CS 6110, Spring 2022, Assignment 5

Given 2/22/22 – Due 3/3/22 by 11:59 pm via your Github

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CHANGES: Please look for lines beginning with underlined words when they are made. none yet.

Answering, Submission: Have these on your private Github: a folder Asg4/ containing your submission, which in detail comprises:

- A clear README.md describing your files.
- Files that you ran + documentation (can be integrated in one place).
- A high level summary of your cool findings + insights + learning – briefly reported in a nicely bulletted fashion in your PDF submission.

Start Early, Ask Often! Orientation videos and further help will be available (drop a note anytime on Piazza for help).

I encourage students constructing answers jointly! *But that does not mean copy solutions, but discuss the question plus surrounding issues.*

1. (10 points) Read and summarize Jackson's article on Alloy from `https://cacm.acm.org/magazines/2019/9/238969-alloy/fulltext#R1` in exactly two pages. Please capture all the details highlighted there. Try to write a good summary for your own understanding! You may include a few diagrams in your 2-pager (hence, revised this question to "2 pages"). Note: here is an embedded video on this page that is very helpful!

   Video:

   • Daniel Jackson, ACM, 2019.

   • Video example, browser security mechanism in Alloy and Alloy analyzer.

   • Introduces signature for endpoints and HTTP events.

   • Jackson shows abstract signatures and signatures that extend them to show how the events and endpoints can be abstracted.

   • They add structure to the clients and servers to makes sure that the requests and responses come from servers and go to client.

   • They add constraints to the model to try and make it work like we expect HTTP request to behave

   • They add a check to see if the HTTP request flow makes sense. It doesn't so they update the models to encode the information that they want to show.

   • They look at the core of the problem in alloy to see which constraints are pertinent to the check that's performed. The check only really looks at 4 lines to make sure that the assertion holds.

   • The video ends with a more complex example that seems to come from the alloy repo of examples.

   Article:

   • Software needs to be expressed as a model so that it can be checked against preconceived notions.

• The current popular approach to this is unit testing, but that comes with difficulties.

• These difficulties include writing tests for all possible cases, and getting bogged down in low level details that are not so consequential.

• Model checking allows for partial checking, instead of unit and integration testing that require the entire logic to be in place before it can be tested.

• Model checking also allows for exploring the entire state space so you ensure there are no blindspots in the testing.

• Model checkers come from a history of mathematical theorem provers.

• Theorem provers required lots of manual intervention and a knowledge-able operator. They also can't provide counter-examples so they have limited utility.

• Model checkers are the solution to these problems in that they don't require as much skill to code properly and they are able to give useful information to the operators. They show counter-examples when something fails.

• Model checkers are susceptible to state explosion.

• Early model checkers worked best on hardware since they had primitive state storage and couldn't support trees, etc.

• SPIN was a more robust software with better state representations, but didn't deal with temporal models well. It also had issues when searching for reachability, since coding that would be tricky.

• Alloy's differentiation comes down to three things: relational logic, small scope analysis, and translation to SAT.

• Relational logic combines first order logic with some set theory and relational calculus.

• Alloy's key operator is the relational join, as we've seen. It's the dot syntax to follow relations.

• Under the hood alloy uses sets to accomplish this joining, which doesn't pin to any specific number of elements to return.

• Using small scope analysis allows Alloy to explore the entire space up to a certain size. This gives a guarantee for everything up to that size, but says nothing of the larger examples. This has pros and cons.

• Converting the problem to a SAT problem allows for alloy to find counterexamples quickly, while not exploring the entire state space. This saves time and makes many problems actually analyze-able.

• The paper then discusses the problem from the video, cross site request forgery.

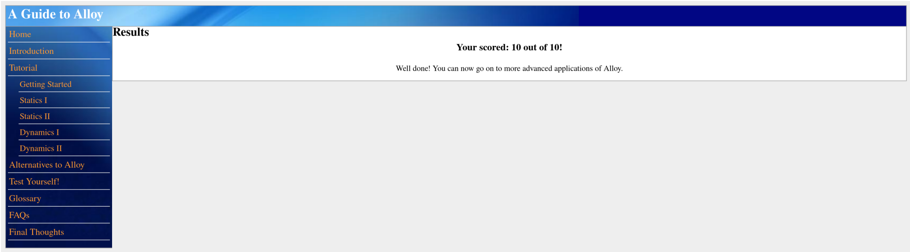
• They walk through the same issues in the video and talk about how Alloy is able to show it with the signatures, checks, assertions, etc. I'll not repeat their analysis

• They finish by stating where Alloy would be useful. It seems to be the same as most other checkers: mission critical software/hardware, and security applications.

• Apparently Alloy has some extensions for temporal logic, higher order solving, numerics, etc.

2. (25 points) Take the tutorial on `https://www.doc.ic.ac.uk/project/examples/2007/271j/suprema_on_alloy/Web/index.php` and take the assessment questionnaire at the end! Try to score a perfect score (it gives you hints and retry opportunities). *Record that you did the above in about two pages – capture screenshots, sessions, etc, convincing me that you took the assessment.* Report your assessment score as a screenshot! (Get a perfect 10/10.)

