Is Linux Kernel Oops Useful Or Not?

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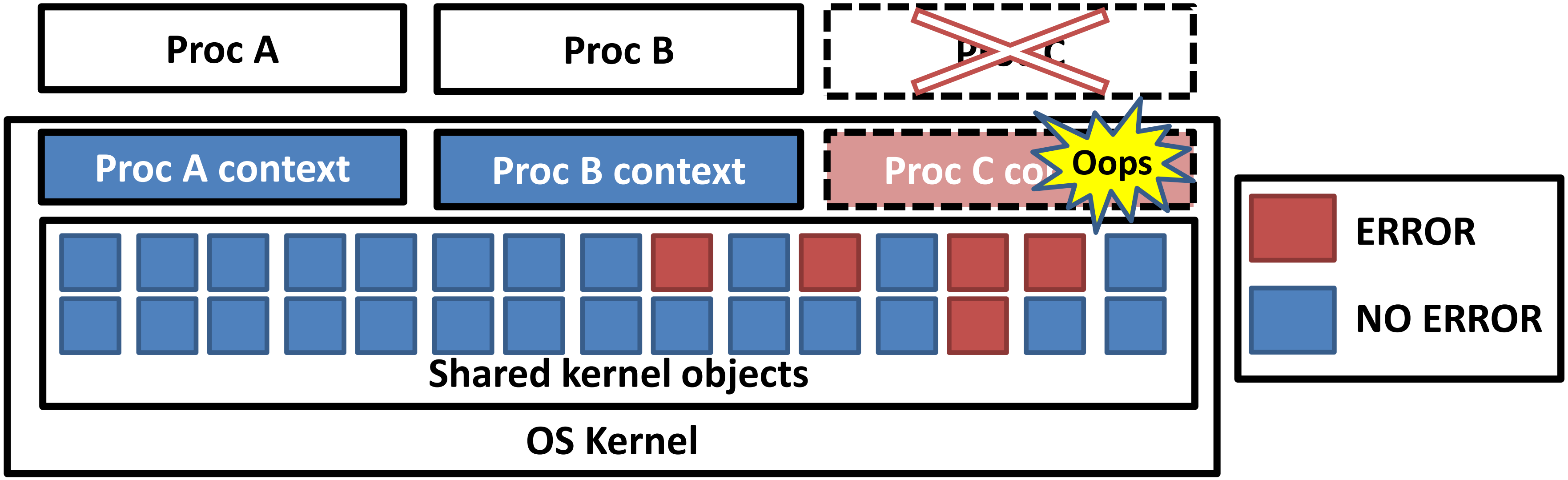
OS Kernel Crash

- OSes need to be highly available
  - Necessary for all apps to continue running
  - A kernel crash can lead to the outage of the entire apps
- Kernel crashes are difficult to be **zero**
  - Bugs inside Linux still exist [Palix et al. ASPLOS ’11]
  - Bugs are not always fixed soon

What Is Kernel Oops?

- A Linux behavior to handle detected bugs
  - e.g., in-kernel NULL deref
- Linux kills a faulty context’s proc in kernel oops
  - Linux attempts to avoid kernel crashes, called “panic”
- Linux continues to run on a compromised reliability



