Review of
Model Checking Large Network
Protocol Implementations

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What problem did the paper address?

Big Picture Problem
Proving correctness of communication protocols used in the Internet

Specific Problem
Verify large network protocol implementations
  • Verify Transmission Control Protocol (TCP) in Linux Kernel

Why is it hard?
Protocol specification could be wrong!
Explosive state space
  • Consider lost packets, re-transmitted packets, reordered packets, timeouts
  • Many More …
Why should we care?

• **Everyone uses the Internet**
  – Online business (e-commerce)
  – Home computing
  – Education
• Incorrect network protocols are harmful!
  – Loss of business (money)
  – Loss of human resources (time)
• User expectations:
  – “Is my network protocol correct?”
  – “Is my transport protocol inefficient?”
  – “Is my network protocol implementations vulnerable to attacks?”
• Network protocols should be correct

Approach: Model Checking

• Prove protocol correctness using formal verification techniques
  – A *model* of the protocol
    • Protocol implementation (ex: TCP in Linux)
  – A set of *correctness properties* (i.e., the formal *specification*)
    • Expressed as Linear Temporal Logic (LTL) formulas

• “Do the correctness properties satisfy for all possible executions of the protocol?”
Model Checking Example

Process main() {
    in = 0;
    a = 0;
    concurrent {
        inc(); dec();
    }
}

Process inc() {
    while (in != 0) {
        skip;
    }
    if (in == 0) {
        in = 1;
        a++;
        in = 0;
    }
}

Process dec() {
    while (in != 0) {
        skip;
    }
    if (in == 0) {
        in = 1;
        a--;
        in = 0;
    }
}

• What are the possible values taken by $a$?
• More specifically, what are the values taken by $in$?
• LTL formula: $\Box p$, where $p$ is $(in \equiv 0 \lor in \equiv 1)$, and $\Box$ means “always” in LTL grammar

This reads, “at all times in the execution of the program, $in$ is either 0 or 1”

Is this true for the above program?

Model Checking Tool

State: The values of variables (globals, locals etc) at a program point

State transition: A possible execution that results in a state change

Algorithm:
1. Start from the initial state $S_0$
2. Execute a state transition
   • Generates new states
3. Add new states to queue
   • Ignore redundant states (using hash)
4. Check if correctness property holds at that point
   • If property does not hold $\rightarrow$ report error
5. Enable (one of) unexplored state from queue
6. Repeat from step 2, until
   • No more resources left, or
   • All states are explored
The C Model Checker

- The C Model Checker (CMC)
  - Backtracking network simulator
  - Works directly on the implementation of the protocol written in C
- Optimized to handle large network protocols
  - Handles large states
    - Hash compaction algorithm
    - Incremental state processing
  - Handles state space explosion problem
    - Incremental heap canonicalization
    - Heuristic based exploration of “interesting” protocol behavior

Conclusions

- Model checking large network protocols possible with CMC
- Linux TCP implementation has 4 bugs!
- TCP specification is ambiguous
- CMC achieves large protocol coverage (92% combined coverage for Linux TCP implementation)
Critique

• Probably the first attempt to model check TCP
• Results are impressive,
  – 4 bugs in Linux TCP
  – 92% protocol coverage
• Assumes the user is aware of a lot of background in model checking
• Should have specified at least a few correctness properties for TCP
• Does not demonstrate the effort needed to model check a protocol

Relation to CS653

• I care 😊
  – Our project is all about model checking network protocols
• Model checking is a form of program analysis (for debugging programs)
• Demonstrates program analysis for nondeterministic systems
  – So far we looked at static program analysis for deterministic systems