Fuzzing for Race bug detection

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- Fuzzing has been very successful in detecting memory corruption bugs. Applying fuzzing for data race bugs is interesting!
- We will be discussing a recent article:
  - D. R. Jeong, K. Kim, B. Shivakumar, B. Lee and I. Shin, "*Razzer: Finding Kernel Race Bugs through Fuzzing,*" 2019 IEEE Symposium on Security and Privacy (SP), San Francisco, CA, USA, 2019, pp. 754-768, doi: 10.1109/SP.2019.00017.
  - https://lifeasageek.github.io/papers/jeong-razzer.pdf
  - Read the paper up to Section III. You can skip low-level implementation details in the subsection III.B **Per-Core Scheduler in Hypervisor**

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- Concurrency bugs are caused by non-deterministic interleavings between shared memory accesses.
- Their effects propagate through data and control dependencies until they cause software to crash, hang, produce incorrect output, etc
- Interleavings are not only complicated to reason about, but they also dramatically increase the state space of software.

Common Concurrency bugs

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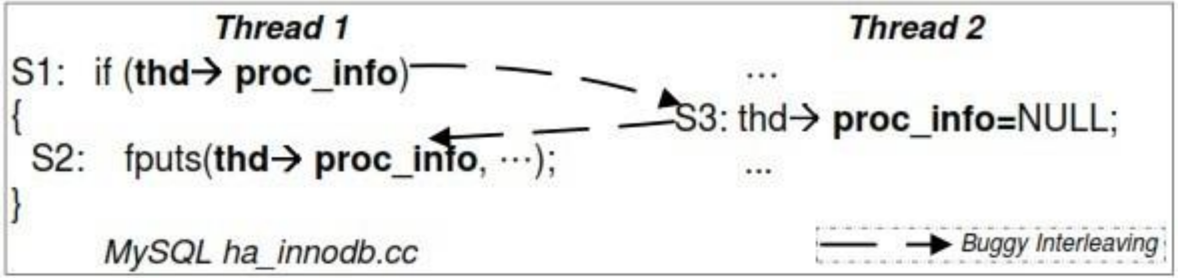
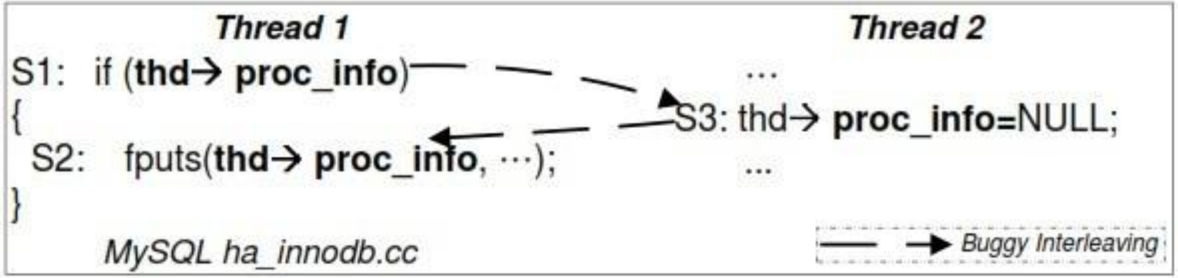


