Specification Mining for Cyber-physical Systems

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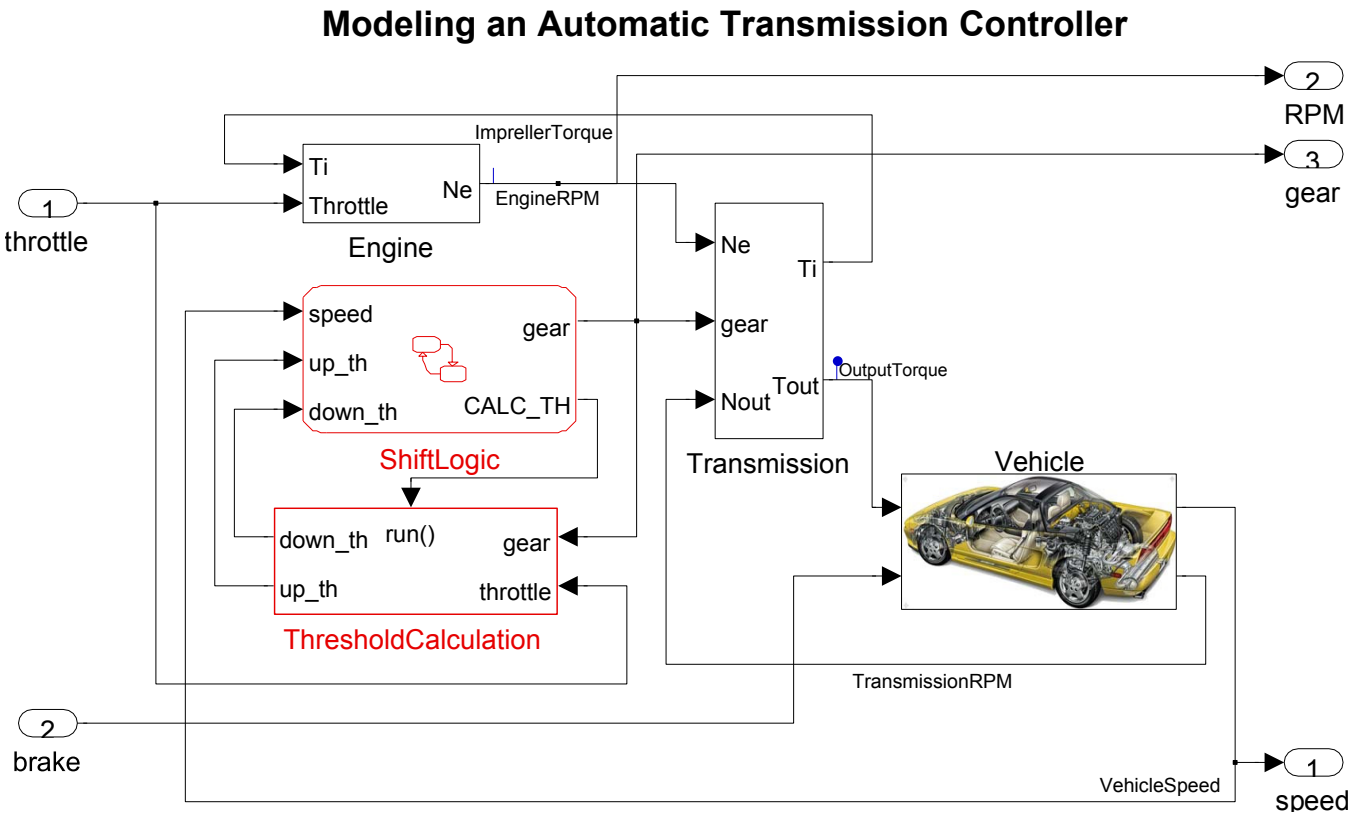
NSF

Chess

Problem formulation

What specifications does this system satisfy ?



- Documentation of legacy code/model
- Mining specifications of prototype models can lead to bugs or undesired behaviors discoveries

Formalizing Specifications

Parametric Signal Temporal Logic (PSTL)

- "The speed never exceeds 120 and RPM never exceeds 4500"

$$\square(\texttt{speed} \leq \pi_{speed}) \wedge \square(\texttt{RPM} \leq \pi_{rpm})$$

where, e.g., $(\pi_{\texttt{speed}} \mapsto 120, \pi_{rpm} \mapsto 4500)$

- "Eventually between time 0 and some unspecified time τ_1, the signal x is less than some value π_1, and from that point for some τ_2 seconds, it remains less than some value π_2"

