Model Checking Project Report – 2023/01/08

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Contents zip: 8 SMT files (one per bug) and report (**command: z3 solution[1-8]\_name\_of\_bug.smt**)

Contents report: 1) main report, 2) results, 3) limitations, 4) potential improvements

1. Report

**Literature** used: The SMT-LIB Standard Version 2.5 (2015), Barret, Fontaine, Tinelli

Both teammembers were new to SMT (and CBMC) and took a while to re-do Assignment 1.2, the simple SMT verification, as preparation for this project. Still, it would not have been possible for us to arrive at a solution from scratch, so **we needed to draw from the tutorial session SMT code substantially to be able to make a hand-in** at all: this is commented in the code as well, as we absolutely do not intend to plagiarize without due attribution.

That said, with this basis, we did rework the code and restructured a bit, so as to best match our own understanding of how these model checking tools are used.

Our first step was to draw the state transitions and check manually (looking at the code) if the state numbering is coherent in buggy05.c. This involved figuring out how state is encoded, in our case:

// new\_keypad(pin) returns a keypad data structure in the Locked state with 0 attempts and stored PIN `pin`

keypad new\_keypad(uint32\_t pin) {

// creates a new keypad with the input PIN

    keypad kp = {pin, {0, 0, 0, 0, 0, 1}};

    return kp;

}

We were able to deduce from the code that the state is encoded in the last array item. The first array item holds the index of the current digit being read.

**Diagram

Description automatically generated**The numbering in the drawing is the state according to this array and matches the program specification as far as we can see without model checking.

Our **assumptions**: Character-reading (Character to PIN conversion) and ASCII-arithmetic work as expected. (We do not encode the specifics in SMT).

Our **basic approach**: we know from the project description that our code contains one of eight bugs (b). So we adapt the SMT to follow the implementation (I) and encode the bugs one at a time. This leads to eight SMT files.

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Together with the specification, the implementation and the bug must hold true. Our **expectation** is therefore one sat execution and seven unsats.

After some discussion, we are thinking of the bug as a specification encoding, deciding to encode the positive of the bug as part of the specification points.

Some more tweaks to our SMT: the comment about 30 keypresses might imply 30 individual keys including digits, but we interpret a keypress as either A, C, a full (4 digit), a partial (less than 4) entry, to be safe (the number of actual presses will be larger, most likely).

Difficulties: Understanding this part

(assert (and

    (<= start failure)

    (<= failure end)

    (not (= (is\_open failure) (impl\_is\_open failure)))))

We realized we need this part because it encode the fundamental flaw of the program (f):

Graphical user interface, text, application, Word

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In other words, this is our basic **countermodel** (failure (state!) is open/closed according to specification, but implementation is closed/open, i.e. the other one).

To keep track of smt correspondences in the code, here is a mapping of Implementation and Specification smt function mappings to C code. To be completely transparent, we note where we edited to the smt relative to the tutorial reference.

**Implementation:**

Impl\_partial\_pin -> cancel\_key() \***not** edited, i.e. same for buggy.c and buggy05.c

Impl\_correct\_pin -> digit\_key(), specifically

if (index == 4) {

if(kp->state[5] == 0) {

kp->pin = input;

**kp->state[5] = 1; 🡨**

} else if (kp->pin == input) {

kp->state[5] = 0;

} else {

kp->state[5] += 1;

}

kp->state[0] = 0;

}

Inside digit\_key() **\*edited**, the first two branches are encoded

Impl\_wrong\_pin -> digit\_key():

if(kp->state[5] == 0) {

kp->pin = input;

kp->state[5] = 1;

} else if (kp->pin == input) {

kp->state[5] = 0;

} else {

kp->state[5] += 1;

}

**\*edited:** the last branch triggers, but it is the same edit as above (first branch)

Impl\_accept 🡪accept\_key() \*not edited

Impl\_skip 🡪 digit\_key(), in the case if (kp->state <= 4) and not if (kp->nread == 4), so nothing happens.

**Specification** (mapping, SMT -> spec. point): Again, this part is largely taken from the tutorial smt reference code! We want to be completely transparent about this.

