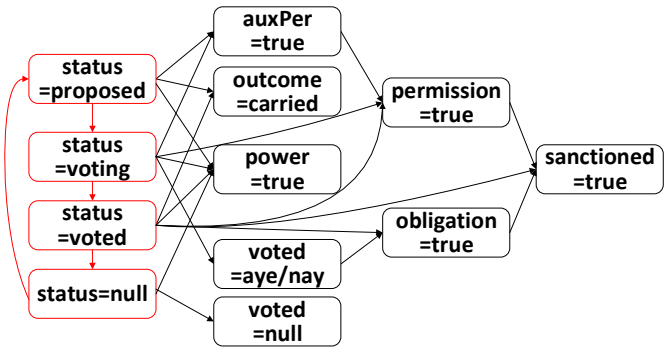
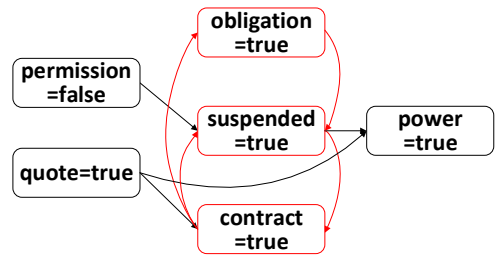

status =proposed
status =voting
status =voted
status=null
auxPer =true
outcome =carried
power =true
voted =aye/nay
voted =null
permission =true
obligation =true
sanctioned =true


permission =false
quote=true
obligation =true
suspended =true
contract =true
power =true

Semantics







Proposition

An event description in RTEC is a locally stratified logic program*.

*Mantenoglou et al, Stream Reasoning with Cycles. Knowledge Representation and Reasoning (KR), 2022.

Reasoning

- Windowing.
- Bottom-up caching for acyclic dependencies.

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  - Optimal rule rewriting.

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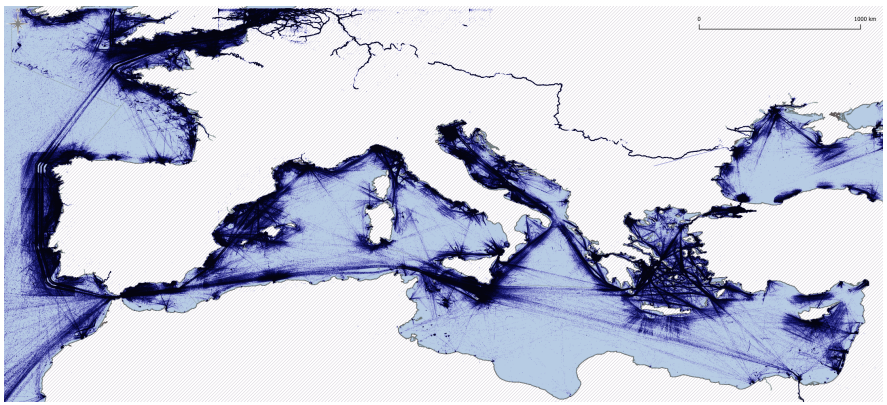

