Improving the Reliability of Commodity Operating Systems

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High Level OS Problems

1. Performance
2. Features
3. Security
4. Reliability

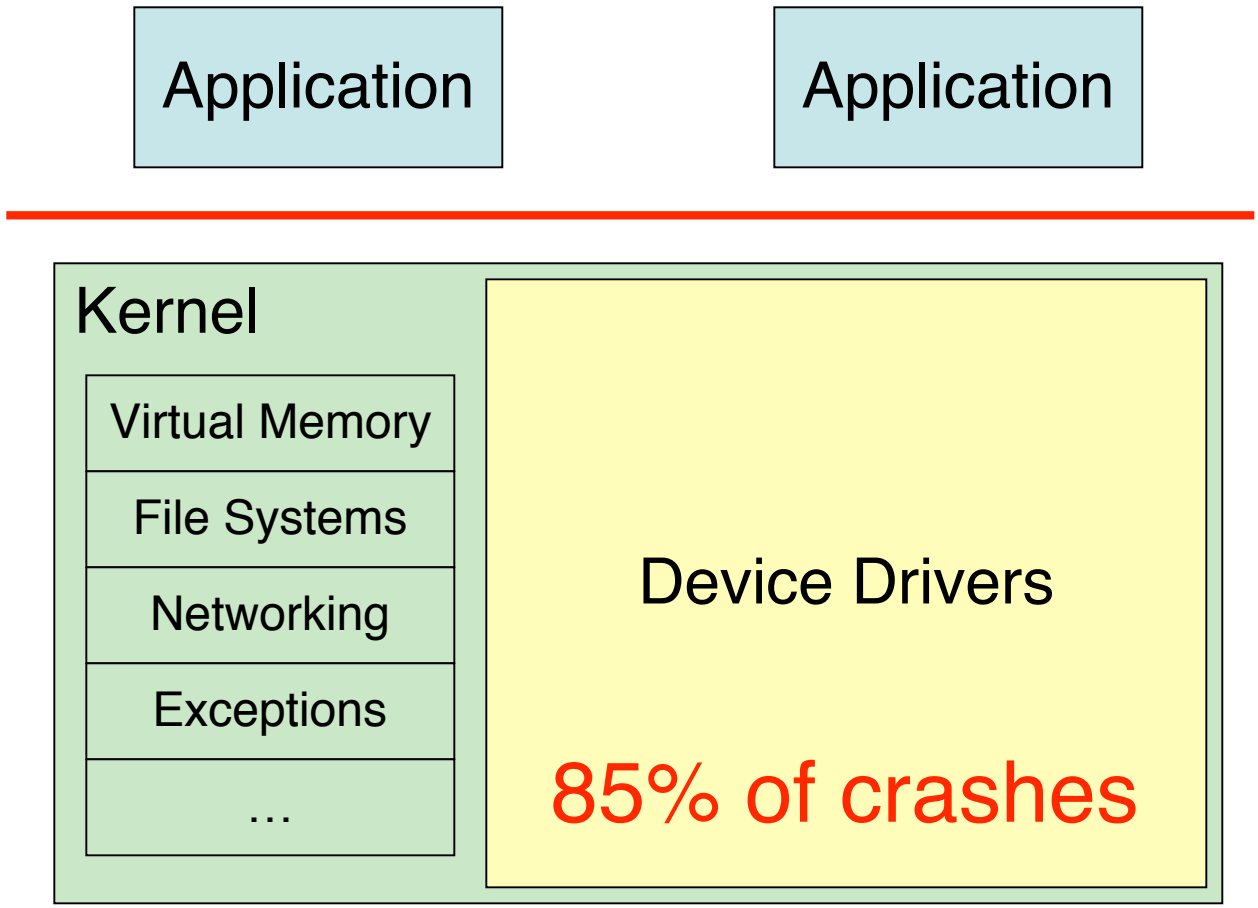
Previous Approaches to Reliability

1. Fix the code
   [MetaCompilation, Windows Driver Verifier]

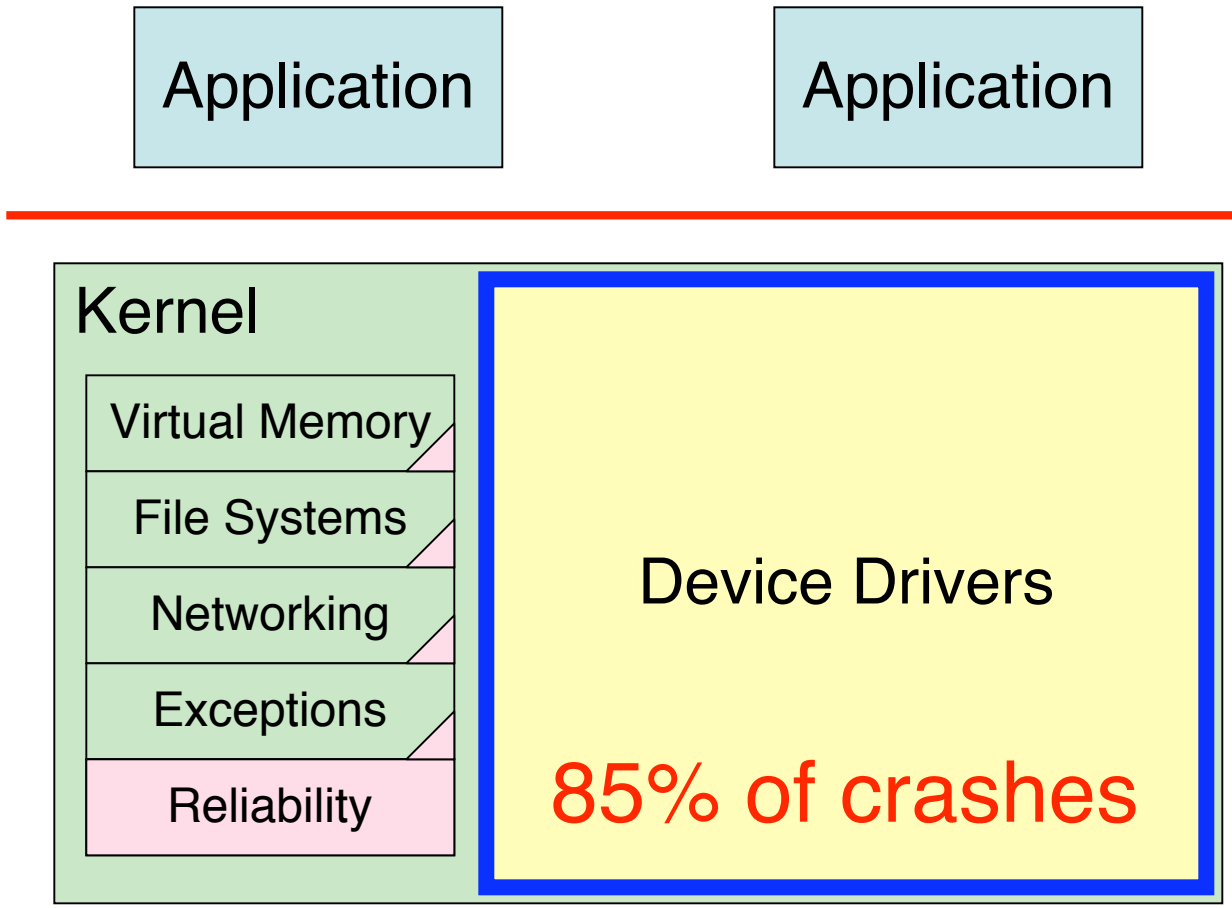
2. Build a new system
   [Singularity, Tandem NonStop, QuickSilver]

3. Add hardware
   [VaxClusters, Wolfpack, Google]

OS Today


Application
Application
Kernel
Virtual Memory
File Systems
Networking
Exceptions
…
Device Drivers
85% of crashes

OS With Reliability



Contributions

We designed and built a new kernel subsystem that:

- Prevents majority of driver-caused crashes
- Requires no changes to existing drivers
- Requires only minor changes to OS
- Minimally impacts performance

Outline

- Introduction
- Problem
- Design
- Evaluation
- Summary

What Is a Driver?

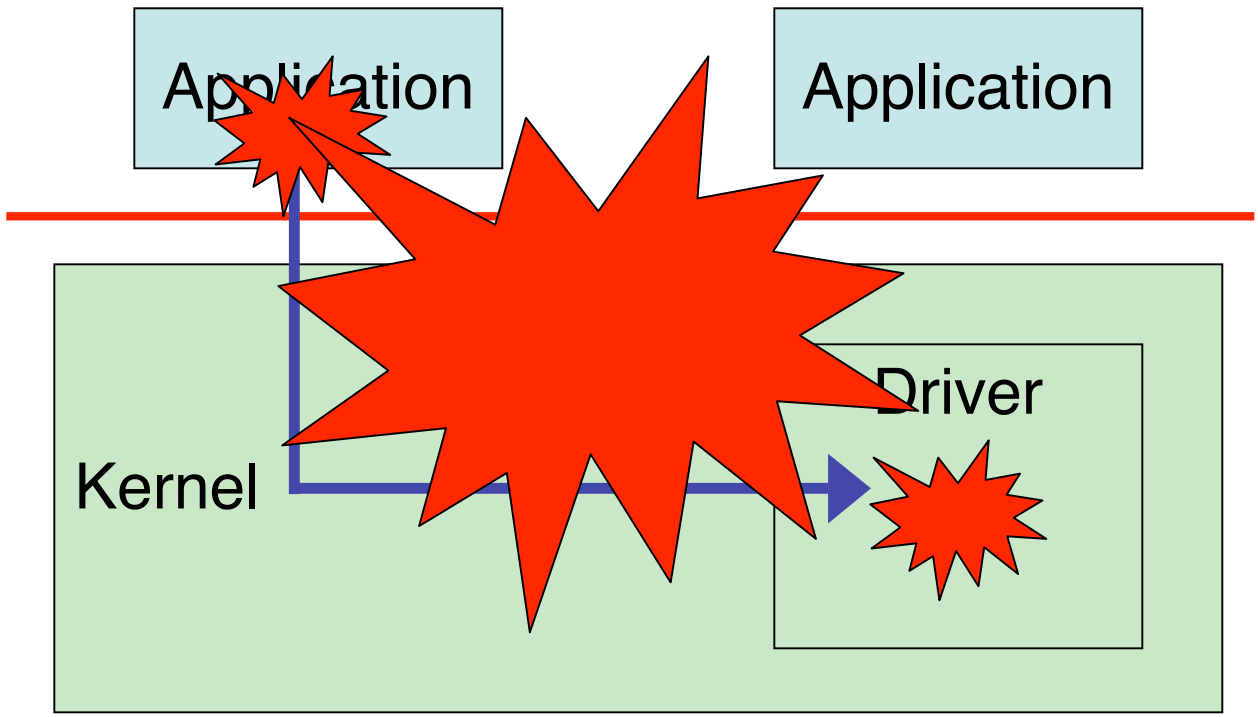
A module that translates OS requests to device requests

