AIST/JAIST joint workshop on verification technology

A Toolkit for Generating and Displaying Proof Scores in the OTS/CafeOBJ Method

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Background

Formal Methods

• effective for systems are built safely and reliably.

The OTS/CafeOBJ method[Ogata 2003-]

- can model distributed systems as transition systems called OTS (Observational Transition Systems)
- can describe the system in CafeOBJ which is an algebraic specification language
- can verify that the system has invariant properties by induction on number of transition rules applied.
- easy to learn for ordinary engineers
 - based on (one-way) equational reasoning

Problem

Verification in the OTS/CafeOBJ method

Hundreds or thousands lines code

Base case

proof passage

Inductive step for Transition

Case splitting with pred. p1

Case: p1 holds

proof passage

Case: p1 doesn't hold

proof passage

Inductive step for Transitionn

- 1. We must write proof score maintaining case splitting
- 2. We must check each reduced result is the expected term (= true)
 Image: human errors may occur.
 Image: disturb humans from concentrating on intellectual work.

open ISTEP

```
op d_1 : -> D_1.
op d_2 : -> D_2.
```

```
eq p_1 = true .
```

```
eq s' = Transition1(s,...) .
red SIH implies istep(...) .
close
```

Our solution

Generating and checking proof scores

We must specify to generate proof scores:

- 1. predicate to be proven
- 2. list of predicates to be used in case splitting
- 3. list of lemmas to be strengthen induction hypothesis

mod PROOF-SCRIPT {
op $d_1 : -> D_1$.
op $d_2 : -> D_2$.
eq basecase = inv().
eq inductive = istep().
trans predicates (Transition ₁ (S)) = p_1 .
trans lemmas (Transition ₁ (S)) = inv_1 .
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CASE tool platform

We propose a CASE tool platform CafeOBJ/XML

- based on XML technology
- has a syntax corresponding to abstract syntax of CafeOBJ
- also represents proofs

Design policy of CafeOBJ/XML

- scope: describing specifications and proofs.
- makes implementing CASE tools easier.
- doesn't depend a specific programming language.

Overview of Buffet toolkit



Ex. A Mutual Exclusion

We verify that

var lock := false
l1: Remainder Section
l2: repeat until ¬(fetch&store(lock, true))
Critical Section
cs: lock := false

has the mutual exclusion property.

Modeling with OTS

Data types:

- $B = \{ true, false \}$ Boolean values
- $P = \{ p_1, p_2, ... \}$ Set of process IDs
- $L = \{ |1, |2, cs \}$ Set of location labels

Note that equivalence relation denoted by '=' for each data type have been defined.

Modeling with OTS

Universal state space: Υ set of Observers = { $o : \Upsilon \rightarrow D$ }

- $lock: \Upsilon \to B$
- $loc_p: \Upsilon \to L \text{ for } p \in P$

set of Initial states

• { $s_0 \mid lock(s_0) = false \land \forall p \in P.loc_p(s_0) = |1$ } set of **Transitions** = { $t : \Upsilon \rightarrow \Upsilon$ }

- $try_p: \Upsilon \to \Upsilon$ for $p \in P$
- enter_p : $\Upsilon \to \Upsilon$ for $p \in P$
- $leave_p: \Upsilon \to \Upsilon$ for $p \in P$

Modeling with OTS

var lock := false

I1: Remainder Section

12: repeat until

¬(fetch&store(*lock*, true))

Critical Section

cs: *lock* := false

Definition of try_p : $c_{tryp}(s) \equiv loc_p(s) = 11$ $try_p(s')$ where $c_{tryp}(s)$ holds lock(s') = lock(s) $loc_p(s') = 12$ $loc_q(s') = loc_p(s)$ if $p \neq q$ where $c_{tryp}(s)$ doesn't holds

nothing changes

Invariants

Execution sequence {*s*₀, *s*₁, ... } satisfies:

- *s*⁰ is in the set of initial states
- there exists a transition for each pair of (s_i, s_{i+1})

Reachability

• State *s* is *reachable*: there exists an execution sequence of an OTS in which *s* appears.