(define-fun partial\_pin\_locked\_or\_unlocked ((i Int)) Bool (=>

    (and

        ((\_ is partialpin) (keypresses i))

        (or ((\_ is locked) (keypadstate i)) ((\_ is unlocked) (keypadstate i))))

    (= (keypadstate (+ i 1)) (keypadstate i))))





(define-fun correct\_pin\_locked ((i Int)) Bool (=>

    (and

        ((\_ is correctpin) (keypresses i))

        ((\_ is locked) (keypadstate i)))

    (= (keypadstate (+ i 1)) unlocked)))

Text

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(define-fun wrong\_pin\_locked ((i Int)) Bool (=>

    (and

        ((\_ is wrongpin) (keypresses i))

        ((\_ is locked) (keypadstate i)))

    (and

        (=> (< (attempts (keypadstate i)) 2)

            (= (keypadstate (+ i 1)) (locked (+ (attempts (keypadstate i)) 1))))

        (=> (>= (attempts (keypadstate i)) 2)

            (= (keypadstate (+ i 1)) blocked)))))

Table

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(define-fun complete\_pin\_unlocked ((i Int)) Bool (=>

    (and

        (or ((\_ is correctpin) (keypresses i)) ((\_ is wrongpin) (keypresses i)))

        ((\_ is unlocked) (keypadstate i)))

    (= (keypadstate (+ i 1)) (locked 0))))

Text

Description automatically generated

Note: a new pin is either the old pin or another pin (incorrect relative to the previously correct pin.

(define-fun open\_unlocked ((i Int)) Bool (=>

    (and

        ((\_ is accept) (keypresses i))

        ((\_ is unlocked) (keypadstate i)))

    (= (keypadstate (+ i 1)) open)))



(define-fun keypress\_open ((i Int)) Bool (=>

    ((\_ is open) (keypadstate i))

    (and

        (=> ((\_ is partialpin) (keypresses i))

            (= (keypadstate (+ i 1)) (locked 0)))

        (=> (not ((\_ is partialpin) (keypresses i)))

            (= (keypadstate (+ i 1)) (keypadstate i))))))



(define-fun keypress\_blocked ((i Int)) Bool (=>

    ((\_ is blocked) (keypadstate i))

    (= (keypadstate (+ i 1)) blocked)))



**This part ist edited -** Reference Code:

(define-fun ignore\_accept ((i Int)) Bool (=>

    (and

        ((\_ is accept) (keypresses i))

        (not ((\_ is open) (keypadstate i))))

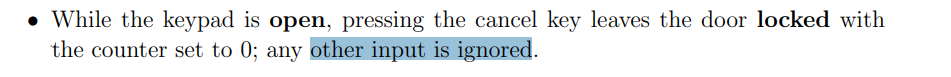
    (= (keypadstate (+ i 1)) (keypadstate i))))

I.e. accept is ignored unless in state open. But we saw: while for blocked and locked this is true, in unlocked, we also have an effect of accept. See the third specification point that follows:









The code becomes:

(define-fun ignore\_accept ((i Int)) Bool (=>

    (and

        ((\_ is accept) (keypresses i))

        (not ((\_ is unlocked) (keypadstate i)))) ; edited: now unlocked, was open

    (= (keypadstate (+ i 1)) (keypadstate i))))

Finally, for the specification:

(define-fun ignore\_skip ((i Int)) Bool (=>

    ((\_ is skip) (keypresses i))

    (= (keypadstate (+ i 1)) (keypadstate i))))

We were a bit unsure, actually, which part is implemented, but left it untouched.

1. Results

Based on our bug specifications (with the same implementation across the eight SMT files), we are ruling out those models that return unsat. We include all the files in the .zip with this report. Our unsat models were, according to the bugs numbered 1 through 8, where some of the bugs were not encoded (see limitations).

* 6 (Currently our only unsat)

1. Limitations

Overall: We did not arrive at just one unsat result, which leads us to believe that our level of simplification/abstraction is not optimal.

1. Potential improvements

One idea we had is: Encoding attempts as states, rewriting specification and implementation with regards to attempts as well. Attempts are currently checked with valid\_state (function), but maybe attempts-manipulation (transition) needs to be covered in the encoding as well, not just the snapshot of the validity.