- 10s of thousands exist
- 81 drivers running on this laptop!
- Run in the OS kernel
- Small # of common interfaces

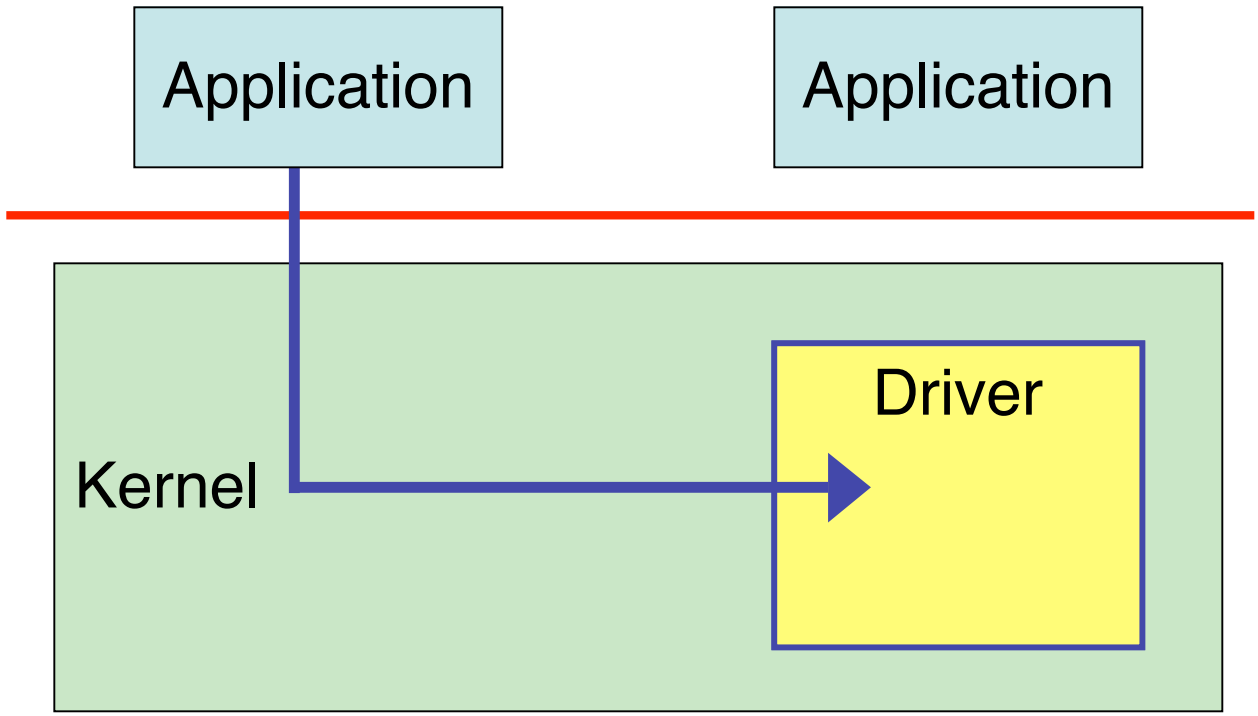
Why Do Drivers Fail?

- Complex and hard to write
  - Must handle asynchronous events
  - Must obey kernel programming rules
  - Non-reproducible failures
  - Difficult to test and debug
- Written by inexperienced programmers

OS Today



OS With Reliability



Objectives

Eliminate most downtime caused by drivers

1. Prevent system crashes - isolation
2. Keep applications running - recovery

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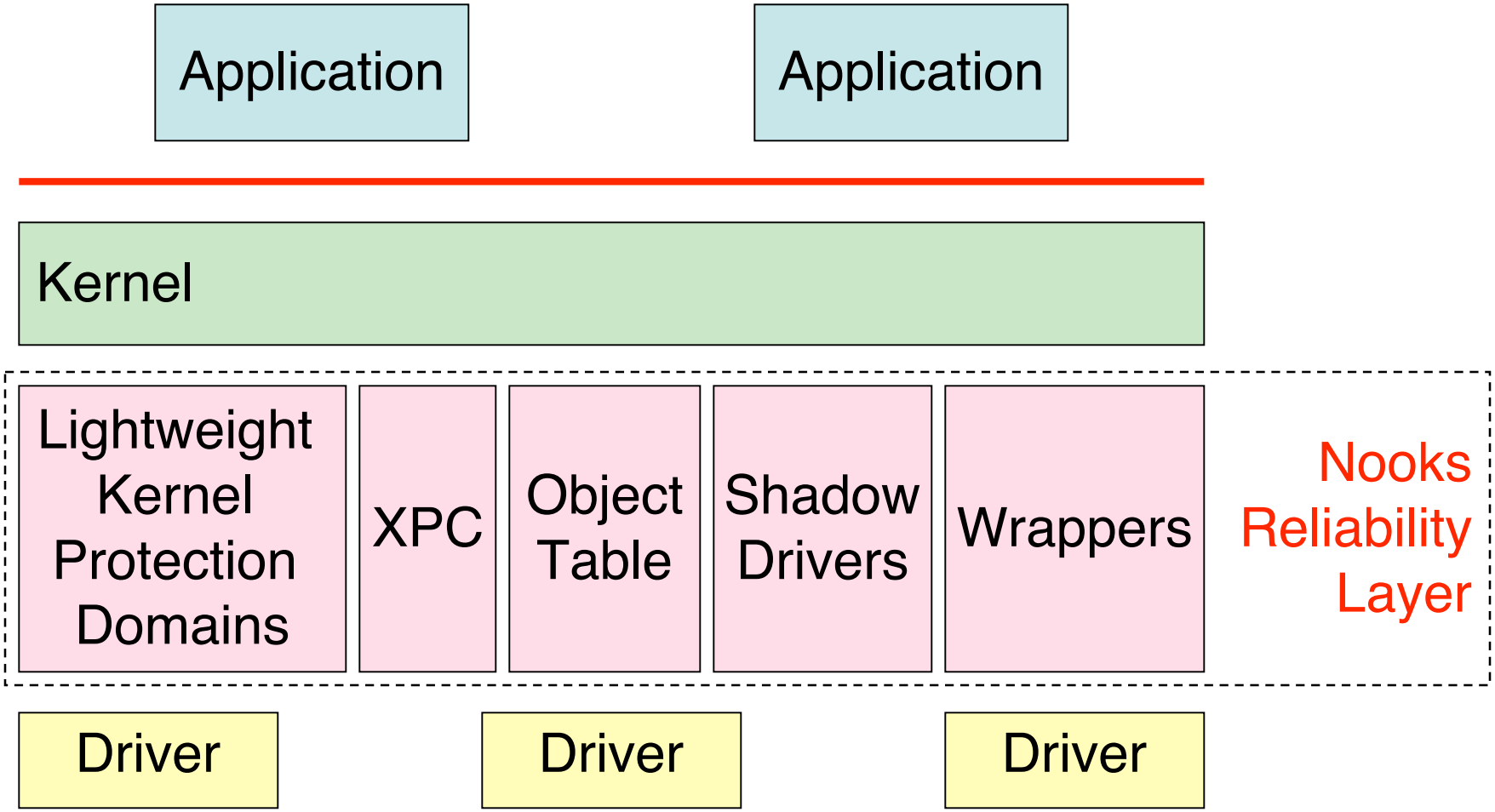
Design of Nooks

- Standard Linux kernel and drivers
- Plus:
  - Isolation
  - Recovery
- Compatible with existing code

