

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**

Concurrency Bugs Detection via Fuzzing

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Concurrency Bugs Detection via Fuzzing

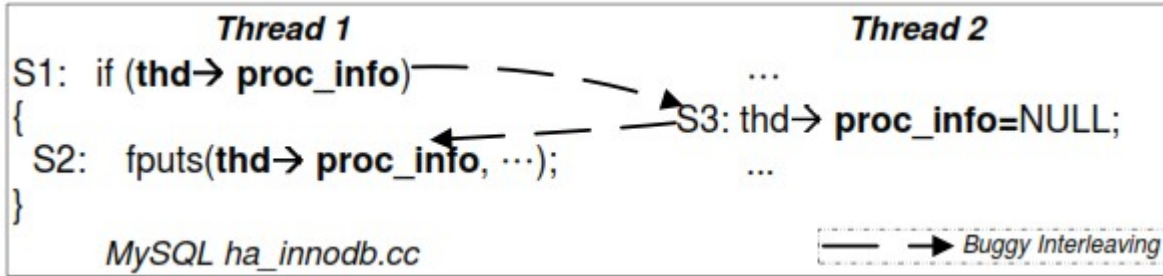
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- Their effects propagate through data and control dependencies until they cause software to crash, hang, produce incorrect output, etc

Concurrency Bugs Detection via Fuzzing

- 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.

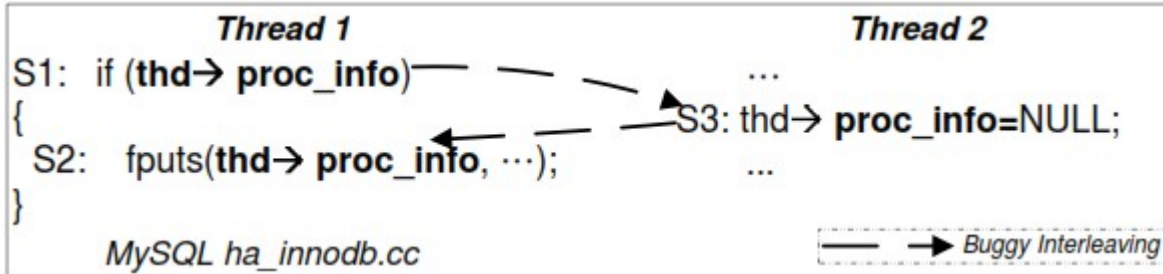
Common Concurrency bugs

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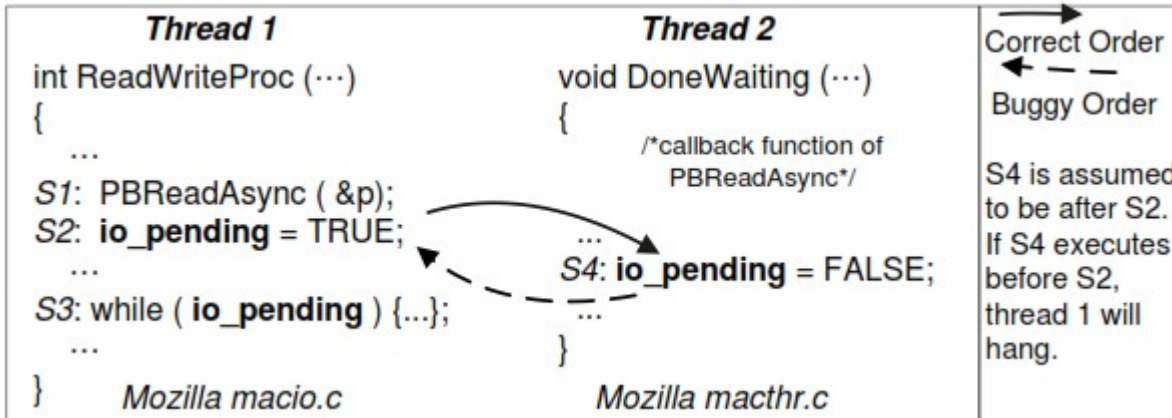


Atomicity violation

Common Concurrency bugs

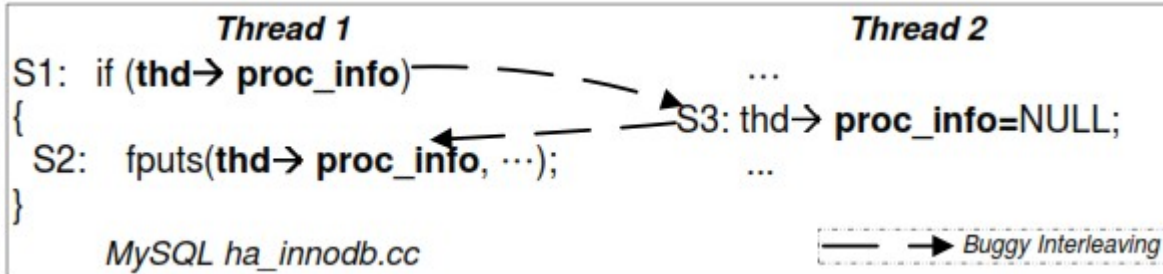


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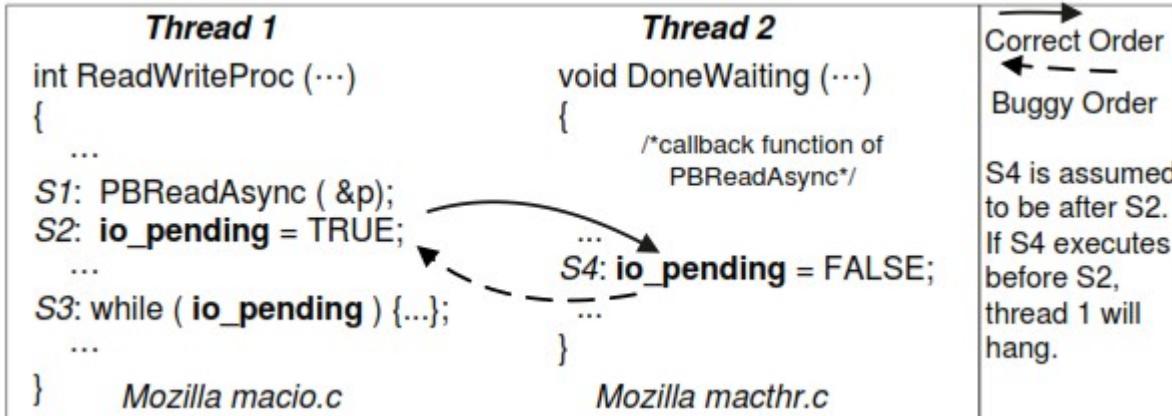


Write-write order violation

Common Concurrency bugs



Atomicity violation



S4 is assumed to be after S2. If S4 executes before S2, thread 1 will hang.

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 ($\text{RacePair}_{\text{cand}}$)

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

2. Scheduler in Hypervisor

- Running the Ruzzer on a tailored VM
 - Fuzzing multi-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 $\text{RacePair}_{\text{cand}}$
- It annotates such syscalls with the corresponding addresses from $\text{RacePair}_{\text{cand}}$

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 $\text{RacePair}_{\text{cand}}$
 - 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.