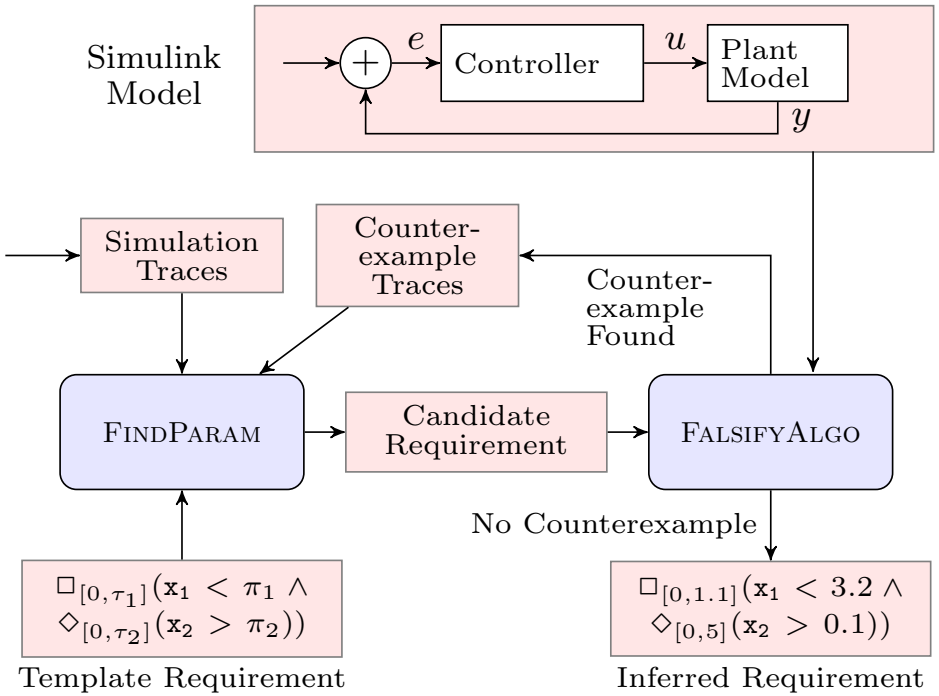
$$\Diamond_{[0,\tau_1]}(\texttt{x} < \pi_1 \ \wedge \ \square_{[0,\tau_2]}(\texttt{x} < \pi_2))$$

- "Whenever the system shifts to gear 2, it dwells in gear 2 for at least τ seconds"

$$\square\left(\left(\begin{array}{l}\texttt{gear} \neq 2 \ \wedge \\ \Diamond_{[0,\varepsilon]}\texttt{gear} = 2\end{array}\right) \Rightarrow \square_{[\varepsilon,\tau]}\texttt{gear} = 2\right)$$

Mining Algorithm

Iterative procedure alternating synthesis and falsification of candidate specifications

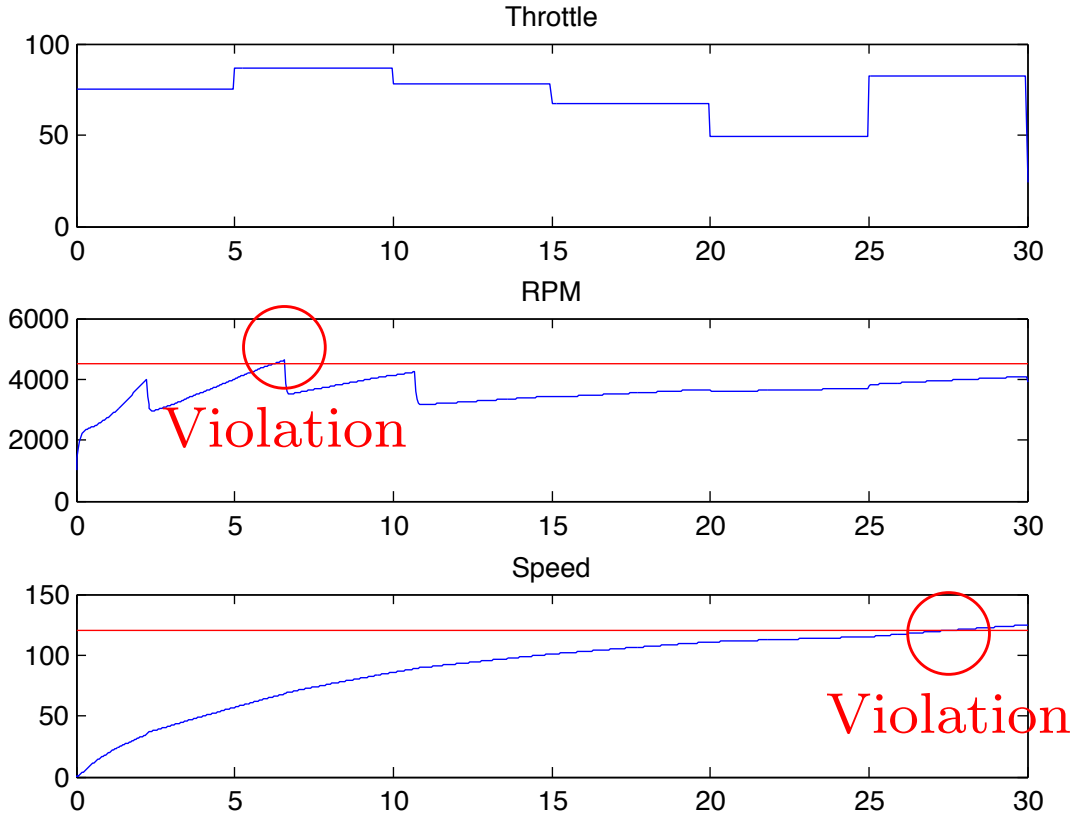


Exploits the **quantitative satisfaction** of STL formulas

$$\rho(\varphi, \mathbf{x}, t) \geq 0 \text{ iff } (\mathbf{x}, t) \models \varphi$$