System Architecture



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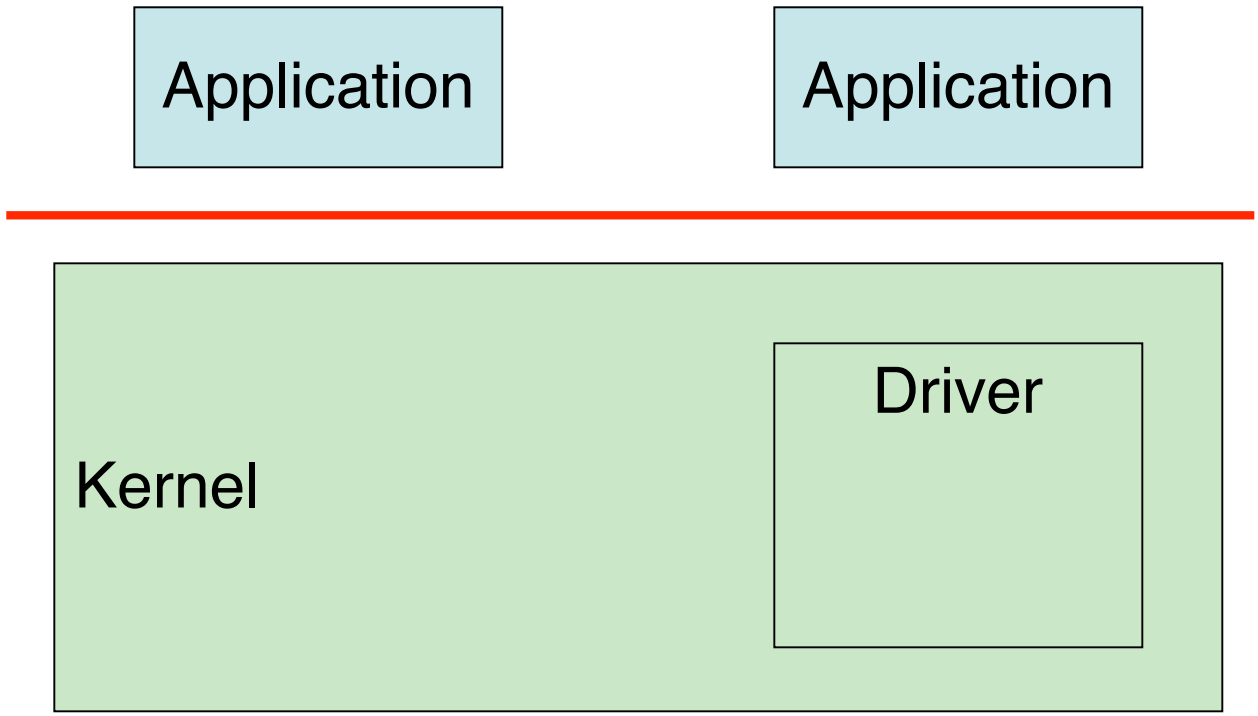
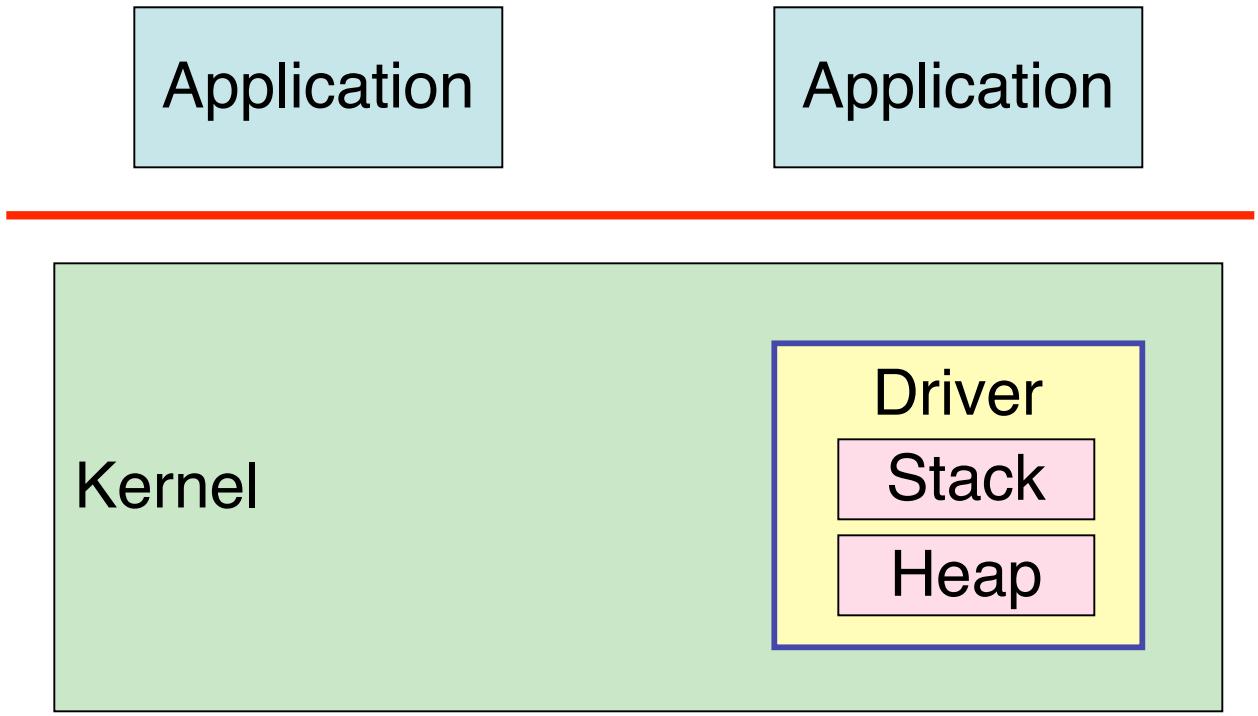
Existing Kernels