Atomicity violation

Common Concurrency bugs



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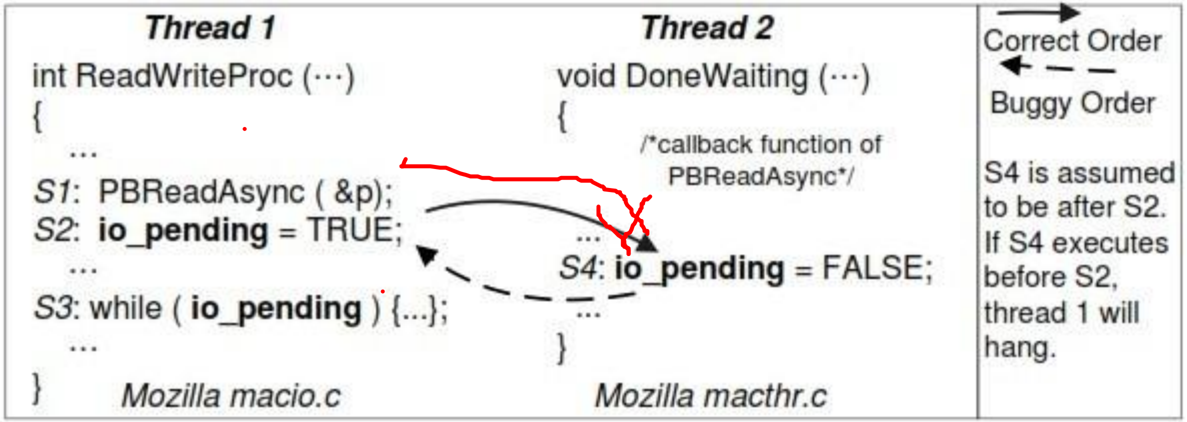
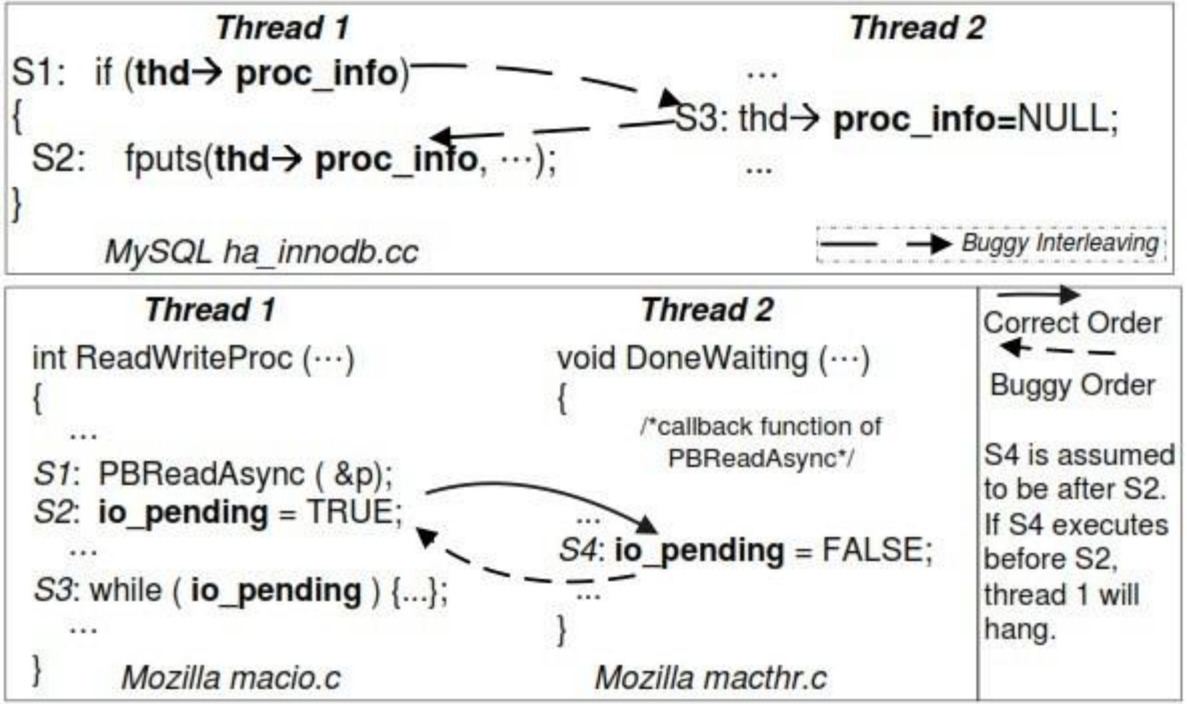


Write-write order violation

Common Concurrency bugs



Atomicity violation

Write-write order violation

Use-after free etc.