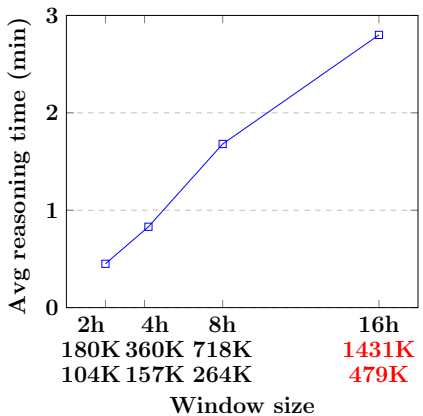

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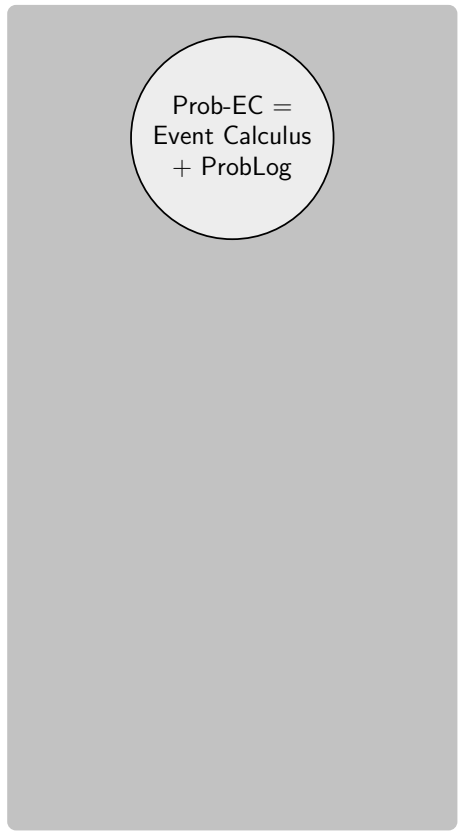
Online Probabilistic Interval-Based Event Calculus*,†



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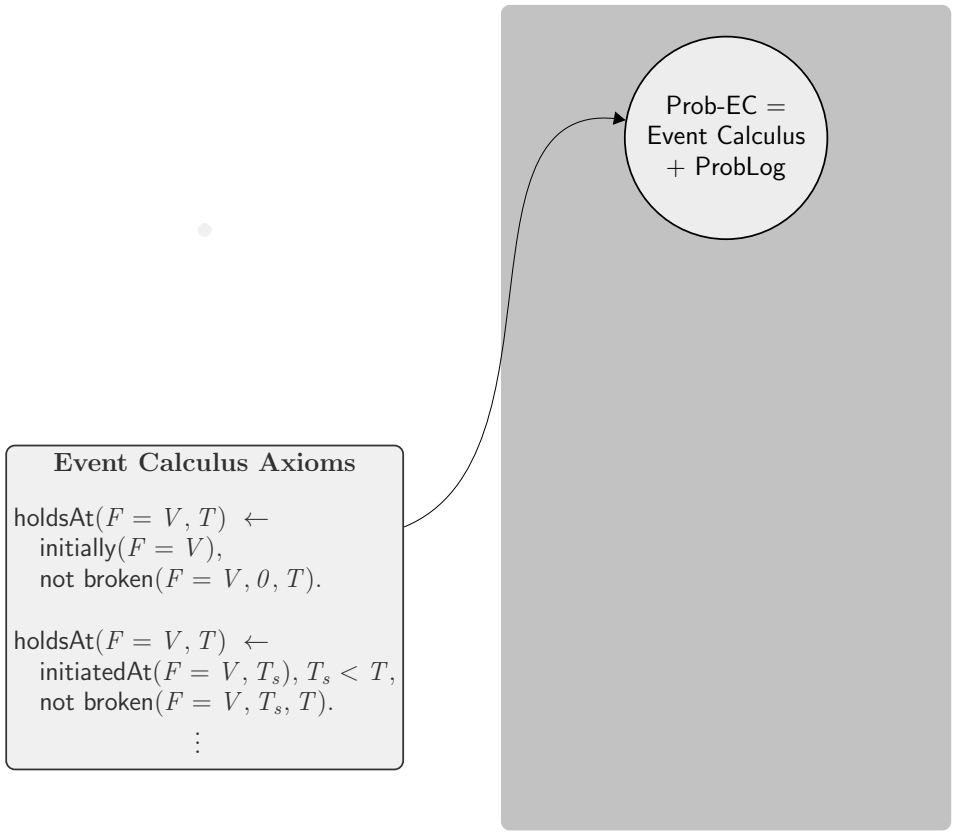