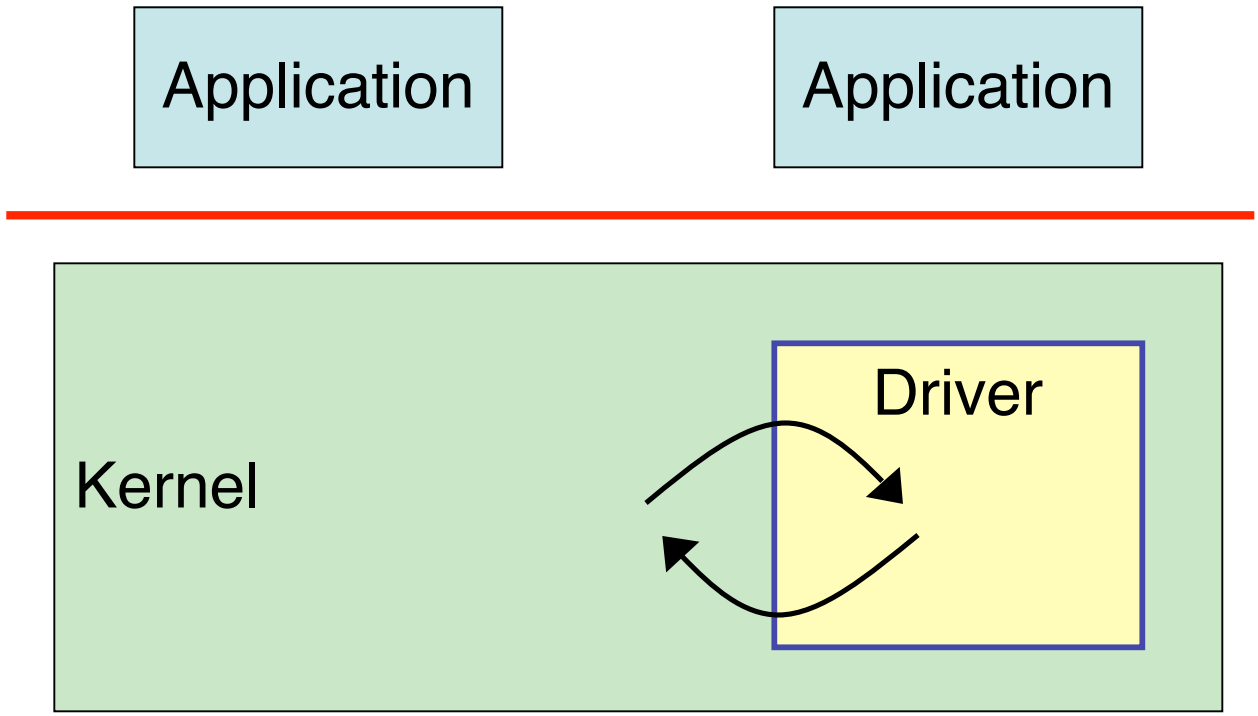


Memory Isolation

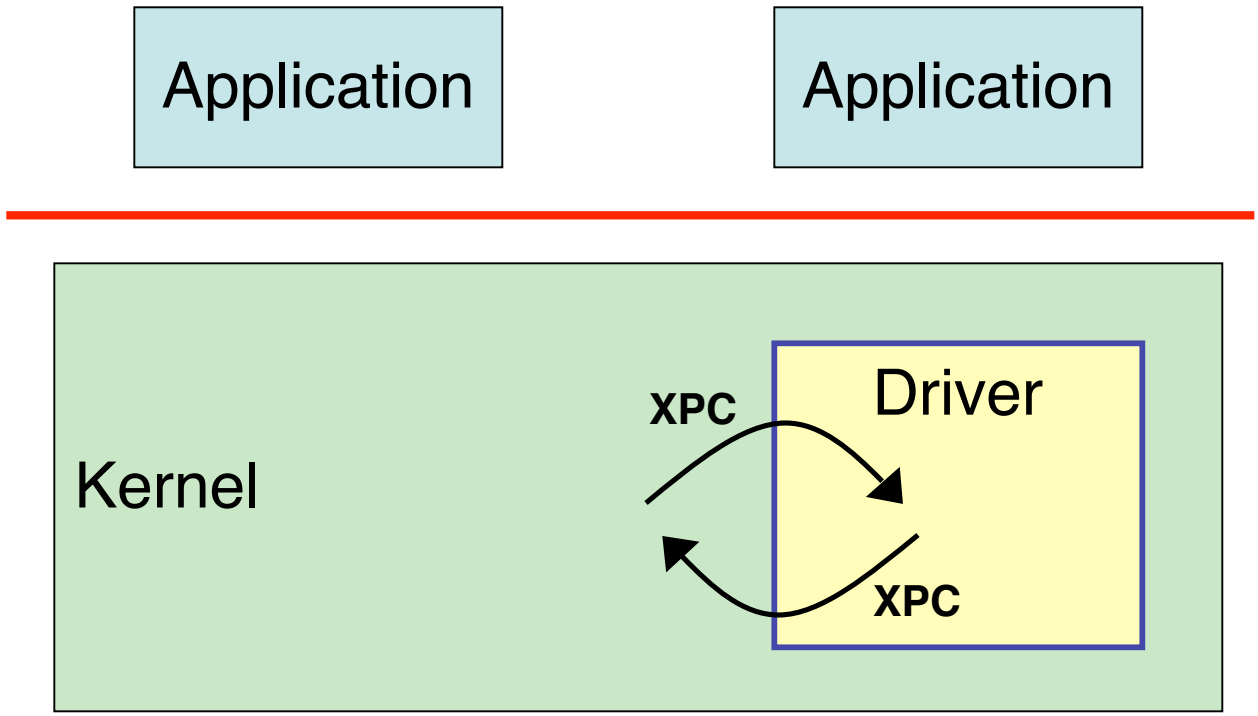


Lightweight Kernel Protection Domains

Control Transfer

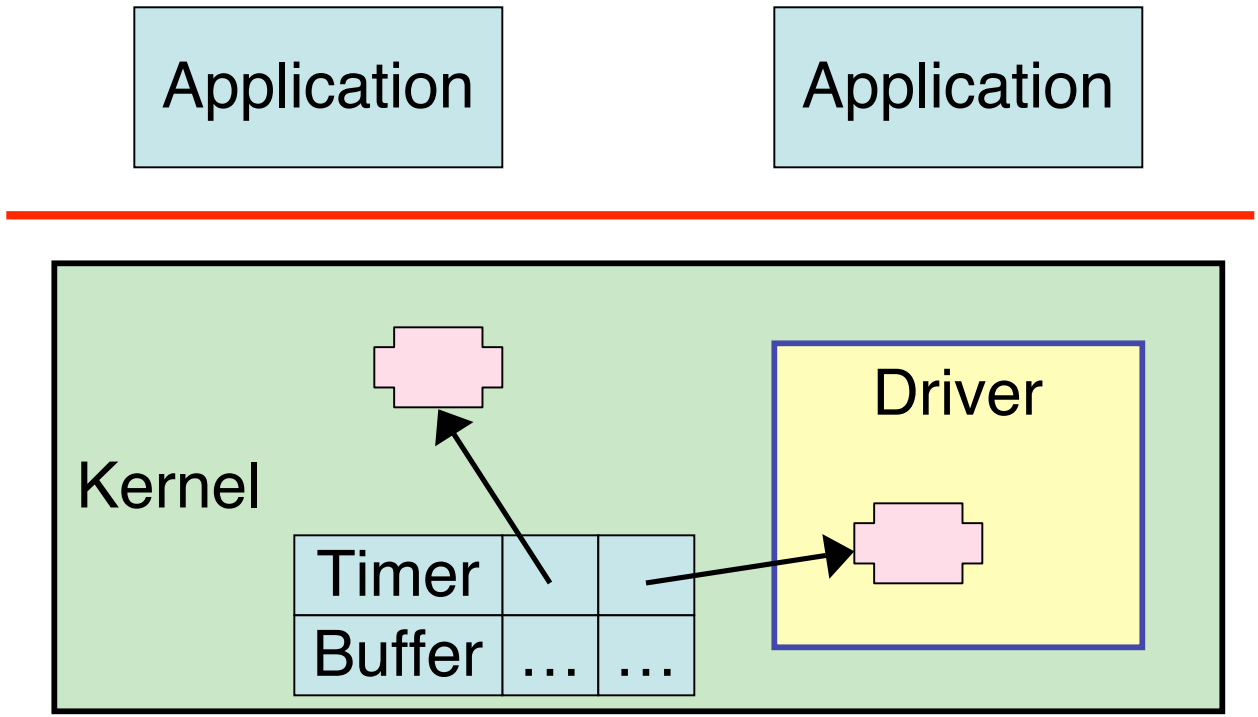


Control Transfer



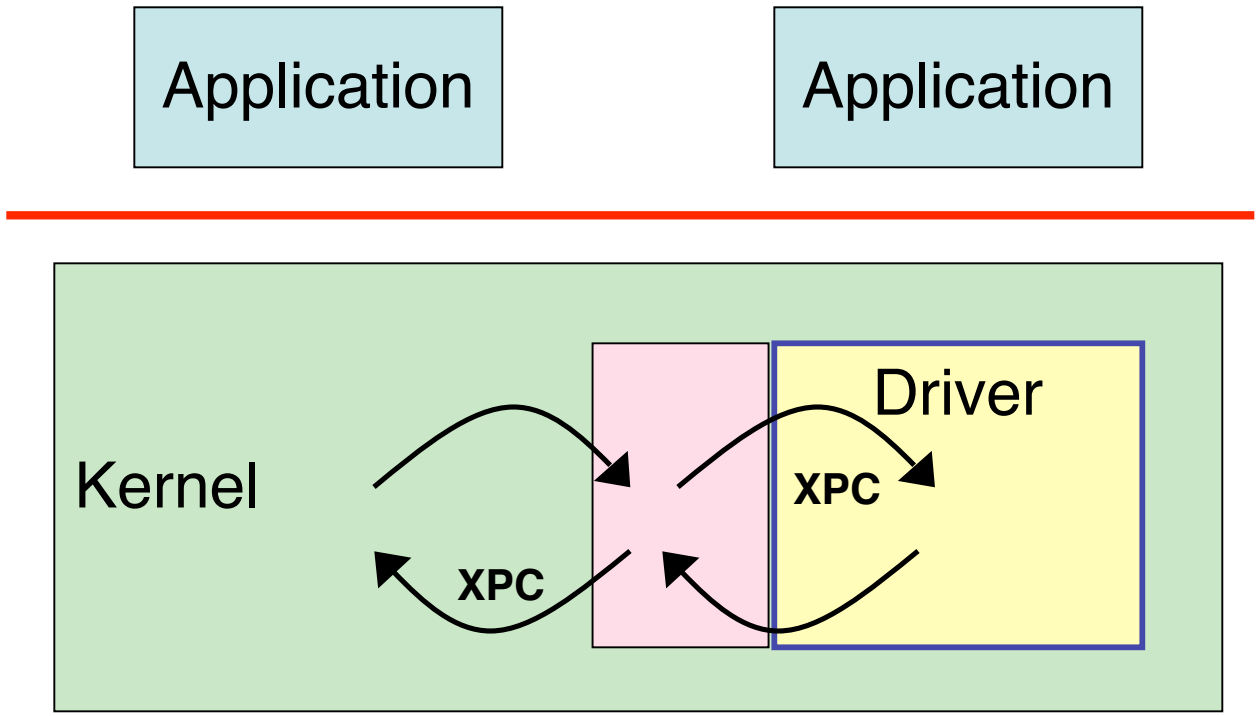
eXtension Procedure Call

Data Access



Object Table

Transparency



Wrappers

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  - Recovery
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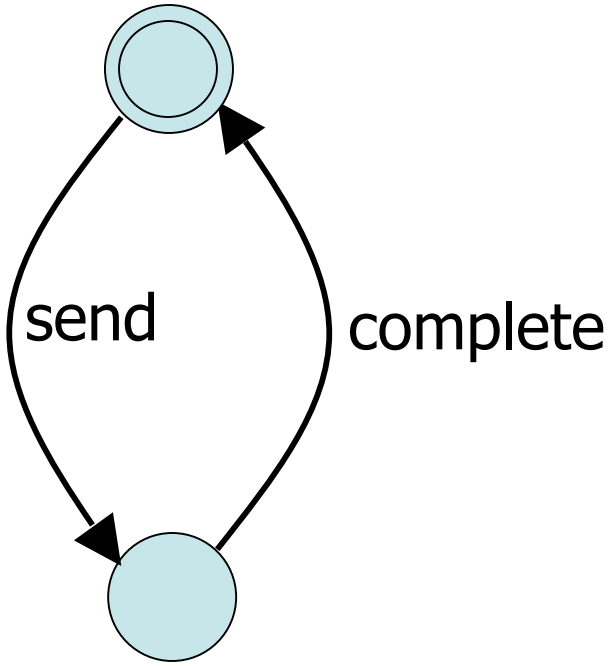
Recovery

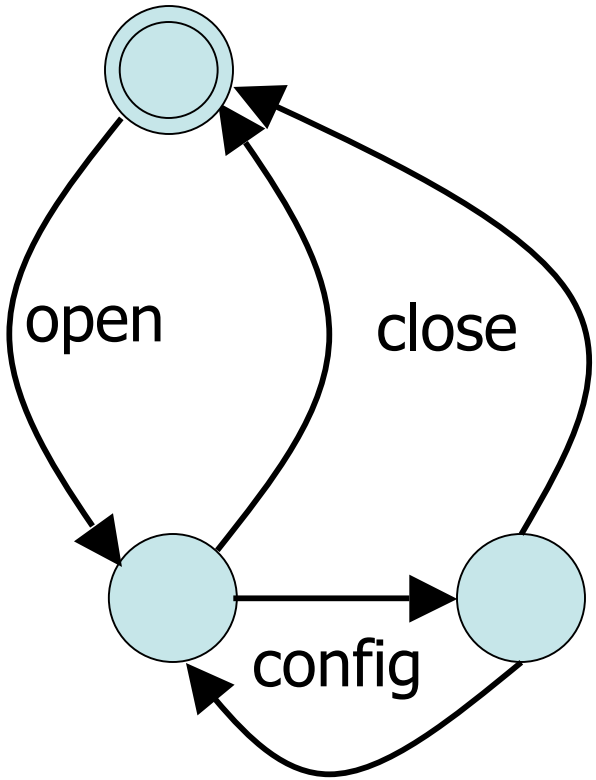
- Goals:
  - Restore driver state so it can process requests as if it had never failed
  - Conceal failure from applications
- Observation:
  - Driver interface specifies how driver responds to requests
- Approach: Model drivers as state machines

Drivers as State Machines



Drivers as State Machines

- Recovery:
  - Advance driver from initial state to state at time of crash
  - Reply to requests with valid responses according to driver state

