# PSL in HolCheck

Thomas Tuerk

February 1st, 2006

## Overview

1. Motivation
   - HolCheck
   - *PSL*
   - Integration of *PSL* into *HolCheck*
2. Used Formalisms
   - Linear Temporal Logic (*LTL*)
   - Reset Linear Temporal Logic (*RLTL*)
   - Accellera's Property Specification Language (*PSL*)
   - Generalised Büchi Automata
3. Translation of a subset of *PSL* to Generalised Büchi Automata
4. Work
5. Conclusions

## HolCheck

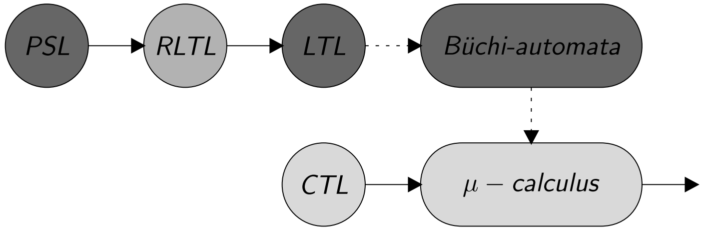
- symbolic model checker embedded in the HOL theorem prover
- all steps of the algorithm are proved in HOL
- based on *HolBdd* developed by Mike Gordon
- developed at the ARG, mainly by Hasan Amjad
- supports $\mu$-calculus and CTL

## *PSL*

- many different formalisms for specifications exists like
  - *LTL*
  - *CTL*
  - $CTL^*$
  - $\omega$-automata
  - monadic second order logics
  - $\mu$-calculus
- **Accellera's Property Specification Language** (*PSL*) is a standardised industrial-strength property specification language
  - Version 1.0: April 2003
  - Version 1.1: June 2004
- *PSL* is quite similar to *ForSpec* Temporal Logic (*FTL*) presented by Moshe Vardi last week

## Integration of *PSL* into *HolCheck*

- in my diploma thesis I formally validated a translation of a significant subset of *PSL* to generalised Büchi automata
- the emptiness problem of generalised Büchi automata remains
- this problem can be easily translated to a $\mu$-calculus formula
- *HolCheck* is able to handle $\mu$-calculus formulas




## Linear Temporal Logic (*LTL*)

- introduced by Pnueli in 1977
- essentially consists of propositional logic enriched with temporal operators **X** and $\underline{\mathbf{U}}$
- for $w : \mathbb{N} \to 2^{\mathcal{P}}$ the semantics is given by:
  - the usual semantics of propositional operators
  - $w \models p$ iff $p \in w^0$
  - $w \models \mathbf{X}\,\varphi$ iff $w^{1..} \models \varphi$
  - $w \models \varphi\,\underline{\mathbf{U}}\,\psi$ iff $\varphi$ holds on $w$ until $\psi$ holds and $\psi$ eventually holds
- additional operators are added as syntactic sugar, e. g. **G**, **F**

## Linear Temporal Logic (*LTL*) II

**Example**

The *LTL* formula

$$\mathbf{G}(\text{req} \to \mathbf{F}\,\text{ack})$$

specifies, that every request (req) has to be followed by an acknowledge (ack).

## Reset Linear Temporal Logic (*RLTL*)

- *RLTL* is an extension of *LTL* with reset operators
- these operators are used to model hardware resets
- introduced by Armoni, Bustan, Kupferman and Vardi (TACAS 2003):
  - abort in *PSL* 1.0 leads to non-elementary blowup
  - ⇒ abort changed according to *RLTL* in *PSL* 1.1
- *RLTL* is as expressive as *LTL*
- translation of *RLTL* to *LTL* known
- unsurprisingly a significant subset of *PSL* 1.1 can be translated to *RLTL*

## Reset Linear Temporal Logic (*RLTL*) II

Example

$$\mathbf{G}\Big((\mathsf{req} \rightarrow \mathbf{F}\,\mathsf{ack})\ \mathbf{ACCEPT}\ \mathsf{cancel}\Big)$$

specifies, that every request (req) has to be followed by an acknowledge (ack), unless a cancellation (cancel) occurs.