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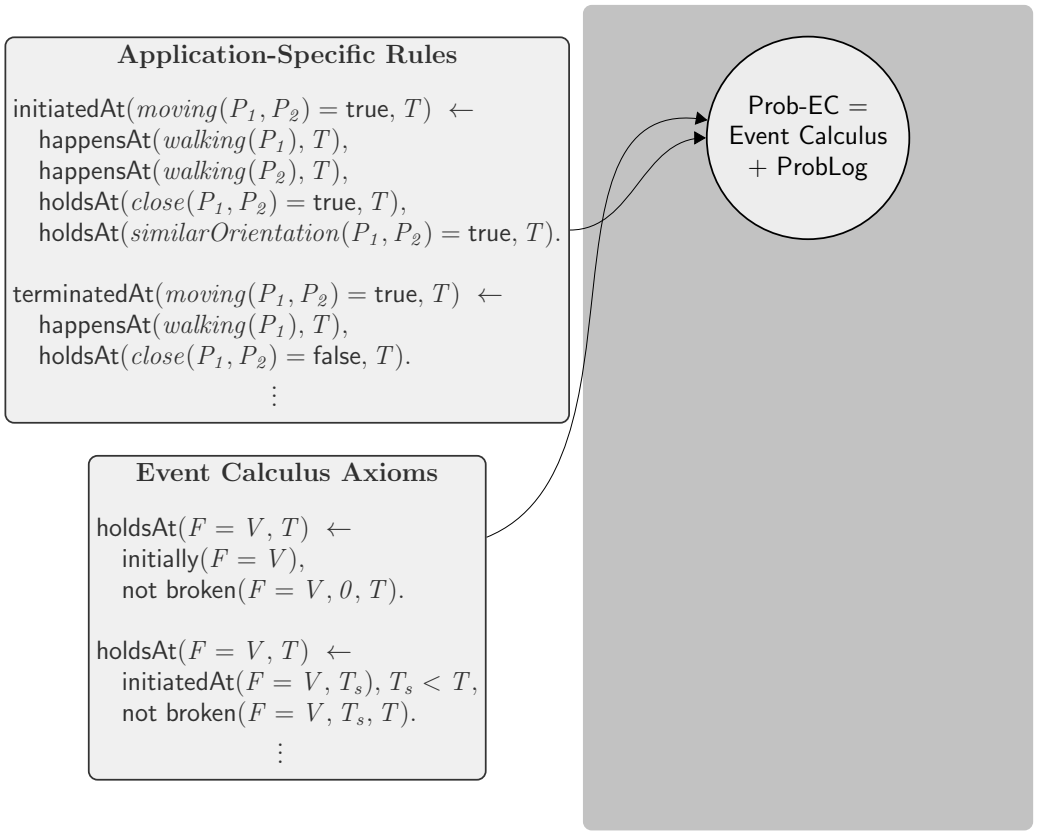

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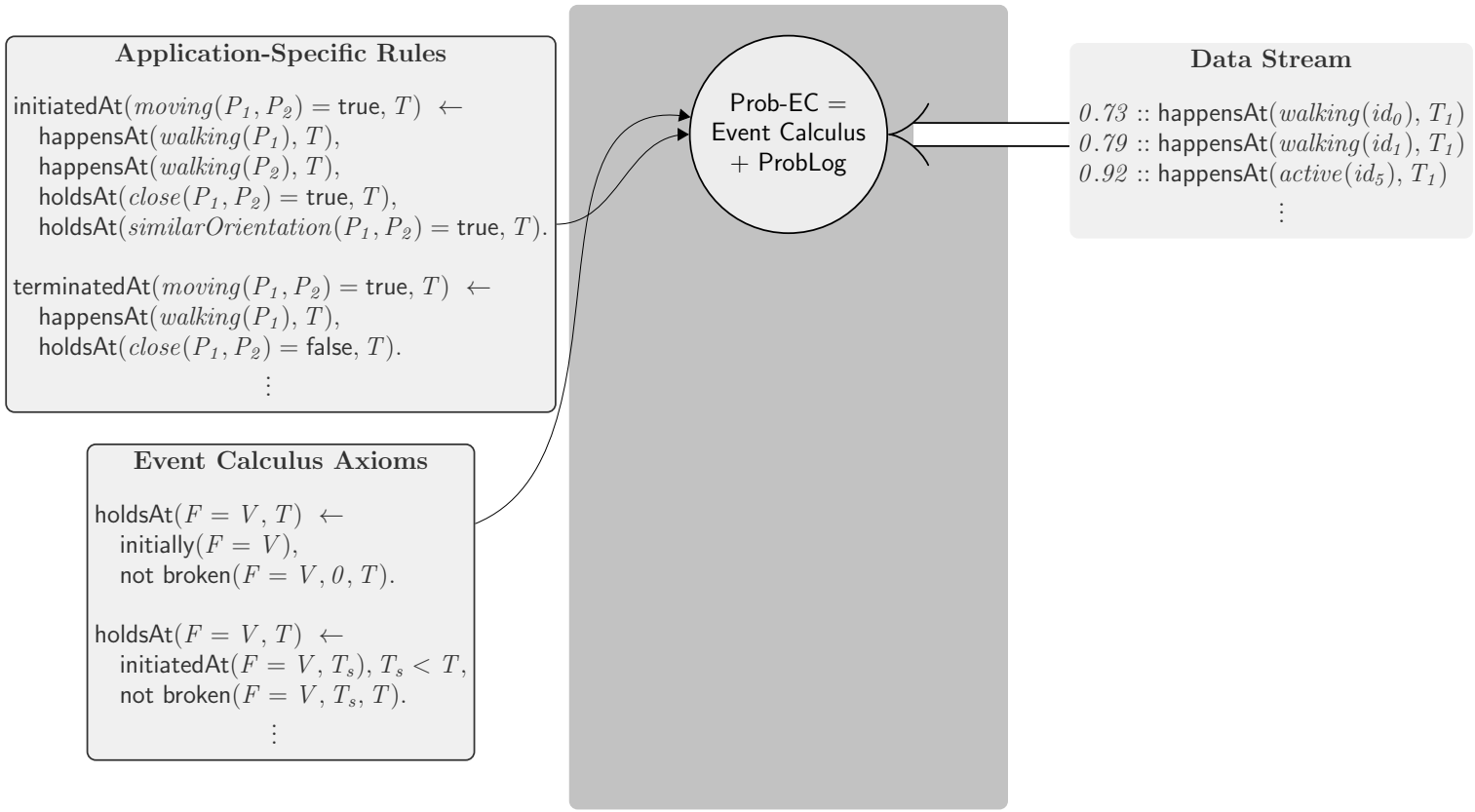