Proc A

Proc B

~~Proc C~~

Proc A context

Proc B context

Proc C co

Oops

Shared kernel objects

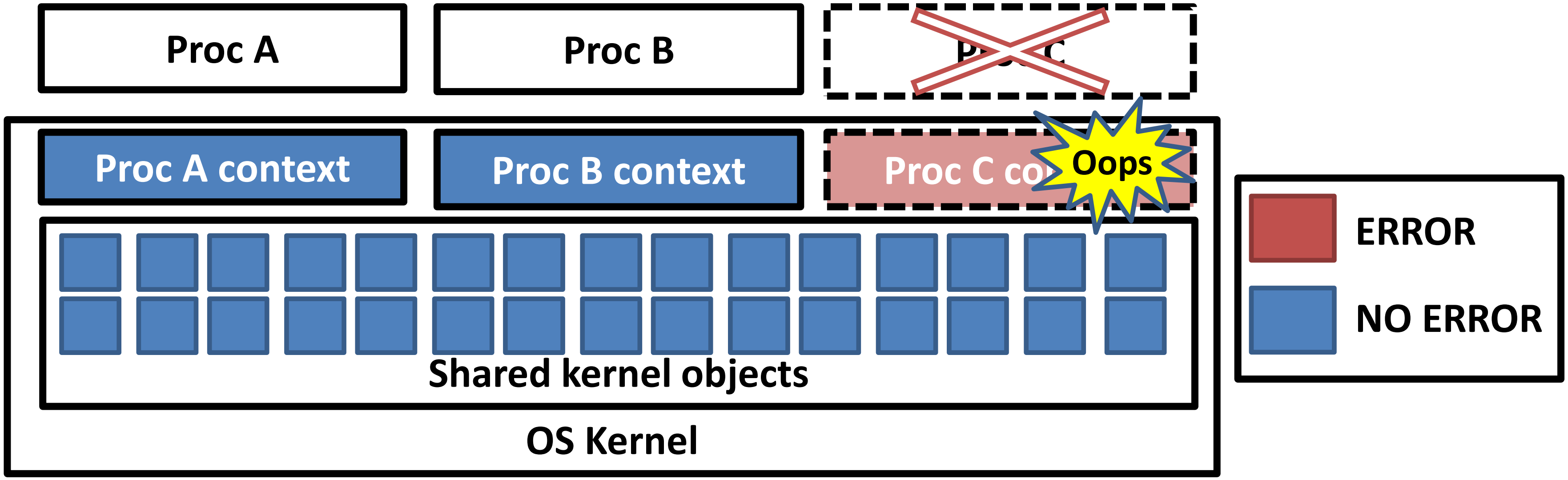
OS Kernel

🟥 ERROR

🟦 NO ERROR

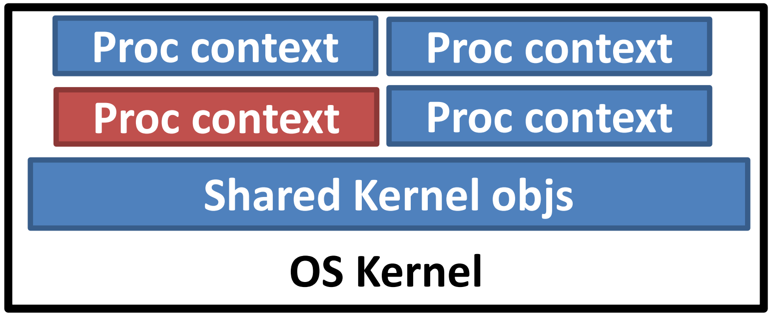
Why Can Kernel Oops Be Useful?

- Linux can remain reliable after kernel oops if errors are confined in a kernel context
  - Shared kernel objects remain correct
  - Non-faulty procs can continue running correctly
    - *Without rebooting or any complex mechanisms*

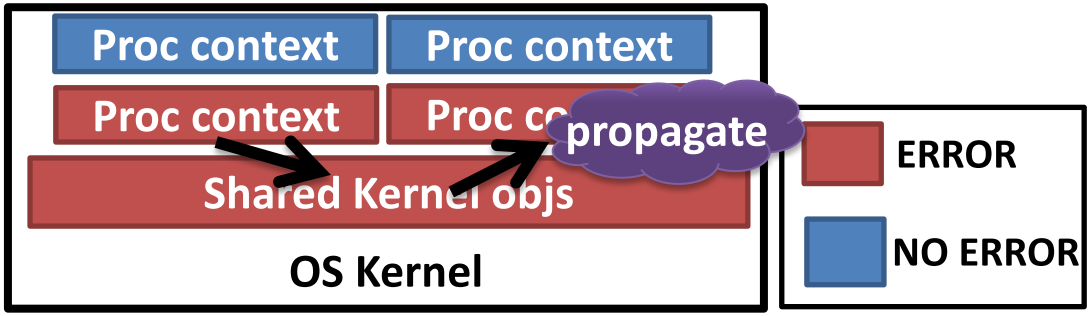


Error Propagation Scope

- ***Process-local*** error
  - – Propagates only within the kernel context of a proc
    - e.g., kernel stack, function-local data
  - – Errors can be removed by killing a faulty proc
- ***Kernel-global*** error
  - – Propagates to data shared among kernel contexts
    - e.g., kernel states, global data, heap data



Process-local error propagation



Kernel-global error propagation

Goal in This Work

G-1: Analyze Linux behavior to faults

- How freqently does Linux invoke oops/panic?