Falsification of STL

Looking for an input of the system leading to a violation of candidate specifications



Minimizing of the quantitative satisfaction function over the space of input signals

$$\min_{\mathbf{u}\in\mathcal{U}} \rho(\varphi, \mathcal{S}(\mathbf{u}), 0)$$

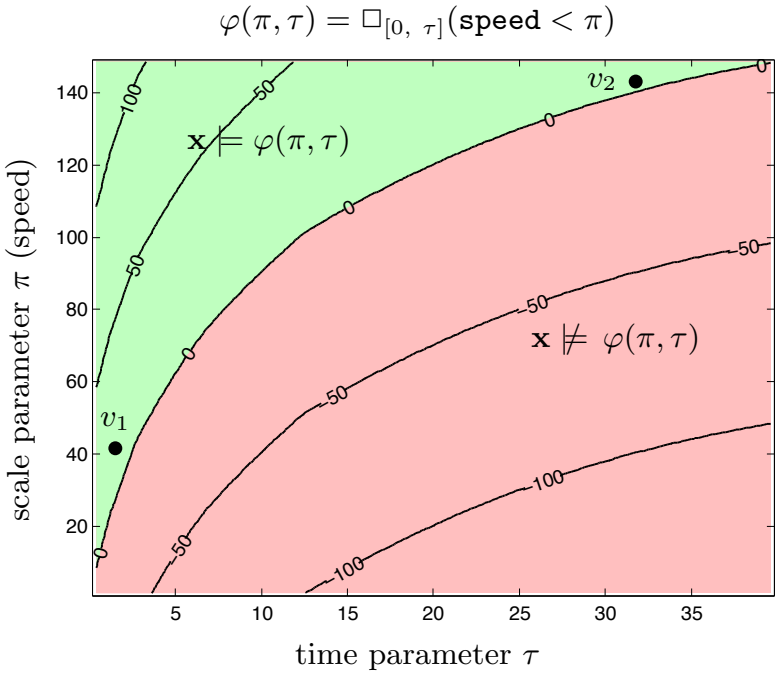
Parameter Synthesis

Looking for parameters values for a candidate specification

- Exploits monotonicity of formulas with respect to its parameters

$$\forall v, v', \mathbf{x}: \ [\mathbf{x} \models \psi(v(\tau)) \ \wedge \ v(\tau) \leq v'(\tau)] \ \Rightarrow \ \mathbf{x} \models \psi(v'(\tau))$$

- We developed an SMT-based approach to check monotonicity
  => Enables dramatically efficient binary search of parameters

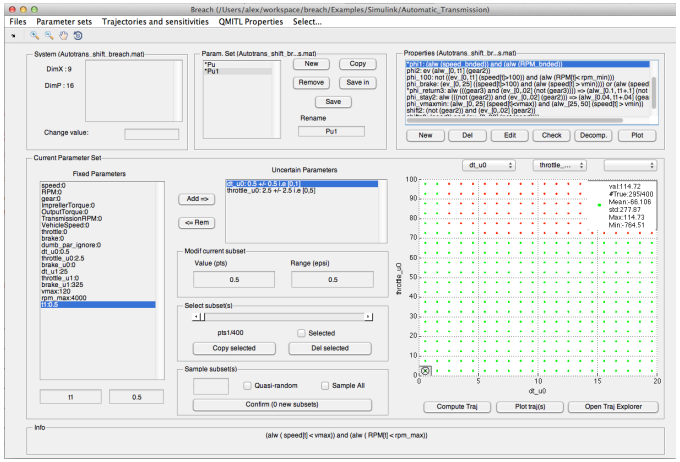


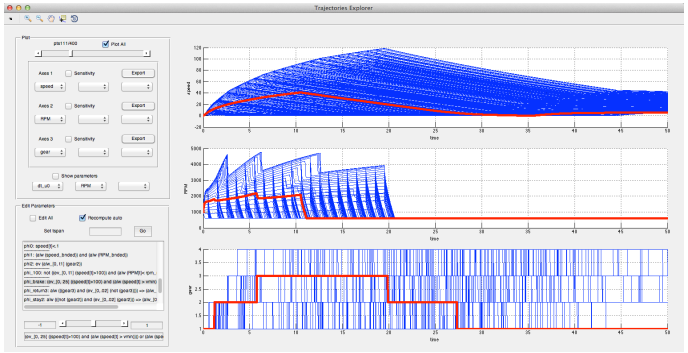
- Avoids over-conservative specifications by tightening around the satisfaction boundary

Implementation and Results

Approach implemented as an extension of Breach toolbox

- Provides Simulink models with a sophisticated test harness supporting PSTL formulas and now specification mining





- Approach validated on an industrial model from Toyota (~4000 blocks)
- We found a suspicious behavior in a closed-loop prototype model of a diesel engine and an actual bug that was causing it