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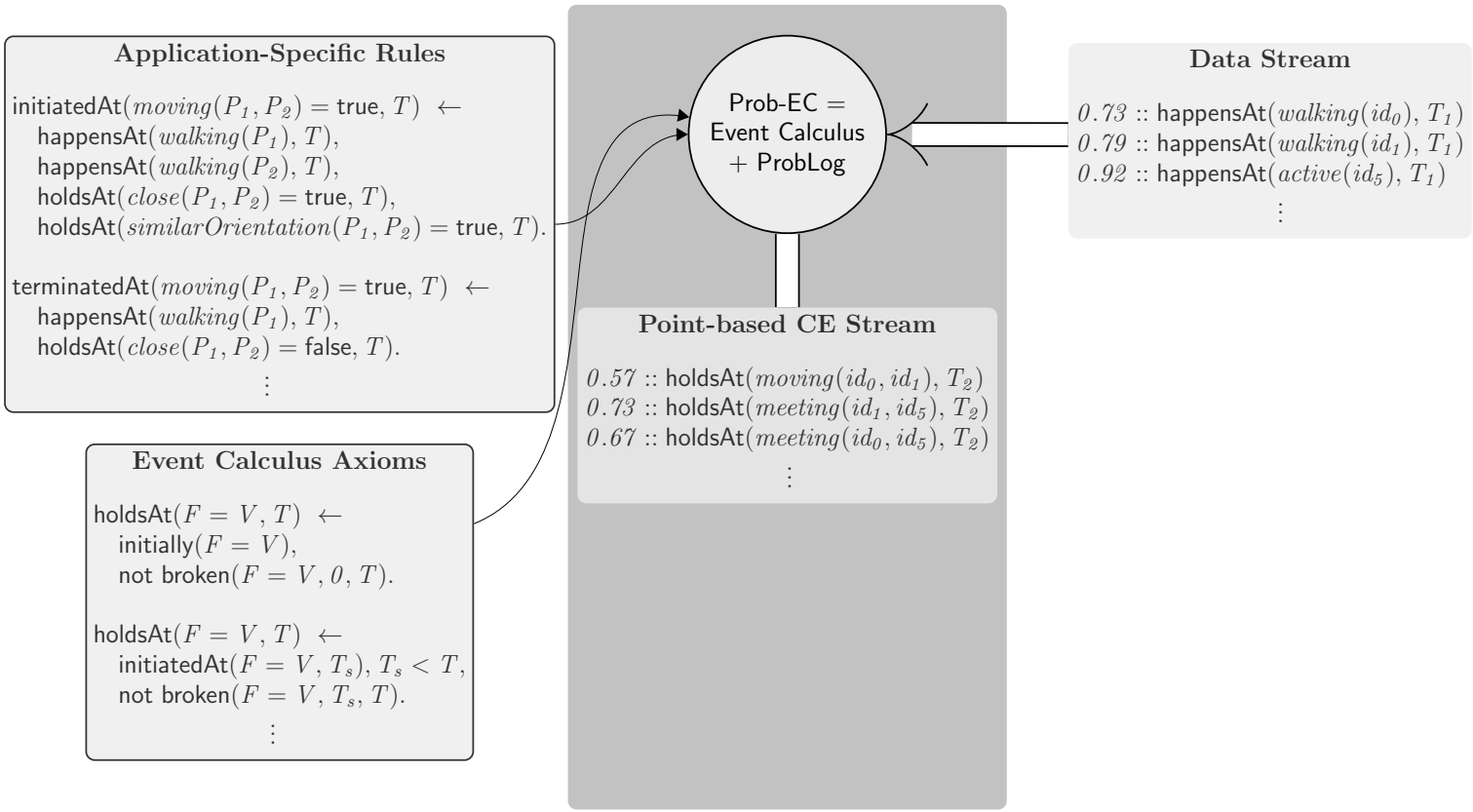