G-2: Analyze error propagation scope in oops

- Are kernel states corrupted after fault activation?

G-3: Estimate the Linux reliability after kernel oops

- How freqently can Linux avoid panic correctly?

- Explore the possibility of using kernel oops as an error recovery method

Experimental Equipment

- Linux 2.6.38 kernel on VMware Workstation 8
    - 1 CPU, 1GB memory, 20GB Disk
- A fault injector used by existing work
    - [Ng et al. ’98],[Swift et al. ’03], [Depoutovitch et al. ’10]
    - Obtained from Nooks Research web site
        - http://nooks.cs.washington.edu/
- KDB, a kernel debugger
    - To trace error propagation
- Six benchmarks as workloads
    - UnixBench on {ext4, fat, USB}, Netperf, Aplay and restarting all the daemon

The Fault Injector

- Emulates 15 fault types
  - Mutates random instr in the running kernel text
  - Extended to imitate some reported bugs in [Palix et al. ASPLOS '11]
    - e.g., deleting NULL check

Examples of the Injected Fault

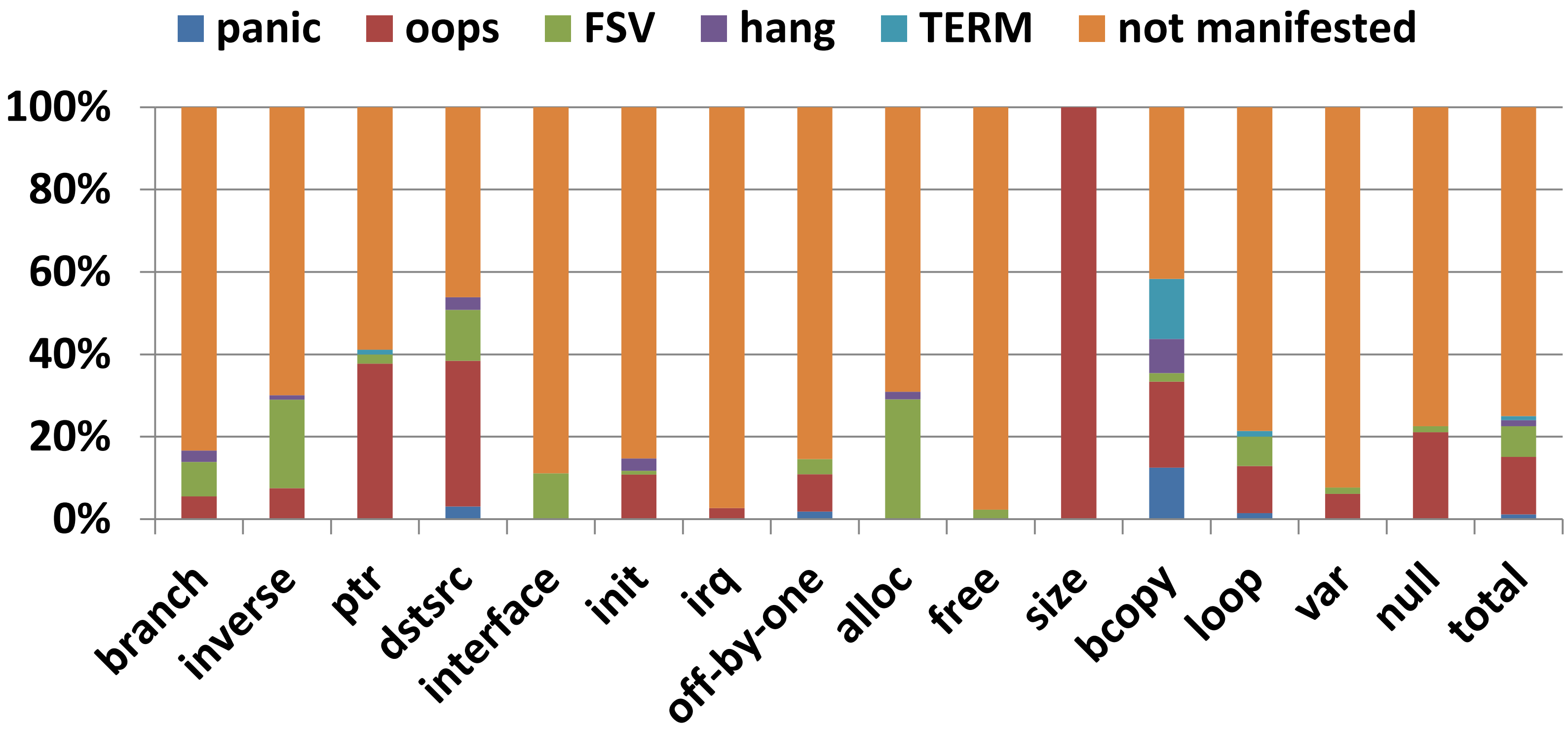
Fault type	before	after
init	int x = 1;	int x;
irq	arch_local_irq_restore()	deleted.
off by one	while (x < 10)	while (x <= 10)
bcopy	memcpy(ptr, ptr2, 256);	memcpy(ptr, ptr2, 512);
size	ptr = kmalloc(256, GFP_KERNEL);	ptr = kmalloc(128, GFP_KERNEL);
free	kfree(ptr);	deleted.
null	if (ptr == NULL) return;	deleted.