Invariants

- A predicate *p* such that *p*(*s*) holds for every reachable state *s*.
- In the ex., $\forall i, j \in P.loc(s, i) = cs \land loc(s, j) = cs \Rightarrow i = j$

Describing invariant

Invariant candidates are described:

mod INV { pr(OTS-SPEC)

op inv_1 : Υ ... -> Bool op inv_2 : Υ ... -> Bool

eq $inv_1(S: \Upsilon, ...) = ...$ eq $inv_2(S: \Upsilon, ...) = ...$ Signatures of invariants

Invariants denoted by CafeOBJ term

```
mod ISTEP { pr(INV)
ops s s' : -> Y
op istep<sub>1</sub> : ... -> Bool
op istep<sub>2</sub> : ... -> Bool
```

eq $istep_1(...) = inv_1(s,...)$ implies $inv_1(s',...)$. Terms denoting reasonings eq $istep_2(...) = inv_2(s,...)$ implies $inv_2(s',...)$. in the inductive step

Buffet server

Buffet server relays requests/responses bespecemodlient to the CafeOBI system

• we can inv mod already get the information of Gateau defined/loaded CafeOBJ specification from the CafeOBJ output

- but, it's fragmentary proof.xml
- Buffet server reconstructs the information in an XMP document

Proof Score Presenter

feedback

output		
proof html		

h	tt	n
• •	ce	μ

Buffet Server
IPC
CafeOBJ

Gateau



How to gen. proof score





There are 7 cases, 3 cases need human's help.

▶ base	Hierarchical view
 action: try 	with disclosing triangle
case splitting: c-trv(s. pid1)	
<pre>v case: true open ISTEP arbitrary objects: op pid1 : -> Pid . assumptions: eq (loc(s,pid1)) = (l1) . eq (s') = (try(s,pid1)) . reduce the following term: red istep1(i, j) . close</pre>	Displaying the part of proof scores for which further case analysis should be done and/or lemmas should be used
<pre>result. ((((if (pid1 = i) then 12 else loc(s,i) else loc(s,j) fi) = cs)) and ((loc(s,i) xor ((((if (pid1 = i) then 12 else loc(s,i) else loc(s,j) fi) = cs)) and (((loc(s,i) j)))</pre>	<pre>fi) = cs) and ((if (pid1 = j) then 12 = cs) and (loc(s,j) = cs))) fi) = cs) and ((if (pid1 = j) then 12 = cs) and (loc(s,j) = cs)) and (i =</pre>
<pre>xor (((if (pid1 = i) then 12 else loc(s,i) f else loc(s,j) fi) = cs))</pre>	i) = cs) and ((if (pid1 = j) then 12
<pre>xor (((if (pid1 = i) then 12 else loc(s,i) f else loc(s,j) fi) = cs) and (i = j)))</pre>	i) = cs) and (((if (pid1 = j) then 12
xor true	
► case: false A hidden part of p	proof scores

▼ action: enter

```
case splitting: c-enter(s, pid1)
```

🔻 case: true

Other case studies

Otway-Rees authentication protocol

- 1 secrecy property (48 cases)
- 3 lemmas (36-37 cases)

NSLPK authentication protocol

- 1 secrecy property (37 cases)
- 6 lemmas (24-65 cases)

Conclusion

We have implemented the Buffet toolkit

- can generate & check proof scores automatically
 - generated proof scores cover all cases
 - success of proofs depends on given predicates and lemmas
- can display proof scores hierarchically
 - provided views helps the verification
- can be applied including non-trivial problems
 - Simple mutual exclusion
 - NSLPK, and Otway-Rees authentication protocols

Implemented tools

Buffet Server (1,200 lines, in Perl) Gateau (800 lines, in Perl) Proof Score Presenter (600 lines, in XSLT) Eclipse plug-ins (working)

- CafeOBJ Editor (300 lines, in Java)
- Proof Score Viewer (400 lines, in Java)
 - the final goal will be an Interactive Editor for Proof Score

Cafe2Maude (by Kong-san, in Java)

Future plan

Integrating Eclipse

- GUI based implementation (Gateau & PSP)
 - more interactive

More tightly integrating Eclipse

- Test Driven Development
 - Test case generation from proof scores

Demonstration