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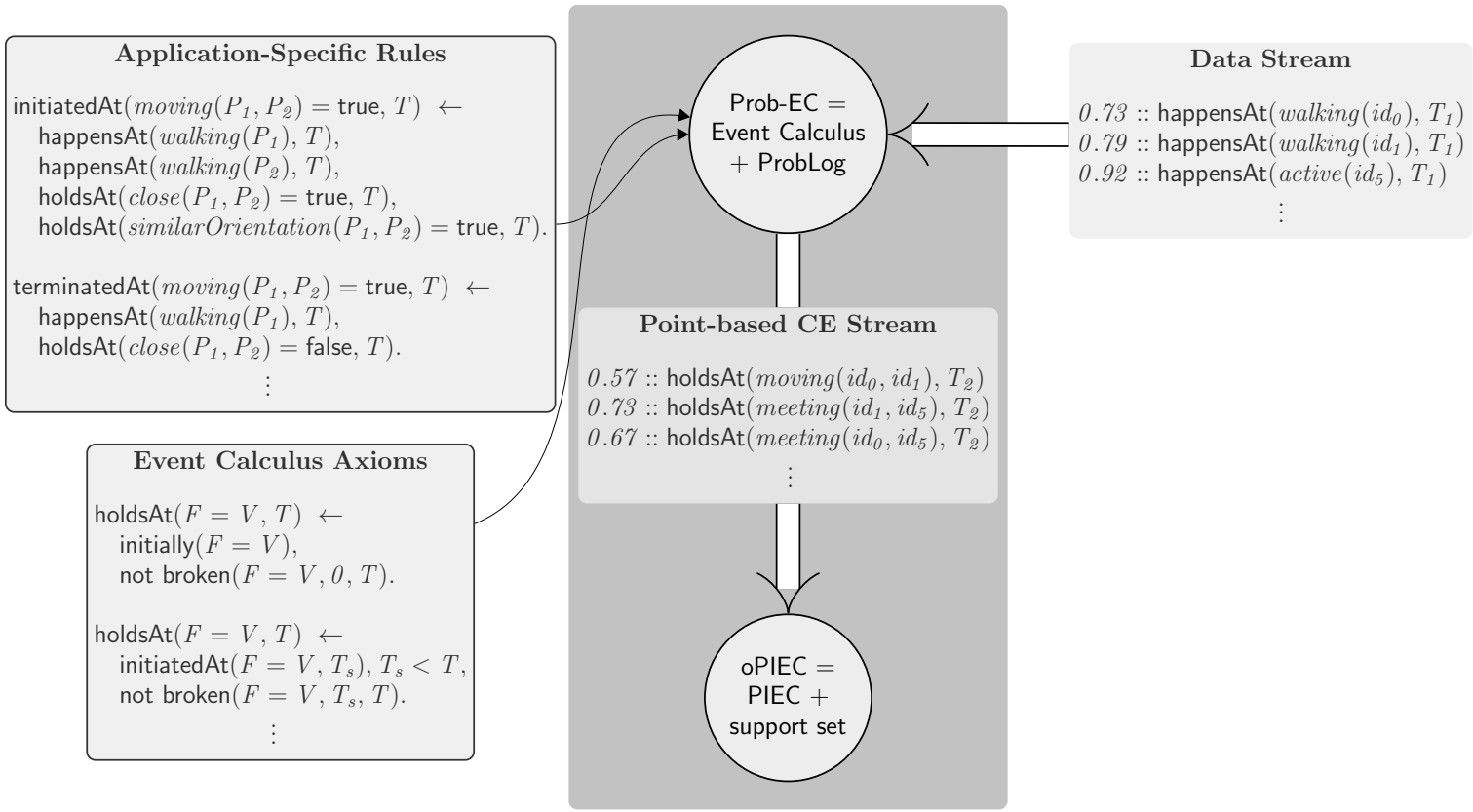