G-1: Analyzing Linux behavior

- Inject a fault
- Set a breakpoint to the faulty instr
- Run every workload in 6 benchmarks
- See if the fault is activated
  - If the kernel hits the breakpoint
- See what happens until the workload fails
  - Or until the workload is finished

G-1 Result: Failure By Fault Type

- 887 faults are activated (6738 are injected)
  - – 75%: not manifested
  - – 15%: oops, panic (propagation scope is investigated)
  - – 10%: fail silence violation, hang, terminated by VMM

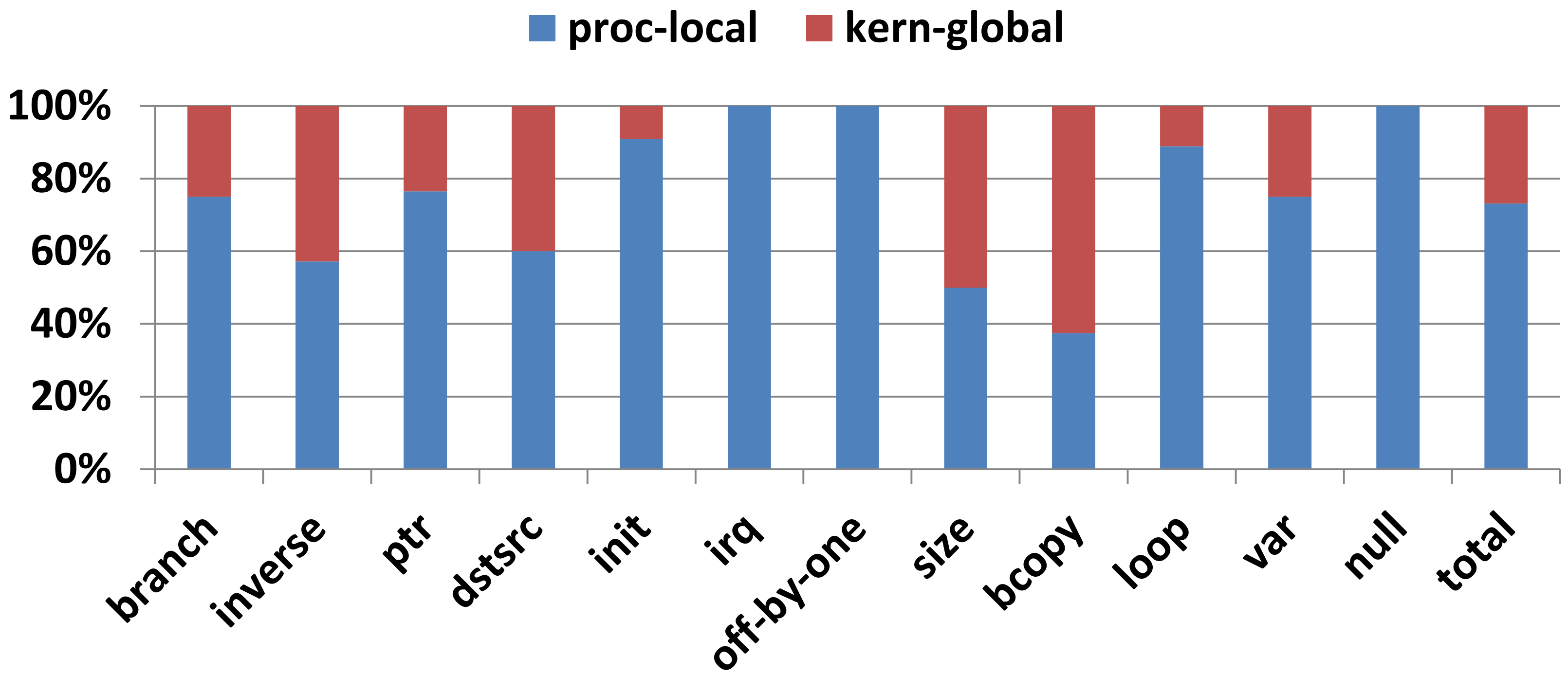


G-2: Analyzing Error Propagation

- Inject a fault causing kernel oops/panic
- Set a breakpoint to the faulty instr
- Run a workload
  - Wait until the kernel hits the breakpoint
