Verifying Train Control Software – Using SAT-based Model Checking.

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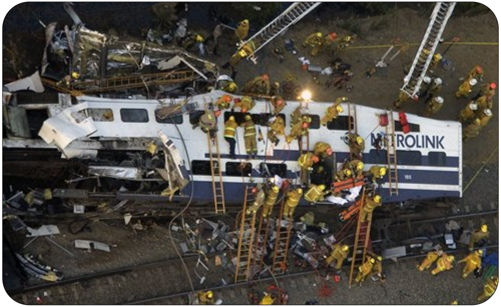
Overview

- Verification Within The Railway Domain.
- Reachable State Algorithms.
- Example Application.
- Ideas On Tackling The State Space Explosion.

Verification Within The Railway Domian

Motivation

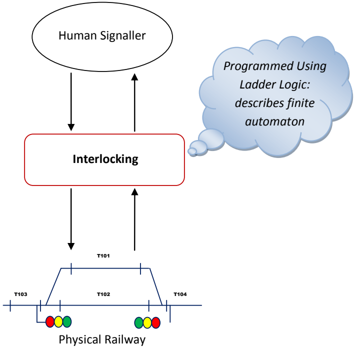
Metrolink passanger train collides with freight train.
Los Angeles – Sept 2008.



25 people killed, over 100 people injured!

Interlockings

A major system responsible for ensuring railway safety is the railway interlocking.



Programmed Using Ladder Logic: describes finite automaton

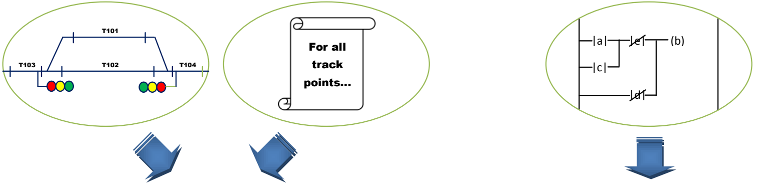
- Interlockings control aspects such as signals and points.
- Interlockings are witten using a logic language similar to propositional logic.

Railway Verification in Propositional Logic – Kanso 2008

Railway Topology

Informal Safety Condition

Interlocking Ladder Logic



$\varphi(\mu)$

Safety Condition

Initial Condition - $I(\mu)$

and **Transition Formula** - $T(\mu,\mu')$

Successful Automated Verification:

1. $\neg(I(\mu) \Rightarrow \varphi(\mu))$
2. $\neg(\varphi(\mu) \wedge T(\mu,\mu') \Rightarrow \varphi(\mu'))$

If 1 & 2 *are not satisfiable* **then output "safe"**

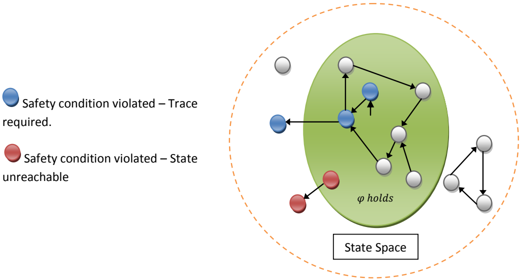
μ, μ' : *Represent system states.*

(i.e. - Valuations of propositional variables)

Problems

Problems with Kanso '08:

- Often there are violations of $\neg(\varphi(\mu) \wedge T(\mu, \mu') \rightarrow \varphi(\mu'))$ that are unrechable.



🔵 Safety condition violated – Trace required.

🔴 Safety condition violated – State unreachable

- Approach leads to many unreachable counter examples – “Not Safe” is returned when in fact program is correct.

Our Aims

Our aims:

- Devise a verification method which ignores unreachable states.
- If a counterexample is found, produce an error trace to the counterexample.
- Implement these techniques into a useable verification tool which works on real world interlockings.

Our Approach

Addressing Reachability

Forwards Reachability in K Steps – Sheeran et al

```
$i \leftarrow 0$
$B_0 \leftarrow \{\mu \mid I(\mu)\}$
do
    $B_{i+1} \leftarrow \{\mu' | T(\mu, \mu')\}$
    for $\mu \in B_{i+1}$, if $\neg(\varphi(\mu)) \in SAT$ return trace
    $i \leftarrow i + 1$
while $i \leq K$
return ”K-Safe”
```

Eliminates unreachable states problem – Only states reachable from the initial state of the system are verified.