## Accellera's Property Specification Language (*PSL*)

- *PSL* is an industrial strength property specification language
- *PSL* is based on IBM's sugar and Intel's *FTL* language
- *PSL* consists of different layers and different flavours
- here only the temporal layer is considered
- the temporal layer consists of
  - the *Foundation Language*
  - the *Optional Branching Extension*, which is essentially *CTL*

## Accellera's Property Specification Language (*PSL*) II

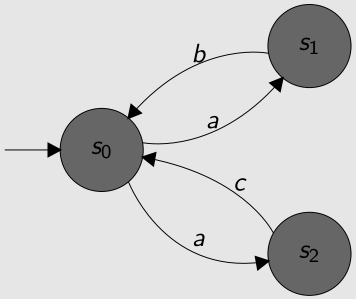
- the foundation language (*FL*) consists of
  - **linear temporal logic operators**
  - **reset operators**
  - clocking operators
  - regular expressions (*SEREs*)
  - a lot of syntactic sugar
- the semantics of *FL* consider finite and **infinite** paths
- we consider a significant subset of *FL* called *SUFL*, that consists of
  - linear temporal logic operators
  - reset operators
- we consider only infinite paths
- i. e. **we consider *FL* without regular expressions for model checking**

## Generalised Büchi Automata

- generalised Büchi automata are finite automata on infinite words
- as the input is infinite, there is no last state of a run
- thus, the acceptance condition has to be defined somehow different
- a input is accepted by a generalised Büchi automaton, iff there is a run that visits some sets of states infinitely often
- these sets of states are called *fairness constraints*

## Generalised Büchi Automata II

### Example




Initial state: $s_0$
Fairness Constraints: $\{s_1\}, \{s_2\}$

Then the given generalised Büchi automaton accepts all runs that visit $s_1$ **and** $s_2$ infinitely often

## Translation of *SUFL* to *RLTL*

- translation quite easy: replace every *PSL* operator with the corresponding *RLTL* operator
- however, correctness proof tricky
- the semantics of *SUFL* is given using special states $\top$, $\bot$
- in contrast *RLTL* uses acceptance / rejection conditions
- these concepts have to be mapped to each other
- a lot of technical problems occur

## Translation of *RLTL* to *Generalised Büchi Automata*

### Translation of *RLTL* to *LTL*

- translation given by Armoni, Bustan, Kupferman and Vardi
- consists of simple rewrite rules
- correctness proof straightforward

### Translation of *LTL* to Generalised Büchi Automata

- translation is well known
- we use a symbolic representation of $\omega$-automata
- translation can be done in linear time with respect to the size of the *LTL* formula

## Overall Model Checking Procedure

- given a kripke structure $M$ and a *SUFL* formula $f$ the problem is to check whether all paths through $M$ satisfy $f$
- translate $\neg f$ to a generalised Büchi automaton $A$
- build the product $M \times A$ of $M$ and $A$
- check whether there exists a fair path through $M \times A$
- this emptiness check can be expressed in $\mu$-calculus or in *FairCTL*
- use *HolCheck* to evaluate this $\mu$-calculus formula

## Work done in *HOL*

- we used Mike Gordon's deep embedding of *PSL*
- we deeply embedded:
  - *RLTL*
  - *LTL*
  - automaton formulas, a symbolic representation of nondeterministic $\omega$-automata
- we formally verified:
  - the translation of *PSL* to *RLTL*
  - a translation of *RLTL* to *LTL*
  - a translations of *LTL* to automaton formulas

## Current Work

- refactoring
- optimising the translation of *LTL* to automaton formulas
- translation of generalised Büchi automata to $\mu$-calculus
- implementing interfaces to *HolCheck*

## Possible Future Work

- adding *FairCTL*, $CTL^*$ and $\omega$-automata as input languages to *HolCheck*
- extending the subset of *PSL* to full *FL*
- we are already able to translate *LTL* safety properties to alternation free $\mu$-calculus
- add a specialised translation of *LTL* liveness properties to alternation free $\mu$-calculus
- ...

## Conclusions

- *PSL* is an important specification language
- *SUFL* is a significant subset of *PSL*
- we translated *SUFL* to *RLTL* and further to *LTL* and generalised Büchi automata
- we deeply embedded *LTL*, *RLTL* and automaton formulas
- we will soon be able to use *SUFL* and *LTL* as input languages for *HolCheck*