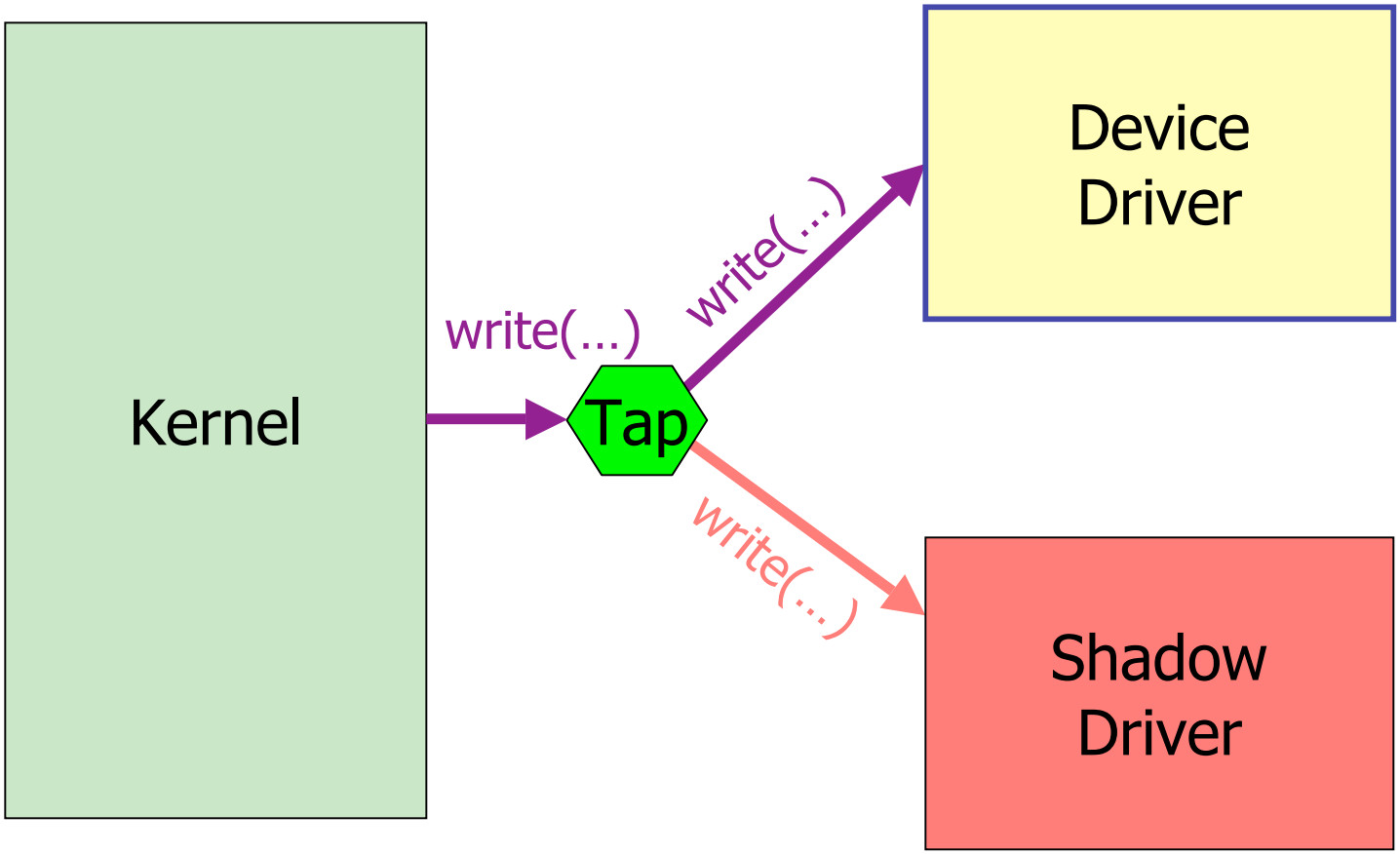


Shadow Drivers

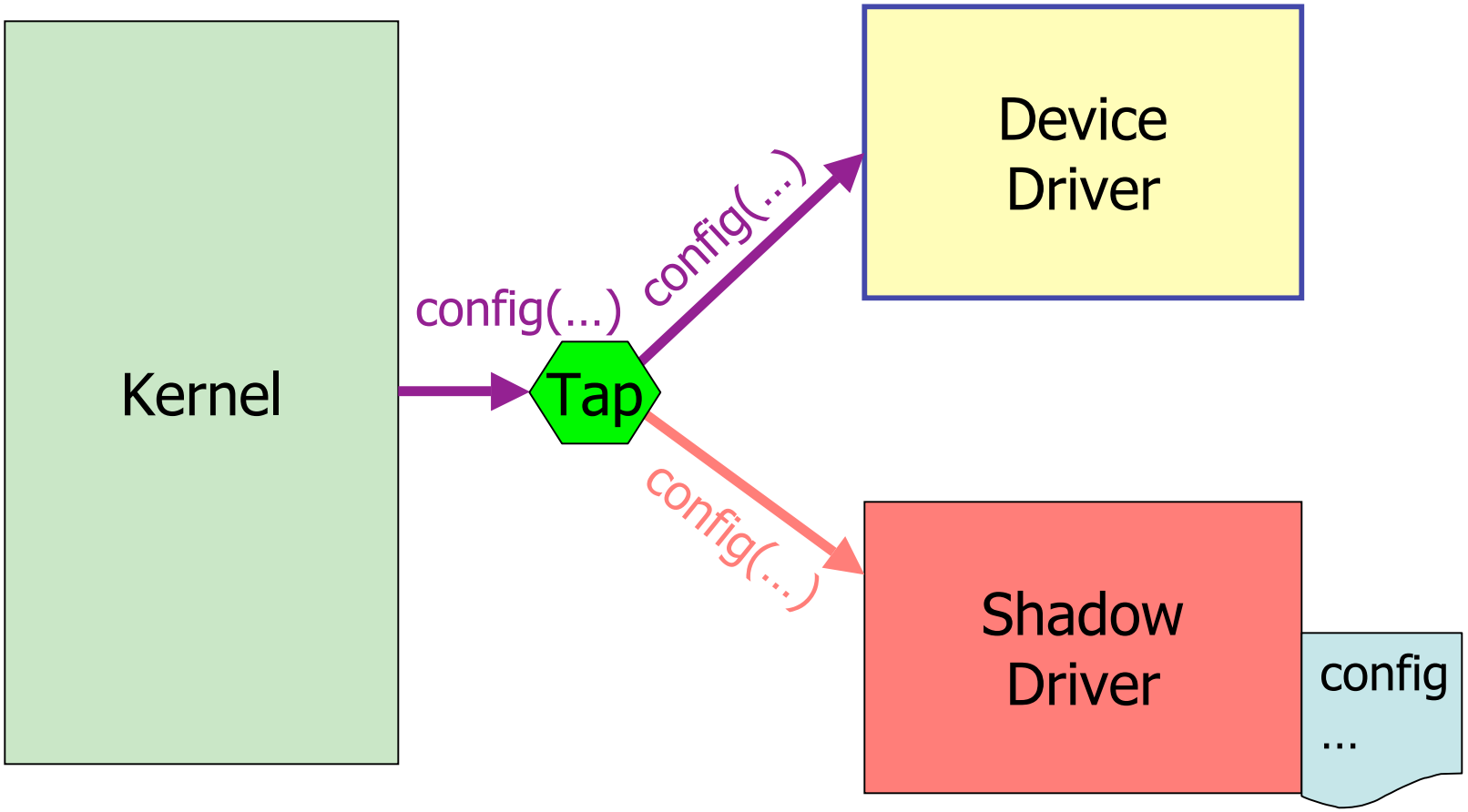
- Generic code that:
  - Normally:
    - Records state-changing inputs
  - On failure:
    - Restarts driver
    - Replays inputs to recover
    - Emulates driver to applications/OS

