Temporal Specification Optimisation for the Event Calculus

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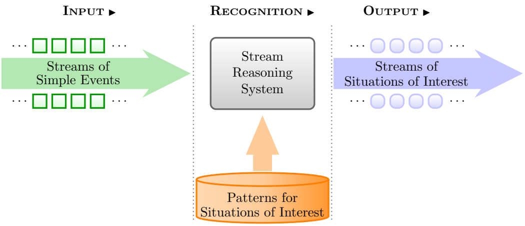
Temporal Pattern Matching over Streams



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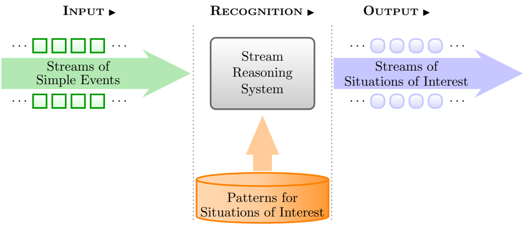

https://cer.iit.demokritos.gr (activity recognition)

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.

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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.

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Run-Time Event Calculus (RTEC)

Simple Fluent (SF):

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

terminatedAt$(F{=}V, T) \leftarrow$
    happensAt(E_{T_1}, T)[,
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where conditions:
$^{0-K}$[not] **happensAt**(E_k, T),
$^{0-M}$[not] **holdsAt**$(F_m = V_m, T)$,
$^{0-N}$atemporal-constraint$_n$

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Statically Determined Fluent (SDF):

$\textbf{holdsFor}(F{=}V, I) \leftarrow$
$\quad \textbf{holdsFor}(F_1 = V_1, I_1)[,$
$\quad \textbf{holdsFor}(F_2 = V_2, I_2), \ldots$
$\quad \textbf{holdsFor}(F_n = V_n, I_n),$
$\quad \text{intervalConstruct}(L_1, I_{n+1}), \ldots$
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where intervalConstruct:

union_all or
intersect_all or
relative_complement_all

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- SDFs:
  - exponentially more compact.
  - more efficient to reason with.

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- Formal characterisation of the class of SFs that are translatable into equivalent SDFs.
- Compiler that identifies and re-writes them as SDFs.
- Reproducible empirical evaluation on numerous real domain specifications.

Example: A Translatable SF

SF:

$\textbf{initiatedAt}(\mathit{meeting}(P_1, P_2) = \mathit{interact}, T) \leftarrow$
$\quad \textbf{happensAt}(\text{start}(\mathit{active}(P_1) = \text{true}), T),$
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SDF is satisfied iff we have: $\mathit{active}(P_1) = \mathrm{true} \wedge \mathit{close}(P_1, P_2) = \mathrm{true}$.

$\mathit{active}(P_1) = \mathrm{true}$ starts to hold while $\mathit{close}(P_1, P_2) = \mathrm{true}$ holds.
$\Rightarrow$ SDF gets satisfied.

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SDF is satisfied iff we have: $\mathit{active}(P_1) = \text{true} \wedge \mathit{close}(P_1, P_2) = \text{true}$.

$\mathit{active}(P_1) = \text{true}$ stops holding.
$\Rightarrow$ SDF gets violated.

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SF includes 1 rule for each possible way of switching the truth value of: $\mathit{active}(P_1) = \text{true} \wedge \mathit{close}(P_1, P_2) = \text{true}$.
$\Rightarrow$ SF is inertial condition symmetric.

Translatable SFs

An SF is translatable to an SDF iff it is:

- inertial condition symmetric,
- guard condition symmetric and
- Boolean representation symmetric.

Theoretical Results

Translatable SFs

An SF is translatable to an SDF iff it is:

- inertial condition symmetric,
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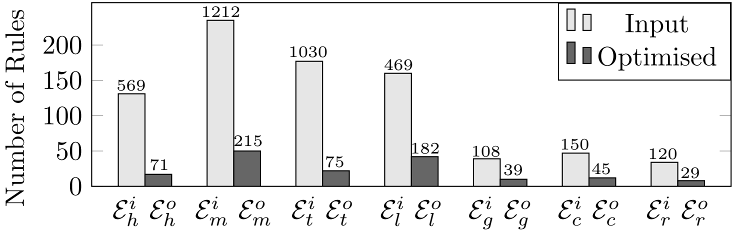
Compiler

We have devised and implemented an algorithm that:

- identifies the SFs that are translatable, and
- maps them into equivalent SDFs.

Experimental Evaluation



Event Calculus specifications for:

- human activity recognition.
- maritime situational awareness.
- city transport management.
- legal contract verification (Parvizimosaed et al. 2022).
- clinical guideline monitoring (Bragaglia et al. 2012).
- authorisation policy conflicts (Zahoor et al. 2022).
- redundant authorisation policies (Zahoor et al. 2023).

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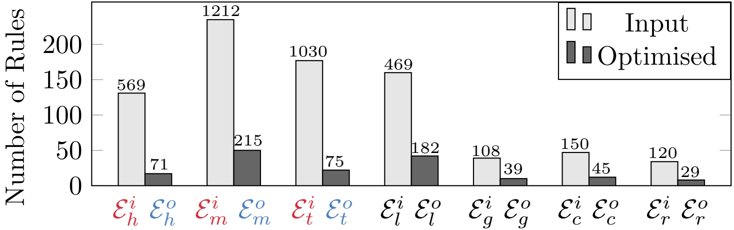

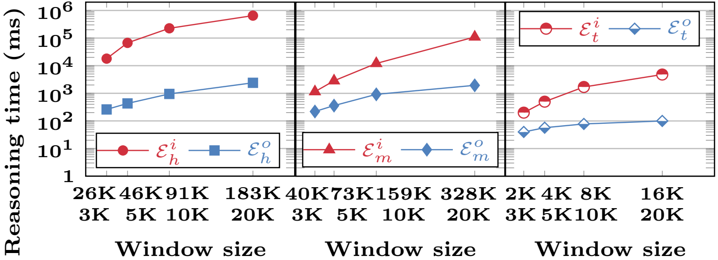

Code, Data & Temporal Specifications: https://github.com/aartikis/RTEC

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Future Work:

- Compile RTEC specifications into automata, towards complex event forecasting[1].

[1] Alevizos et al., Complex event forecasting with prediction suffix tress. In VLDB Journal, 31(1), 157–180, 2022.