Paul E. McKenney, IBM Distinguished Engineer, Linux Technology Center
Member, IBM Academy of Technology
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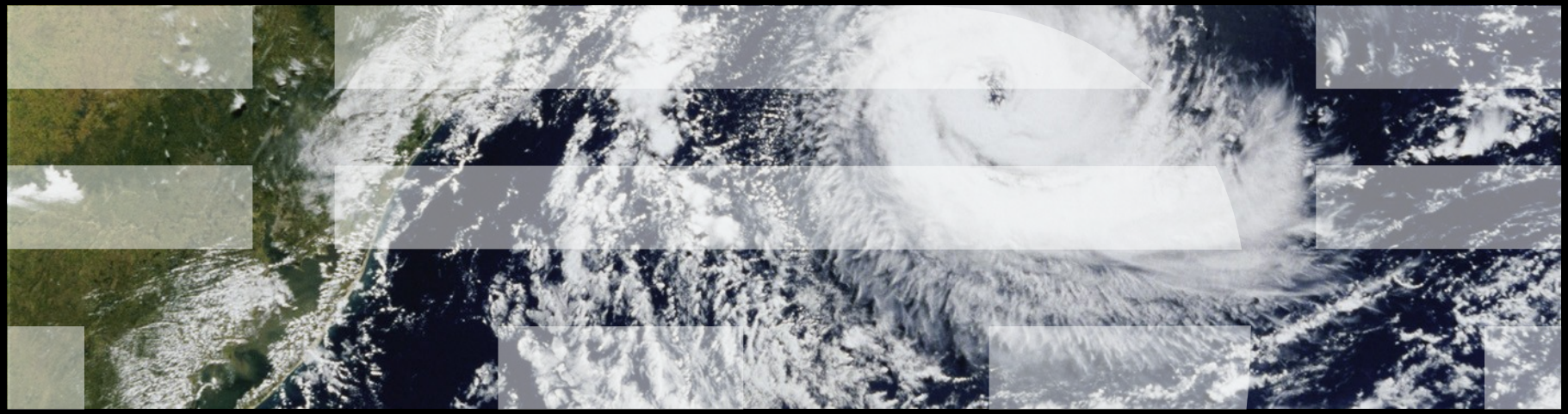
Mutation Testing and RCU

Joint work with Iftekhar Ahmed, Alex Groce, and Carlos Jensen of Oregon State University



Motivation

- More than a billion instances of the Linux kernel running
- Yay, we have won!!! But...
- A million-year race-condition bug is happening three times a day across the installed base
- We need to up our validation game...
- Part of this new game might be mutation testing

What is Mutation Testing?

- Mutate the code to see if testing catches it
  - Delete lines
  - Change constants
  - Change operators
  - Negate conditionals
- Generate a separate source file for each mutation
  - Thousands of mutants for RCU
  - Long test time, also need manual analysis of the cases that don't fail
    - Should the test have caught it, and if so, how to fix the test?

Replacing a Constant

- In data declaration:
  - /* MUTANT (rep_const) */ .level = { &sname##_state.node[1] },
  - Was zero... Test catches this one.
- Some have no effect:
  - /* MUTANT (rep_const) */ while (2) {
  - Skip testing things that generate identical binary to original
- Some have no effect in more complicated ways:
  - /* MUTANT (rep_const) */ return 2;
  - Manual inspection required, perhaps use compiler tricks later
- Some have no effect in *really* complicated ways:
  - /* MUTANT (rep_const) */ .gpnum = 0UL - -1UL,

Advantages and Disadvantages of Mutation Testing

- No specification required
  - Which is a good thing, because an RCU specification would be as big and as buggy as the Linux-kernel RCU implementation
- Another way to put this: Mutation testing leverages the specification implicit in the compiler, the assertions, and rcutorture
- Some mutants introduce low-probability race condition
  - Extreme runtimes for those cases
- Some mutants require significant manual analysis
  - That would be me...

Mutation Testing Strategy

- Discard uninteresting mutants as quickly as possible
- Generated 3393 mutants for Tiny RCU
  - Resulted in 3394 kernel compilations
- Narrowed search field:
  - 378 failed to compile
  - 321 generated same binary as original
  - 746 generated same binary as some other mutant
- 2339 mutants remaining (69% of total)
  - 2180 failed running rcutorture on two-CPU x86 for two minutes
- 159 required manual analysis (4.68% or total)
  - That wouild be me...

Result of Manual Analysis

- Patch 1: Update rcutorture to cover SRCU cleanup path
- Patch 2: Make rcutorture test Tiny RCU-bh
- Patch 3: Fix Tiny RCU callback list bug
  - Bug detected by running with Patch 2

- So mutation testing has had some good results
- Next step: Try it on Tree RCU

Preliminary Results From Tree RCU Mutants

- Seven potential rcutorture improvements:
  - Ensure callback lists are non-empty when CPU goes offline
    - (Though I suspect that callback flooding does this.)
  - Enhance rcutorture to detect performance and realtime degradations
    - (But rcutorture intentionally does many degrading things.)
  - Review rcutorture's RCU priority boost testing
  - Invoke call_rcu() from an idle CPU when torture testing
  - Sometimes invoke call_rcu() with interrupts disabled
  - Come up with some way to test counter-wrap conditions
    - (Could be tough... Shrink counters to eight bits?)
  - Add scenarios that adjust rcu_fanout_leaf to cover more boot code
- Stats and overview TBD

What is Next?

- Actually do some of the rcutorture improvements
- Heavier-duty torture testing of mutants
- Introduce parallel testing to speed up the process
  - Running 16 rcutorture scenarios a few thousand times each does not happen overnight...
- Improved automated detection of uninteresting mutants
- Add additional classes of mutants

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Questions?