➔One shadow driver handles recovery for an entire class of drivers

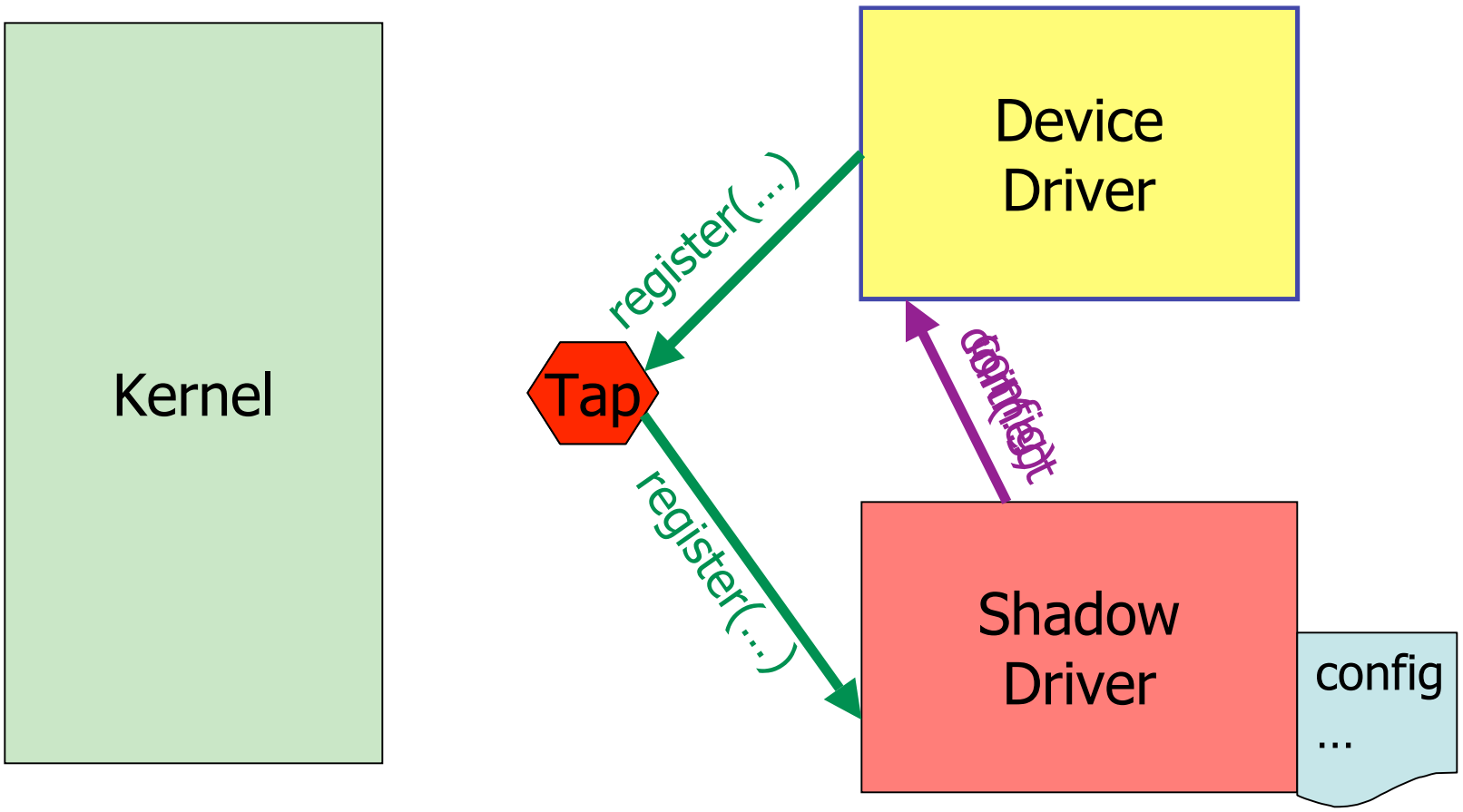
Shadow Driver Overview



Preparing for Recovery



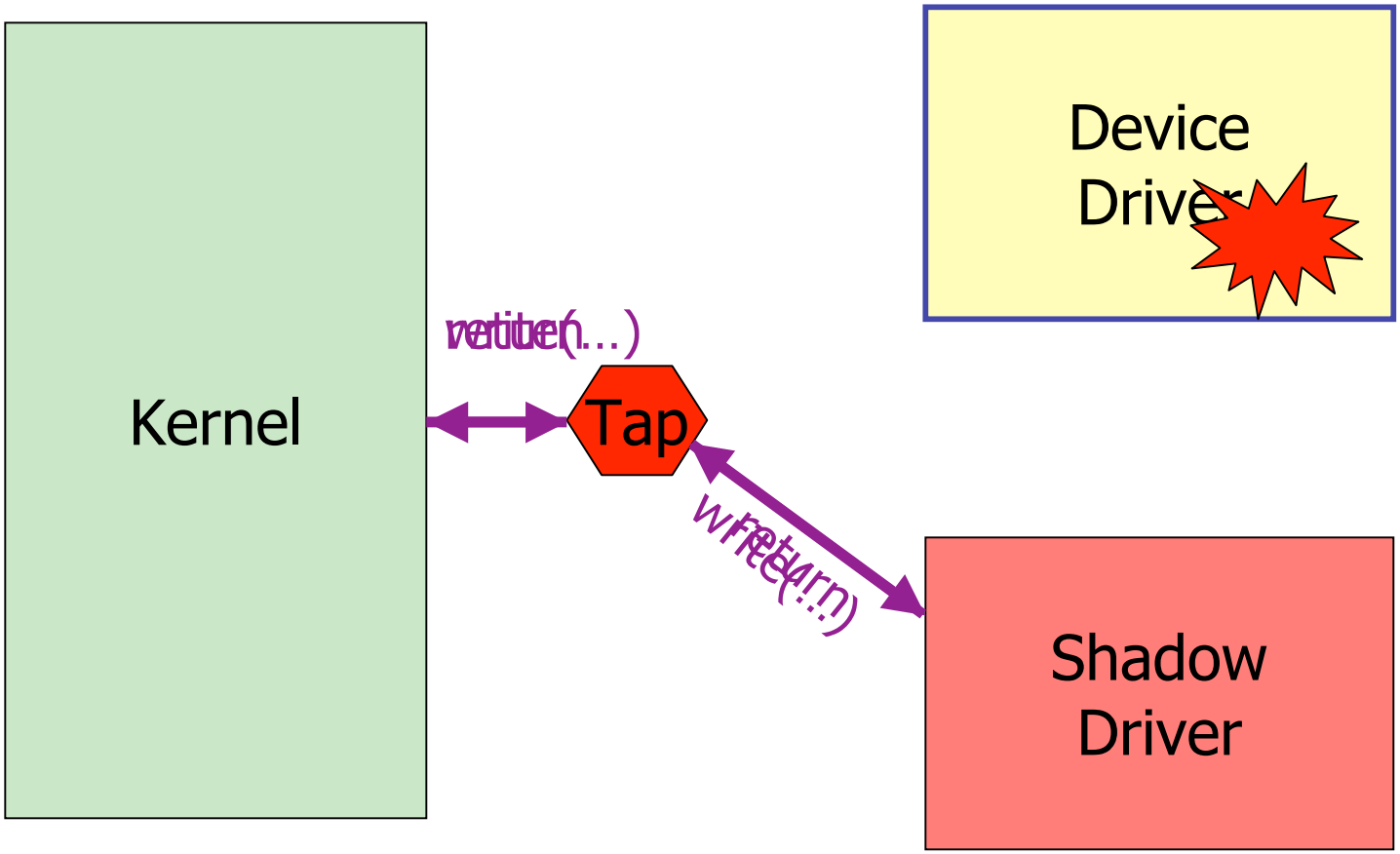
Recovering a Failed Driver



Recovering a Failed Driver

- Summary:
  - Reset driver
  - Reinitialize driver
  - Replay logged requests

Spoofing a Failed Driver



Spoofing a Failed Driver

Shadow acts as driver -- replies to requests with valid possible responses

- Applications and OS unaware that driver failed
- No device control

General Strategies:

1. Answer request from log
2. Act busy
3. Block caller
4. Queue request
5. Drop request

Design Summary

- Isolation
  - Lightweight Kernel Protection Domains
  - eXtension Procedure Call (XPC)
  - Object Table
  - Wrappers
- Recovery
  - Shadow Drivers

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Drivers Tested

Class	Drivers
Sound	Soundblaster Audigy, Soundblaster 16, Soundblaster Live!, Intel 810 Audio, Ensoniq 1371, Crystal Sound 4232
Network	Intel Pro/1000 Gigabit Ethernet, AMD PCnet32, Intel Pro/100 10/100, 3Com 3c59x 10/100, SMC Etherpower 100
IDE Storage	ide-disk, ide-cd

Implementation Complexity

- Changes to existing code
  - Kernel: 924 out of 1.1 million lines
  - Device drivers: 0 out of 50,000 lines

Implementation Complexity

- New code
  - Isolation: 23,000 lines
  - Recovery: 3,300 lines

Driver Class	Shadow Driver L.O.C.	1 Device Driver L.O.C.	All Drivers Count	All Drivers L.O.C.
Sound	666	7,381	48	118,981
Network	198	13,577	190	264,500
Storage	321	5,358	8	29,000