- Trace instrs until the kernel oops
  - Currently, examine if stack or heap is corrupted
  - Analysis similar to a taint-analysis

G-2 Result: Scope Analysis

- 124 kernel oops & 10 panic are investigated
  - 73%: process-local error
  - 27%: kernel-global error
    - Overrun, corrupt list_head or callback ptr, etc.

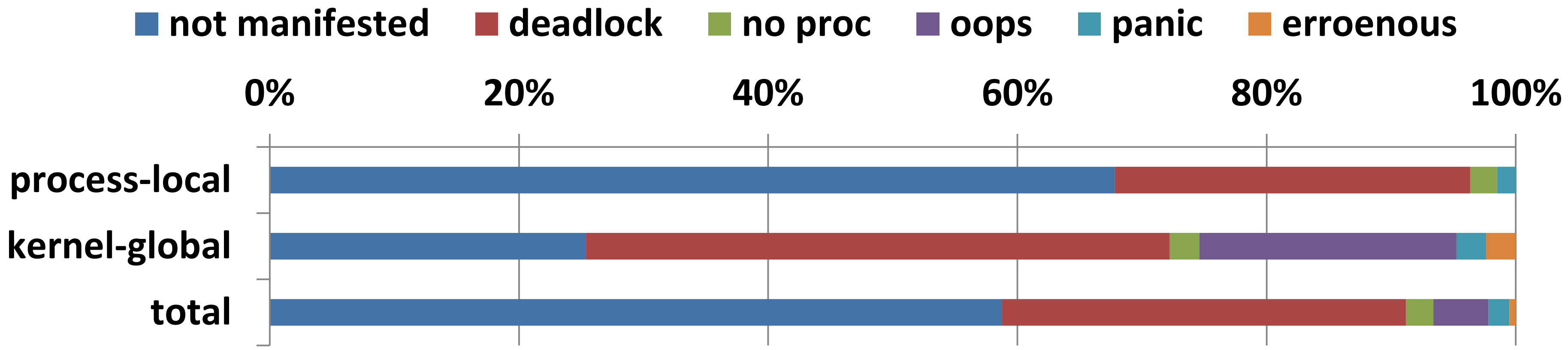


G-3: Estimating Reliability

- Inject a fault
- Run a workload
- Confirm kernel oops and the kernel kills a proc
- Remove the injected fault by using KDB
  - To imitate transient faults by the existing injector
- Run a workload in 6 benchmarks for each oops
- See what happens until the workload fails
  - Or until the workload is finished