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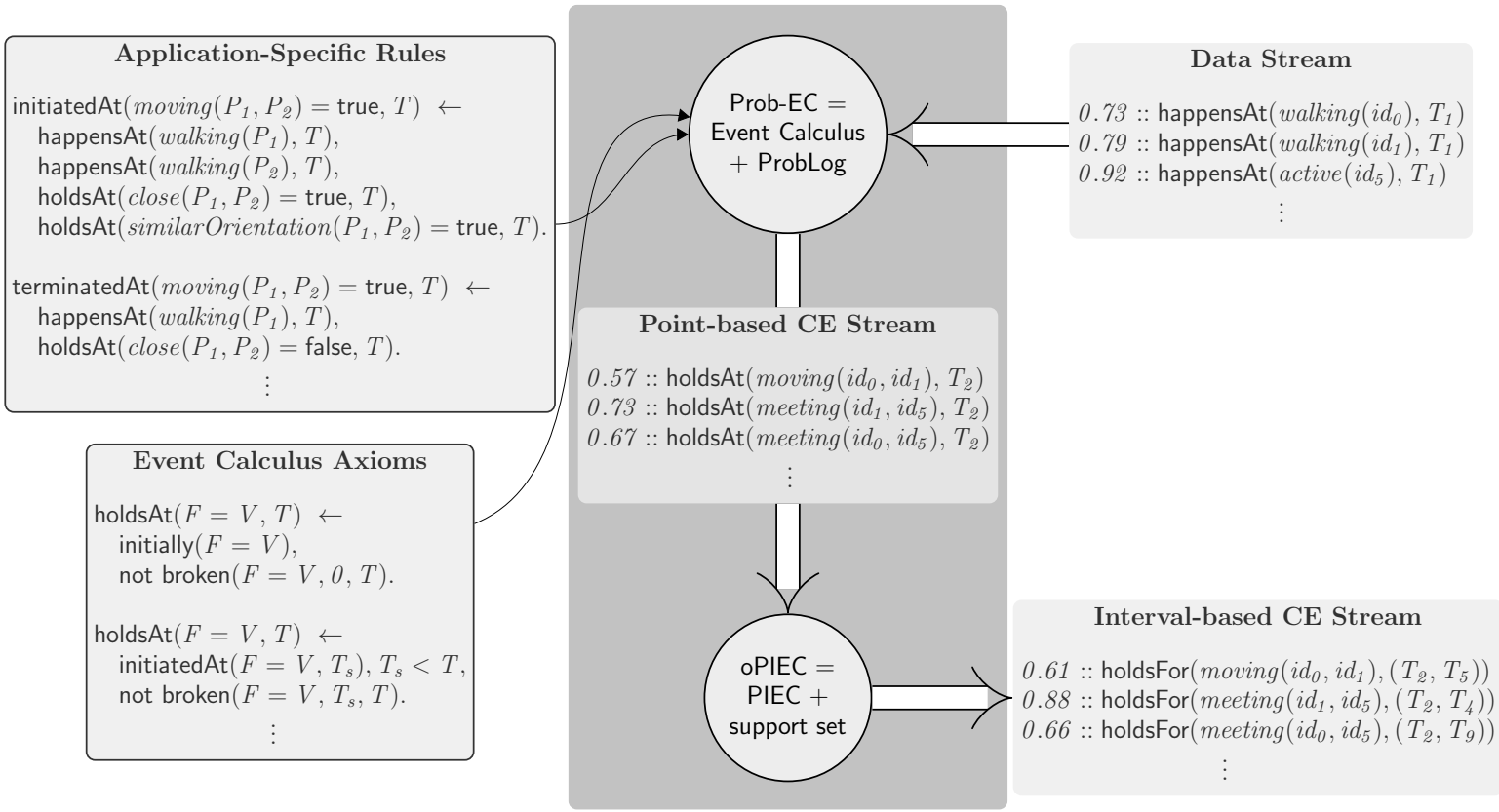