Implementation Complexity

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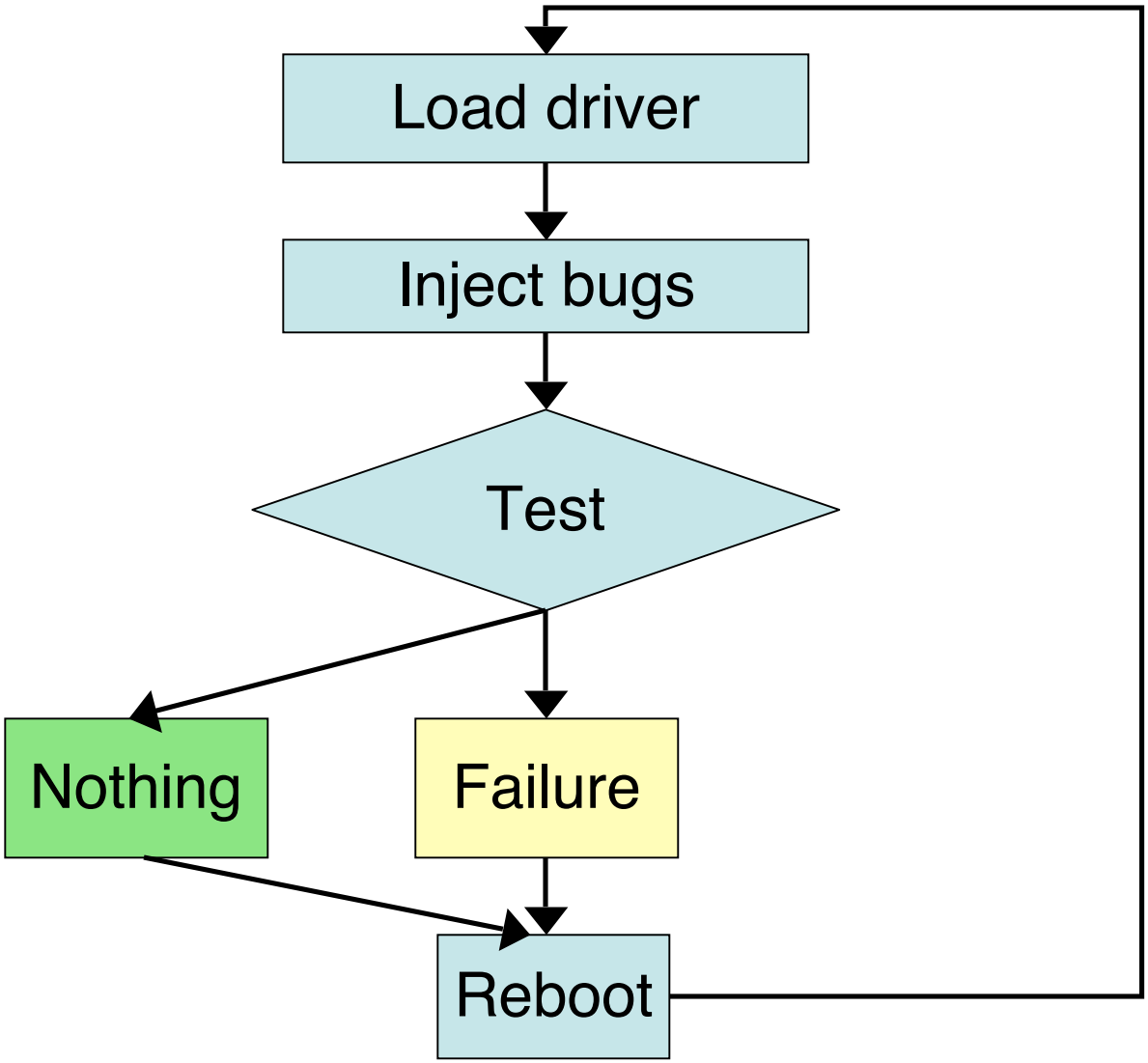
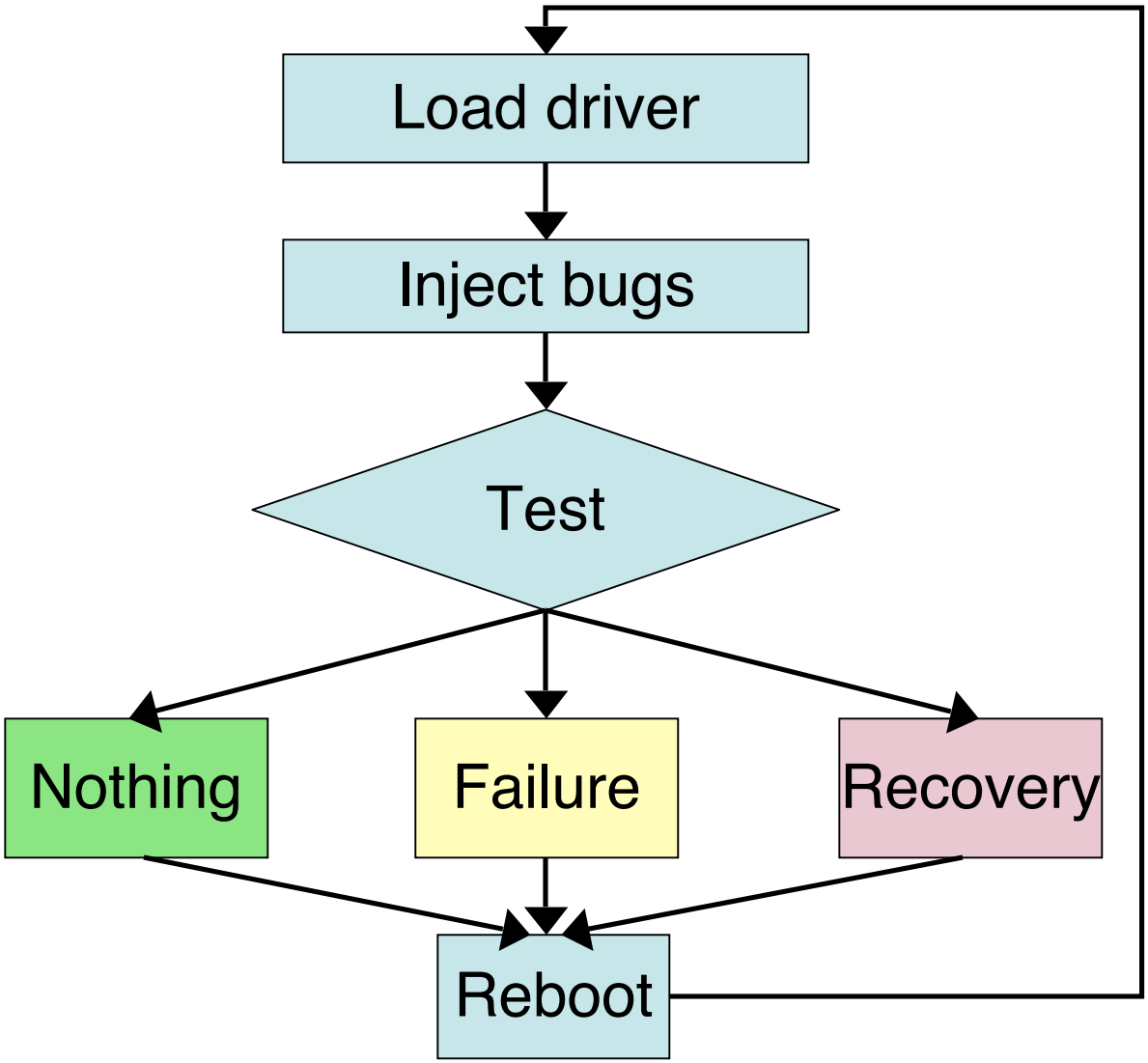
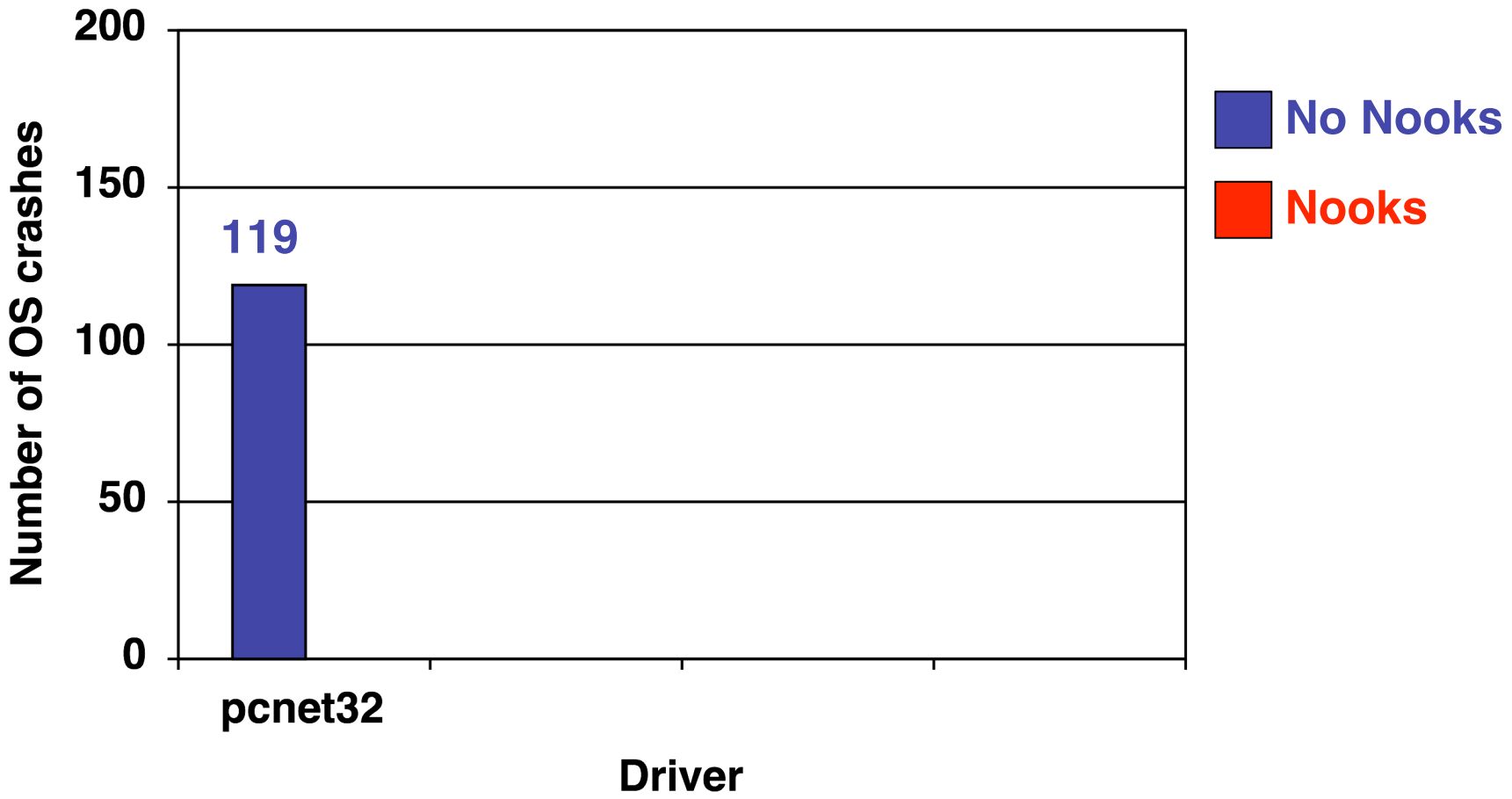
Reliability Test Methodology