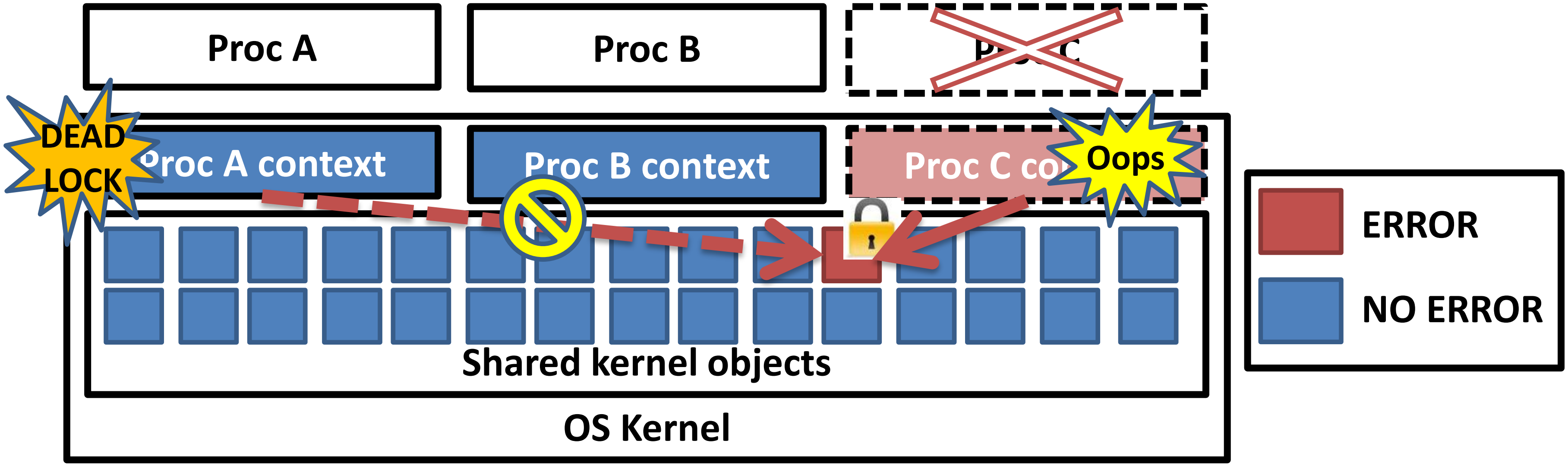
G-3 Result: Failure After Oops By Scope

- 589 workloads are investigated
  - 58.7% of the workloads keep running
    - Workloads use a subsystem unrelated to the error
  - 40.8% of the workloads stop or do not start
    - Deadlock, oops/panic, and killing a important proc
  - 0.5% of the workloads run incorrectly



Is Linux Kernel Oops Useful?

- 99.5% of the workloads run correctly or fail-stop after kernel oops
  - – Deadlock occurs context’s fail-stop
    - The mutual execution is done to write shared data
    - A context killed in a critical section holds the lock
  - – Linux shows fail-stopness even when errors are kernel-global



Related work

- A study of Linux behavior under errors [Gu et al. DSN ’03]
  - Conduct fault injection experiments
  - Show error propagation among subsystems
- Linux faults study [Palix et al. ASPLOS ’11]
  - Use a static analyzer to Linux kernels
  - Show the life-time and the distribution of bugs in Linux
- Reboot-based recovery with apps’ state reserved

  [Depoutovitch et al. EuroSys ’10, HotDep ’08]
  - Switch to the slave kernel when the master kernel crashes
  - Take downtime & need to re-design apps

Conclusion

- OSes need to be highly available
- Linux kills only a faulty proc instead of crashes
  - This kernel behavior is called “kernel oops”
  - Any complex mechanisms are not required
- Kernel oops can be useful as an error recovery
  - 99.5% of workloads run correctly or fail-stop after killing a faulty process