Timed Perception Pattern Matching using Spatial Timed Automata

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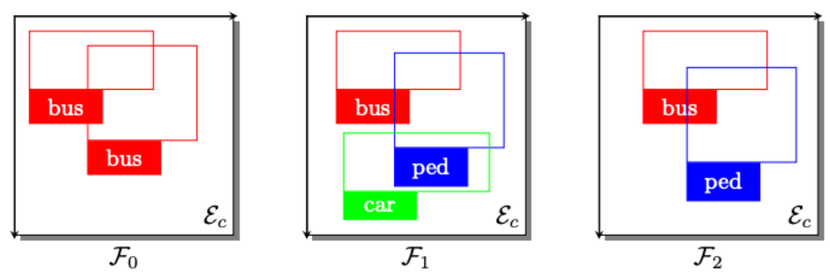
Background

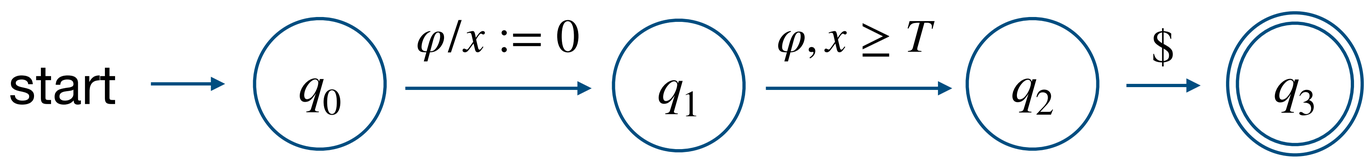
Goal: Enable precise timed perception pattern matching for continuous spatial conditions.
(e.g., "Is there a pedestrian within 3m of the car for at least 0.5s?")
Prior Work: Existing tool (STREM [Anderson et al., 2024]) excel at frame-by-frame spatial matching.



How to achieve precise temporal matching (e.g., "a pedestrian stays in the danger zone for at least 0.5 seconds")?

The Solution: Spatial Timed Automata (SpTA)

Input: A stream of perception frames with physical timestamps.
Output: The set of all time intervals where the pattern is strictly satisfied.



SpTA Example for "Spatial Logic φ holds for $\geq T$ seconds".

Accumulate $\Delta\tau$ into clock x to identify every interval (t, t') where the spatial logic φ holds continuously for $\geq T$ seconds.

Formal Foundations

Spatial Logic $\mathcal{S}4_u^+$:

$\varphi ::= \alpha \mid \exists v(\alpha) \,.\, \phi \mid \tau_1 \sqsubseteq \tau_2 \mid \psi_1 \leq \psi_2 \mid \ldots$

Evaluates $F \vDash \varphi$ to determine if the spatial pattern exists.

SpTA Transition Logic $q \xrightarrow{\varphi,\lambda,\delta} q'$:

$\varphi \in \mathcal{S}4_u^+$: Spatial requirement for the current frame.

δ, λ: Clock constraints and resets.

Implementation & Future

Algorithm: Parallel configuration tracking to capture the complete interval set Z.
Current: A single-path prototype that evaluates pattern frame-by-frame and returns per-step acceptance, not the full interval set.
Future: Full parallel configuration maintenance and experimental evaluation.