Fuzzing the scheduler: existing approaches

- Identify shared objects
- An input that executes instructions involving shared objects
- Thread scheduler
  - Rather than letting OS decides, introducing a scheduler that can control the thread scheduling
  - Schedule threads w.r.t. different ordering

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- In: 2019 IEEE Symposium on Security and Privacy (SP)
- Involves static and dynamic analysis
- Found 30 new race bugs in the latest kernel
- Main Idea:
  - Find shared interleaved objects (static analysis)
  - Find an input (by fuzzing) that hits a race (in single thread)
  - Use the input for fuzzing the interleaving of thread in kernel

Data race condition

- a data race occurs when two memory access instructions in a target program meet the following three conditions:
  1) they access the same memory location.
  2) at least one is a write instruction. And
  3) they are executed concurrently.

1. Static analysis component

Identifying Race candidates (`RacePair`$_{cand}$)

- Instructions that access (points) to the same memory location (satisfy the three conditions stated earlier)
- Point-to analysis
- Difficult to get it right!
  - ➢ Interprocedural analysis
  - ➢ Conservative
  - ➢ Partition based analysis (scalability)
  - ➢ Rather than analysing the entire kernel code, it partition the space w.r.t. directory structure, e.g. `Kernel, mm, fs, drivers`

- we use RacePair$_{true}$ for those that are confirmed to meet the three conditions.

2. Scheduler in Hypervisor

- Running the Razzer on a tailored VM
  - Fuzzing mulit-threaded program in guest user-land
  - Triggering races in guest OS
- Uses Virtual Machine Control Structure to:
  - Set hardware breakpoints
  - To catch when the interrupt occurs
- Resume per-Core Execution
  - At each breakpoint, ability to decide which thread to resume.

3. Two-phase fuzzing

- Single-Thread Fuzzing
  - User program generation (Single thread)
    - ➢ Random sequences of syscalls with random values of parameter
    - ➢ It uses Syzkaller (a kernel fuzzer)
  - User program execution (single thread)
    - ➢ Execute the above program and monitors (kcov)
      - Checks if two syscalls execute addresses related to a single $\texttt{RacePair}_{cand}$
    - ➢ It annotates such syscalls with the corresponding addresses from $\texttt{RacePair}_{cand}$

3. Two-phase fuzzing conti…

- Multi-Tread generator
  - Creates a multi-thread version of the single-thread user program
    - If the annotated syscalls are i, j
    - Corresponding instructions are RP_i and RP_ j

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```
# Get pinned threads, thr0 and thr1
thr0 = get_pinned_thread(vCPU0)
thr1 = get_pinned_thread(vCPU1)

# Assign syscalls to thr0 and thr1
syscalls = get_syscalls(Pst)
thr0.add_syscalls(syscalls[:i])
thr1.add_syscalls(syscalls[i+1:j])

# Determine the execution order
r = random([vCPU0, vCPU1])
thr0.add_hypercall(hcall_order(r))

# Trigger and check races
thr0.add_hypercall(hcall_set_bp(vCPU0, RP_i))
thr0.add_syscalls(syscalls[i])
thr0.add_hypercall(hcall_check-race())

thr1.add_hypercall(hcall_set_bp(vCPU1, RP_j))
thr1.add_syscalls(syscalls[j])
thr1.add_hypercall(hcall_check_race())
```

3. Two-phase fuzzing conti…

- Multi-Thread Executor
  - Sets breakpoints at addresses in $\texttt{RacePair}_{\texttt{cand}}$
  - Checks if the breakpoints are hit
  - Concrete addresses pointed to by the respective instructions
- Resume threads (one by one) to check if race vulnerability is triggered
- Several address sanitizers are enabled during the kernel compilation.