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Machine Learning for Complex Event Recognition*,†

- Online structure and weight learning for Event Calculus programs.
- Non-monotonic ILP over established ASP tools.
- First-order logic graph-cut minimisation for supervision completion.
- Approximation of globally-optimal solutions from locally-optimal ones.

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*Katzouris et al, Online Learning Probabilistic Event Calculus Theories in Answer Set Programming. Theory and Practice of Logic Programming, 2022. https://github.com/nkatzz/ORL

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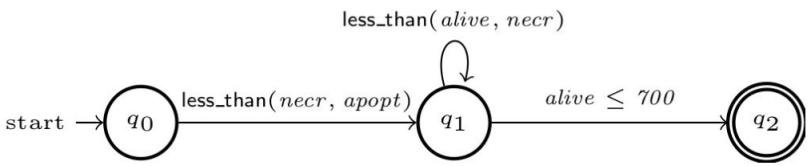
Complex Event Forecasting*

- Forecast the occurrence of a complex event.
- Symbolic automata for complex event patterns
  - Closure properties.
  - Formal compositional semantics.



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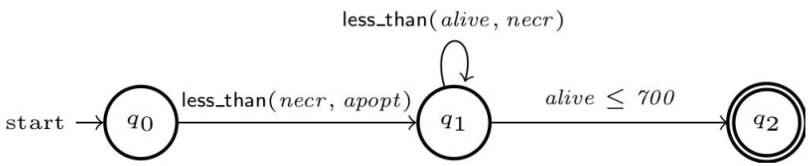

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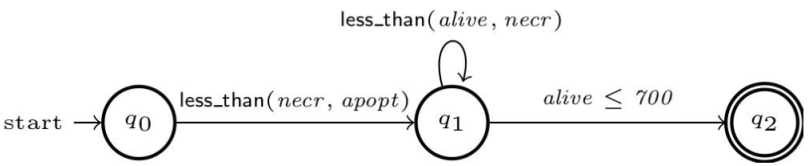

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- Symbolic Register Automata:
  - Symbolic automata with 'memory'.
  - Express *n*-ary relations between events.

https://cer.iit.demokritos.gr (maritime-forecasting)

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Funding & Further Work

Reasoning over Web-scale, inconsistent knowledge graphs*.

Use cases: business software services; geospatial intelligence; data-driven brand communication.

*ENEXA: Efficient Explainable Learning on Knowledge Graphs. Topic: HORIZON-CL4-2021-HUMAN-01-01.

Funding & Further Work

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Robust neuro-symbolic learning for complex event forecasting†.

Use cases: oncological forecasting in precision medicine; autonomous robot navigation in smart factories; life cycle assessment of critical infrastructure.

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†EVENFLOW: Robust Learning and Reasoning for Complex Event Forecasting. Topic: HORIZON-CL4-2021-HUMAN-01-01.

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Use cases: oncological forecasting in precision medicine; autonomous robot navigation in smart factories; life cycle assessment of critical infrastructure.

Multi-resolution complex event forecasting‡.

Use cases: hazardous maritime situation forecasting; weather emergency management; pandemic management.

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†EVENFLOW: Robust Learning and Reasoning for Complex Event Forecasting. Topic: HORIZON-CL4-2021-HUMAN-01-01.

‡CREXDATA: Critical Action Planning over Extreme-Scale Data. Topic: HORIZON-CL4-2022-DATA-01-01.