Model-Checking Based Verification of Cyber-Physical Systems with Alternating Signal Temporal Logic

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Motivation

Cyber-physical systems (CPS) utilize software while at the same time being able to sense or interact with the real world. We could model the system "Environment and CPS" and then verify the CPS by model checking a specification against the system.

Signal Temporal Logic

$$\varphi ::= s \sim c \mid \top \mid \neg\varphi \mid (\varphi \vee \varphi) \mid (\varphi \,\mathbf{U}_I\, \varphi)$$

Real-time • Real-valued • Linear-time

Alternating-Time Temporal Logic

$$\varphi ::= p \mid \top \mid \neg\varphi \mid (\varphi \vee \varphi) \mid \langle\!\langle A \rangle\!\rangle \bigcirc \varphi \mid \langle\!\langle A \rangle\!\rangle \Box \varphi \mid \langle\!\langle A \rangle\!\rangle (\varphi \,\mathbf{U}\, \varphi)$$

Discrete-time • Discrete-valued • Branching-time
Can express existence of strategies for players

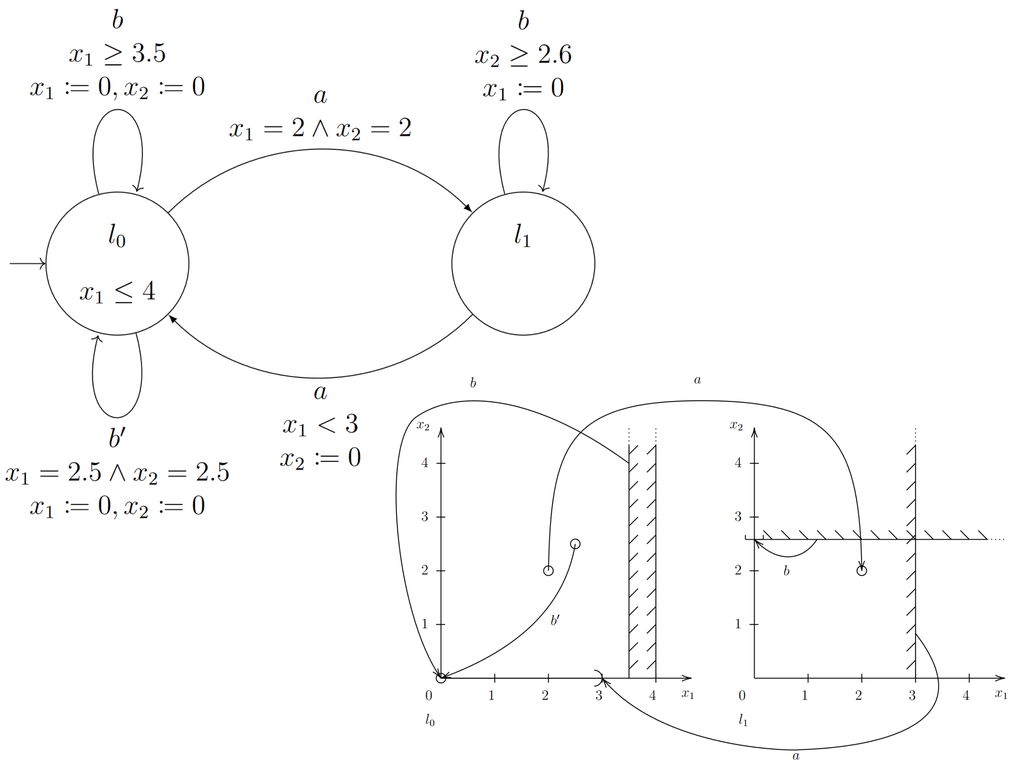
Alternating Signal Temporal Logic

$$\varphi ::= s \sim c \mid \top \mid \neg\varphi \mid (\varphi \vee \varphi) \mid (\varphi \,\mathbf{U}_I\, \varphi)$$

Real-time • Real-valued • Branching-time
Can express existence of strategies for players

Timed Games

Timed automaton extension with multiple players and actions for said players activation transitions



Bounded Model Checking

Extension of Pre-Image based algorithm for ATL

Algorithm 1 ASTL symbolic model-checking

Input: timed game $\mathcal{T}$, ASTL formula φ
Output: boolean *true* or *false*

for φ' **in** $\mathrm{Sub}(\varphi)$ **do**
  case $\varphi' = \top$
    $[\varphi'] \leftarrow Q_I$
  case $\varphi' = x \sim c$
    $[\varphi'] \leftarrow \mathrm{Reg}_{\mathcal{T}}(x \sim c)$
  case $\varphi' = \neg\theta$
    $[\varphi'] \leftarrow Q_I \setminus [\theta]$
  case $\varphi' = (\theta_1 \vee \theta_2)$
    $[\varphi'] \leftarrow [\theta_1] \cup [\theta_2]$
  case $\varphi' = \langle\!\langle A \rangle\!\rangle (\theta_1 \,\mathbf{U}_I\, \theta_2)$
    $[\varphi'] \leftarrow \mathrm{Pre}^*_{\mathcal{T},I}(A, [\theta_2], [\theta_1])$
end for
return $q_0 \in [\varphi]$

Rules
1. System "timed game" as game-structure extension of timed automata
2. Only non-zeno structures
3. No infinite intervals in specification

Proof Ideas

Correctness: Induction over ASTL semantics
Computability:

1. Split pre-image computation into series of discrete (action) and continuous (time) steps
2. Show that each step is computable, and a pre-image computation involves finitely many steps
3. Show that any pre-image can be symbolically represented as regions in state-space
4. Final inclusion check of algorithm through translation of symbolic representation to first-order logic formulas over the theory of real-closed fields, quantifier elimination computable (Tarski-Seidenberg Theorem)

Caveats and Further Work

- Infeasible runtime (quantifier-elimination in the theory of real-closed fields) – really necessary?
- ASTL* in relation to ASTL (analogously to ATL*)
- Robust semantics for ASTL

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