Modelchecking Non-Functional Requirements for Interface Specifications

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Software Ubiquitous in Safety Critical Systems

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Importance of Specification and Verification of rich Interfaces

Our Approach: Requirements Feedback Loop

- Feedback loop between requirements and design phases
  1. Requirements: Object-Z specification M (functional), Temporal Logic formulas ρ (non-functional)
  2. Translate to SMV: $\phi(M), \phi(\rho)$
  3. Modelcheck result (Consistency and $\phi(M) \vdash \phi(\rho)$)
  4. Use feedback for improvement of requirements and iterate

Overview

1. Background
2. Translation from Object-Z to SMV
3. Case Study TWIN-Elevator
4. Feedback Loop: Example
5. Conclusions

Specification in Object-Z

- Extension of specification language Z by objects:
  - OO-features: Classes, objects
  - Interfaces (by visibility lists)
  - Inheritance, polymorphism
- Formal specification of Interfaces in a very general way
- Full predicate calculus available to specify invariants and operations

$\Rightarrow$ Rich interfaces (for functional requirements) can be explicitly specified

$\Rightarrow$ Non-functional requirements integrated through temporal logic and feedback loop

SMV Modelchecking

ACM Turing Award Honors Founders of Automatic Verification Technology

Researchers Created Model Checking Technique for Hardware and Software Designers

- SMV is a classical Modelchecker for CTL and LTL
- SMV's input language similar to programming language (Verilog style)
- Supports simple datatypes and modules

Translation from Object-Z to SMV

- *Profit from syntactic similarities*
  - ⇒ Translation identifies: types(bool), constants, classes, instantiation
- *Watch out for semantical differences*
  - ⇒ Special: state transition, operations, operation composition

plus	minus
Δ(var)	Δ(var)
var' = var + 1	var' = var - 1

```
next(var) := var + 1;          next(var) := var - 1;
```

⇒ SMV: `"redefining var"`

Special Translation for Operations: Stimulus

In O-Z operations are offered, must be invoked by environment
Additional variable mimicks operation stimulus explicitly in SMV

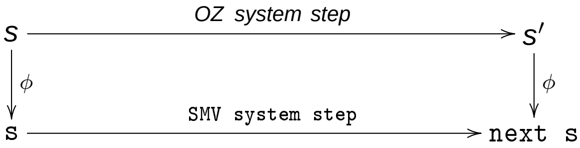
```
minus
Δ(var)
────────
var > 0
var' = var - 1
```

```
minus_pre : boolean;
minus_pre := (var > 0);
```

```
next(var) := case {
  plus_stimulus & plus_pre : var + 1;
  minus_stimulus & minus_pre : var - 1;
  default: var; };
```

Translation from Object-Z to SMV

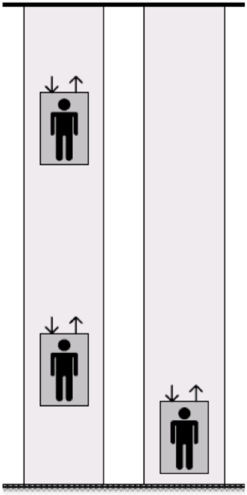
- Translation Soundness
  - Translation is a homomorphism ϕ of the boolean lattices of Object-Z and SMV
  - State change preserves ϕ: both formalism contain logical representation of "change"
    - In Object-Z: pre-state s, post-state s'
    - In SMV: pre-state `s`, post-state `next s`

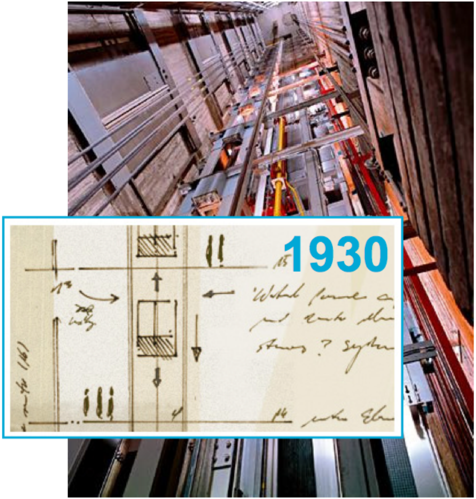


- Translation *not* complete:
  - Quantification only for finite domains
  - OO notion of self not supported by SMV modules

. . . but sufficiently practical

The TWIN Problem and ThyssenKrupp Solution





Feedback Loop: Example from TWIN

Cabin

$\upharpoonright (curr\_level)$

$curr\_level : Level$

INIT

$curr\_level = LevelGround$

MoveUp

$\Delta(curr\_level)$

$curr\_level' = curr\_level + 1$

- Example requirement: cabin's movements are restricted by boundaries shaft:

```
LevelGround ≤system.curr_level ≤ LevelTop
```

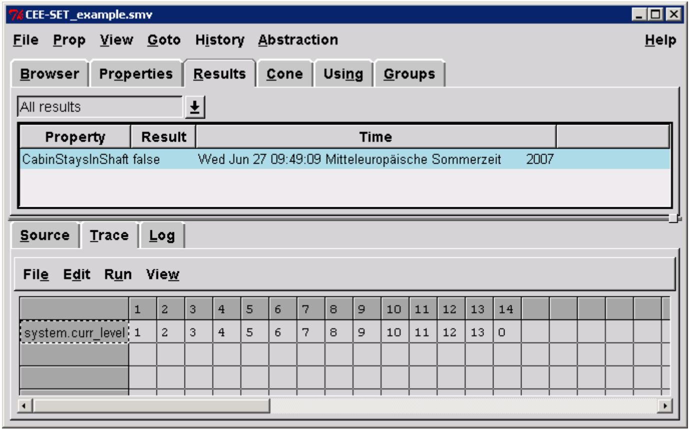
- Translation into SMV:

```
CabinStaysInShaft: assert
  G (LevelGround <= system.curr_level)
 & (system.curr_level <= LevelTop);
```

[cont'd]

Feedback Loop: Example from TWIN [cont'd]

- SMV detects violation of safety requirement:



⇒ Operation `MoveUp` responsible for illegal change of `curr_level`

⇒ Add precondition `curr_level < LevelTop`

Results of the Case Study

- All safety properties of TWIN system could be successfully verified
- Observations:
  - Feedback loop enables detection of inconsistencies
  - Specification is abstract description of interfaces reducing to behaviour relevant for safety, e.g. DSC

actual implementation of cabin selection is irrelevant

⇒ this part of the behaviour is *not* part of interface

Summary and Lessons Learned

- Summary:
  - Interface specification with Object-Z
  - Feedback loop to requirements for quality:
    - Translation to SMV
    - Modelcheck specification
  - Case study TWIN-elevator shows feasibility
- Object-Z: formal specification “traditional way”
  - Stepwise, iterated specification refinement
  - Elegant and abstract (in comparison to SMV)
  - Temporal logic together with Object-Z seems natural
  - Pragmatism of translation; so far no restriction