Pelican Crossing Example

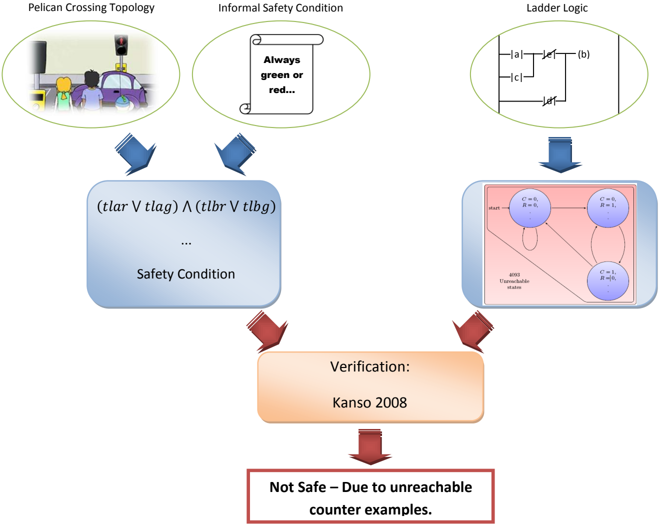
A Pelican Crossing

Specifying in Hets

Pelican Crossing Ladder Logic (Transition Formula)

```
spec Transition [State0][State1] =
  . crossing1 <=> req0 /\ not crossing0
  . req1 <=> pressed0 /\ not req0
  . tlag1 <=> not crossing1 /\ (not pressed0 \/ req1)
  . tlbg1 <=> not crossing1 /\ (not pressed0 \/ req1)
  . tlar1 <=> crossing1
  . tlbr1 <=> crossing1
  . plag1 <=> crossing1
  . plbg1 <=> crossing1
  . plar1 <=> not crossing1
  . plbr1 <=> not crossing1
  . audio1 <=> crossing1
end
```

Kanso Approach - Verification Wrongly Fails



Pelican Crossing Topology

Informal Safety Condition

Always green or red...

Ladder Logic

$(tlar \vee tlag) \wedge (tlbr \vee tlbg)$

...

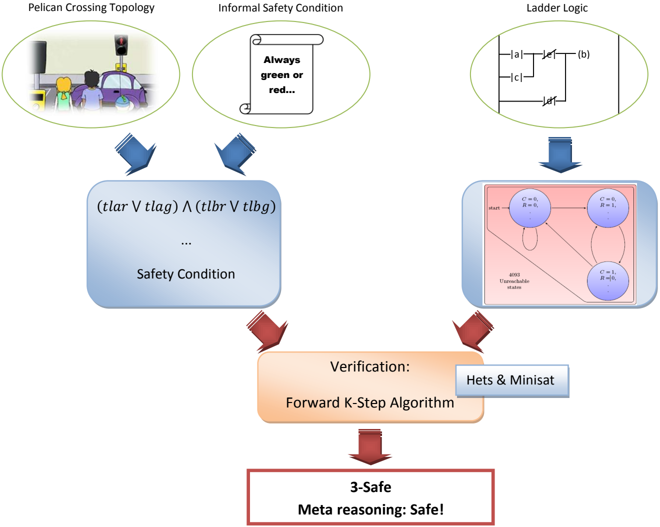
Safety Condition

Verification:

Kanso 2008

Not Safe – Due to unreachable counter examples.

Our Approach Verification Successful



Pelican Crossing Topology

Informal Safety Condition

Ladder Logic

$(tlar \lor tlag) \land (tlbr \lor tlbg)$

...

Safety Condition

Verification:

Forward K-Step Algorithm

Hets & Minisat

3-Safe

Meta reasoning: Safe!

Pelican Crossing

Tool Example.

State Space Explosion

Insights Gained

- Only a fraction of complete state space is reachable.
- This should help greatly on larger examples (2^{12} states in example, 2^{300} for interlockings).
- Possible to make whole process automatic by adding state inclusion tests.

Methods Of State Space Reduction

- Remove variables that depend on similar values.
  E.g. if $X_3, X_4 ::= \neg X_1 \wedge X_2$.
- Exclude invariants (Physical and Encoding).
  E.g. 3 valued data encoded in two bits.
- Slicing transition formula, relative to safety condition. E.g. only include parts of ladder logic that safety condition depends on.

Summary & Future Work

Forwards reachability approach works well on simple examples:

- Eliminating problem of unreachable violating states,
- Produces error traces.

We plan to...

- Implement backwards reachability algorithm.
- Explore performance on real world problems (train control).
- Study slicing methods to improve any performance issues.