   I took the assessment at the link:

3. (40 points) First, deep-read the Alloy “Red book” linked on the class website from the beginning till Page 80. Summarize the concepts you find on these pages in four pages. *I want to see a good summary.*

   Then do the work below. Three models for trees are below (these are from `https://stackoverflow.com/questions/41707898/is-there-a-better-alloy-model-of-a-tree`). I saw the beginnings of Costello’s tree solution (which Daniel Jackson, author of Alloy, improves upon) and wrote my own solution. Thus, there are three tree models below. Study them and do the problems stated below them:

```
/*-- BEGIN: common to all three tree definitions --*/

sig Node {
  tree: set Node
}

one sig root extends Node {} // root is a subset of Node

/*-- END : common to all three tree definitions --*/

pred GGTree{
 no n : Node | root in n.^tree // Q-1
 --
 no n : Node | n in n.^tree    // Q-2
 --
 all n : Node - root | n in root.^tree // Q-3
 --
 all n : Node |
 all disj n1, n2 : n.tree |    // Q-4
   no (n1.*tree & n2.*tree)
}
```

   Q-1,2: Express what these definitions are saying, in English. Why can’t these definitions use ∗? What happens if you do that? Generate a few tree instances (models) and show what happens if you use ∗ for Q-1 and Q-2?. *To generate instances,* you must remove the "pred" temporarily, and express its contents as signature facts. This is what you would be doing initially in your work on creating a model, anyhow. Then follow such a modified definition with a `run {} for 3`, or `run {} for exactly 10 node` or similar notations (consult the “Red” Alloy book mentioned on the class website for details). Then execute, and the “run” gives you the instances I’m looking for.

   Q-3: Express what this definition is saying, in English. Why do we need `Node - root`? Why can’t you use `Node` here? Again show by generating instances saying what happens if you do that.

   Q-4: What is this saying in English? What happens if you leave out `disj`? Show by generating some instances.

   - Now put the `pred` definitions back. So you have three "pred" definitions as presented below.

```
pred GGTree{
 no n : Node | root in n.^tree
 --
 no n : Node | n in n.^tree
```

```
 --
 all n : Node - root | n in root.^tree
 --
 all n : Node |
 all disj n1, n2 : n.tree |
   no (n1.*tree & n2.*tree)
}


pred DJTree {
    Node in root.*tree // all reachable
    no iden & ^tree // no cycles
    tree in  Node lone -> Node // Q-5
    }

pred CostelloTree {
    // No node above root (no node maps to root)
    no tree.root
    // Can reach all nodes from root
    all n: Node - root | n in root.^tree
    // No node maps to itself (irreflexive)
    no iden & tree
    // No cycles
    no n: Node | Node in n.^tree
    // All nodes are distinct (injective)
    tree.~tree in iden -- need this
}
```

Explain the line tagged Q-5, above. You will find the constraints of signatures explained in the “Red” book. Look around Page 78, Section 3.6.3.

The goal is to show the equivalences below:

(a) Issue `check {GGTree iff DJTree} for 5` and see if the definitions are equivalent.

(b) Just break the Q-1 to have $*$ and not the correct `^`. Do the “`iff`” check above. Do you get an understandable counterexample? Describe it.

(c) Issue `check {CostelloTree iff DJTree} for 5` and see if the definitions are equivalent.

Here’s the start of the 4 pages of notes:

Q1 states that there is no node such that the root is reachable from that node. Basically, that the root is not a child of a node in the tree.

Q2 states that there is no node such that itself is reachable in the tree. No node is a child of itself.

We can’t use * in these definitions, because that gives us the reflexive-transitive closure. That’s a symmetric relationship and we’re using the directionality of the edges to encode the properties we care about.

Q3 states that for all nodes that are not the root, n is reachable from the root using the tree relationship. You can’t use just Node here, because the root doesn’t necessarily need to be reachable from the root. If the root is there, there will likely be a cycle from the root back to the root through the nodes.

Q4 states that for all disjoint nodes that are reachable from any other node, there are no nodes that are reachable from both children. This means that the children only live on one branch of the tree and that the branches don't merge.

Q5 states that each node has at most 1 parent.

a) Yes, it passes for size 5.

b) The trees looked okay to me, but maybe some of the nodes are not reachable or are not descended from the root.

c) Yes, CostelloTree iff DJTree holds for size 5.

4. (25 points) Write your own quicksort in C for a character array of 5 (five) locations, and subject it to KLEE tests, as illustrated in Lecture 13. Write a bug-free version. Then put one bug that does not sort correctly. Put an assertion at the end for a mis-sorted outcome. Hit that assertion using a KLEE-test.

```
quicksort.c gives:
KLEE: Using STP solver backend

KLEE: done: total instructions = 74140
KLEE: done: completed paths = 274
KLEE: done: generated tests = 274

For buggy quicksort, I just commented out the sort since that has the same effect as yo
buggy-quicksort.c gives:
KLEE: Using STP solver backend
KLEE: ERROR: /tmp/code/code.c:61: ASSERTION FAIL: is_sorted()
KLEE: NOTE: now ignoring this error at this location

KLEE: done: total instructions = 119
KLEE: done: completed paths = 5
KLEE: done: generated tests = 2

Failed tests:

Assertion fail on line 61.

assert(is_sorted());
```

Piazza posting:

```
PIAZZA posting:

I changed 8 to 5 in the HW specification (with 5 itself, it generates 120 tests).
With 8, it takes forever. Why torture you?

Also try and remove printf etc before generating tests.

One can write a script to automatically run for all the synthesized tests.

For "breaking" qsort, you can do it in a certain way (to make our life easy,
I'll suggest one):

1) make the pivot = the first element of the incoming array

2) Write a broken qsort by checking the pivot first. If the pivot is < 5 (say),
break the qsort (let it return w/o sorting). For >= 5, make the qsort sort the array
```

3) Try it and keep telling me what you find out.

This shows that symbolic execution of C is not "that free" - yet highly automated.
Also I’ll read-up on how to declare larger arrays and maybe make the elements selectively symbolic (only some symbolic).

Ganesh