Reliability Test Methodology



Isolation Works



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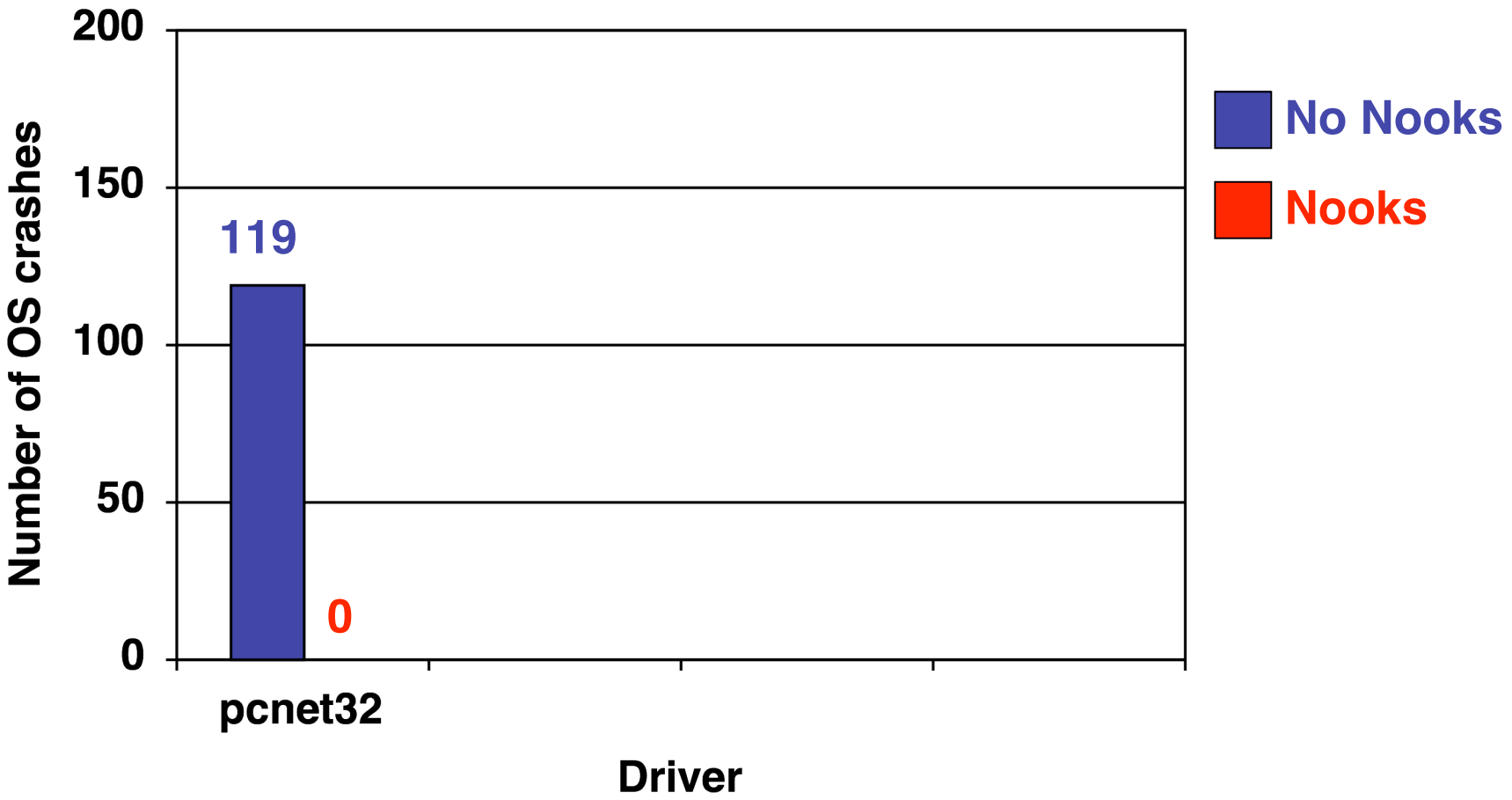

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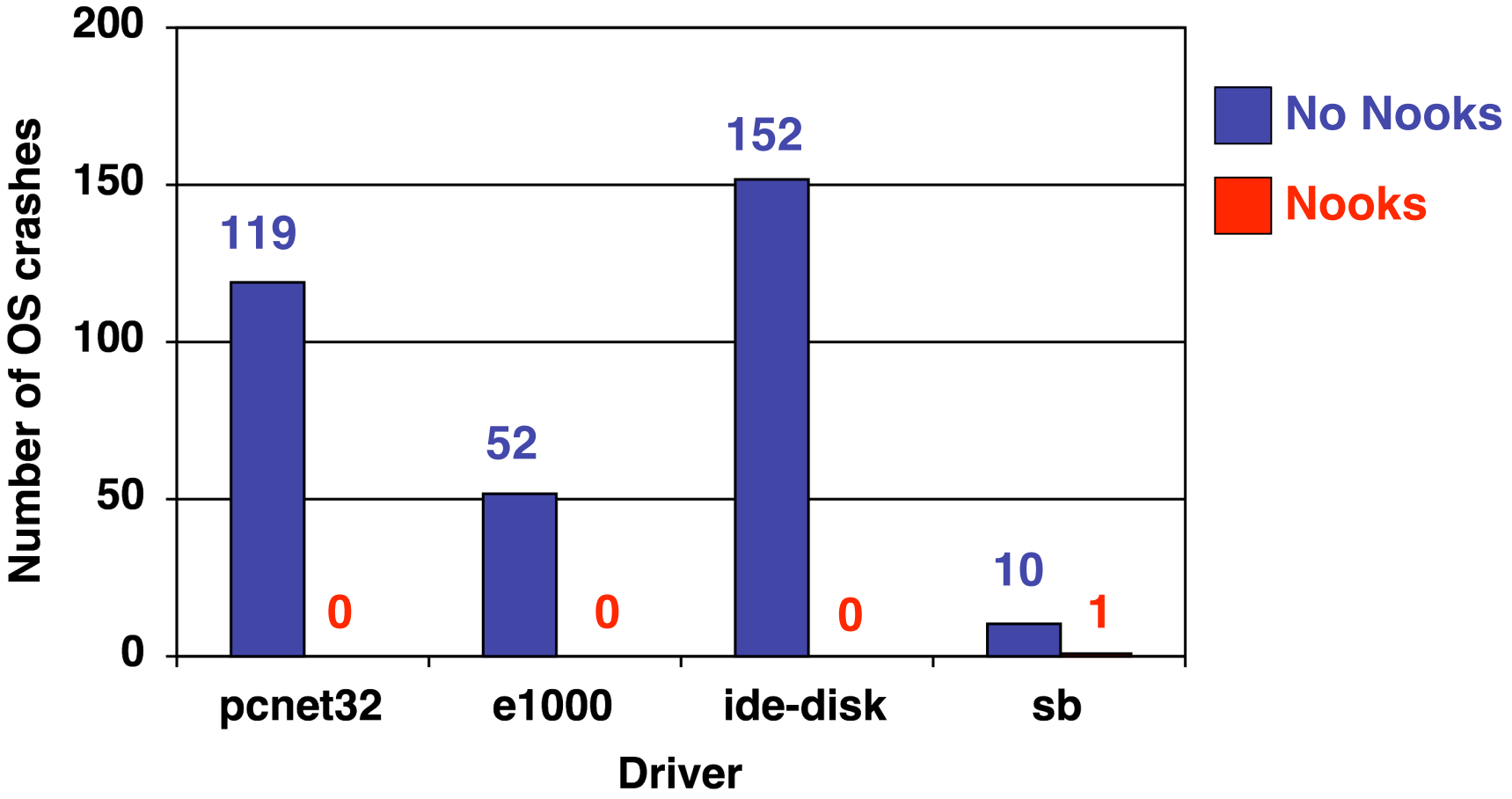
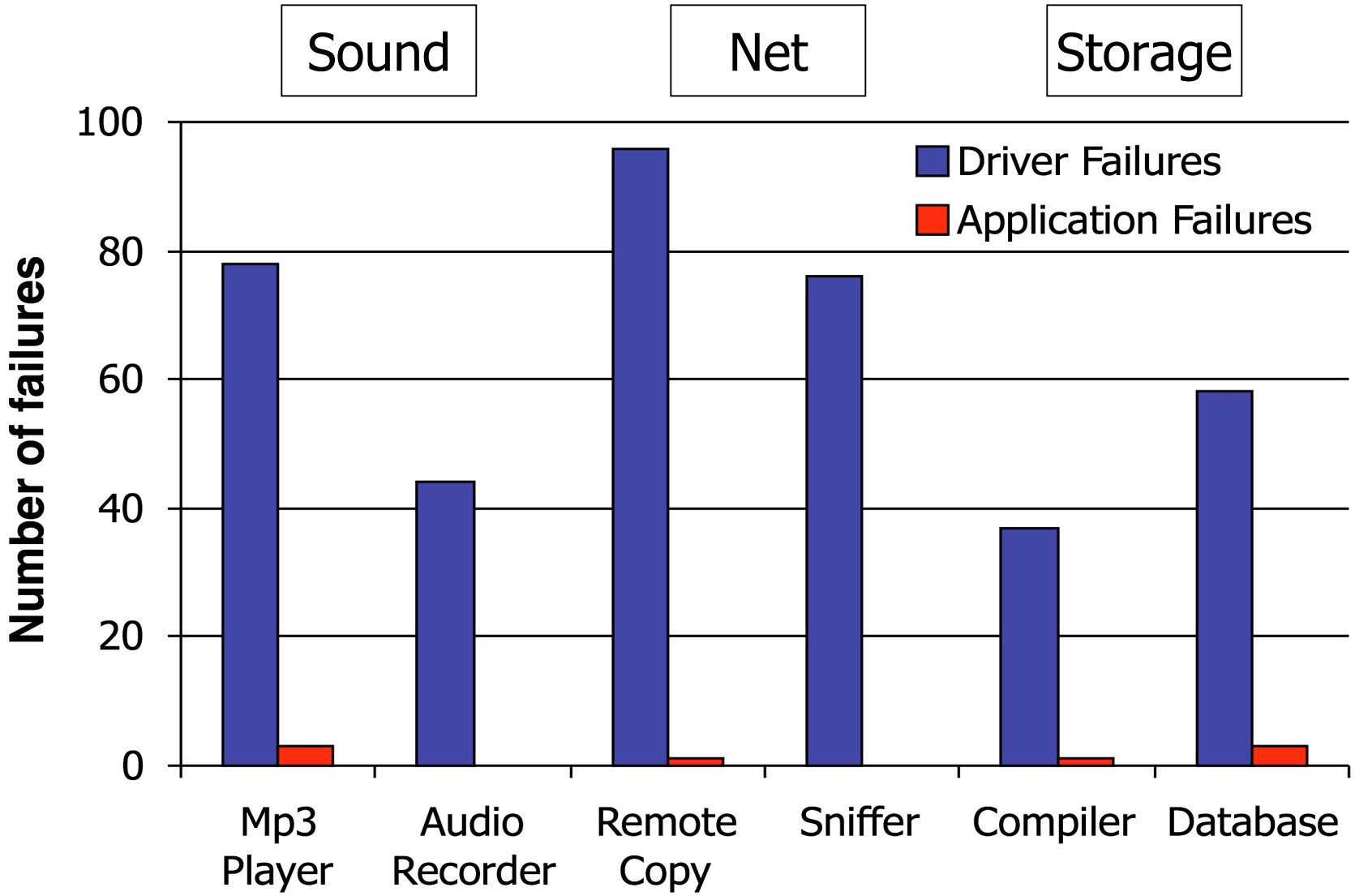
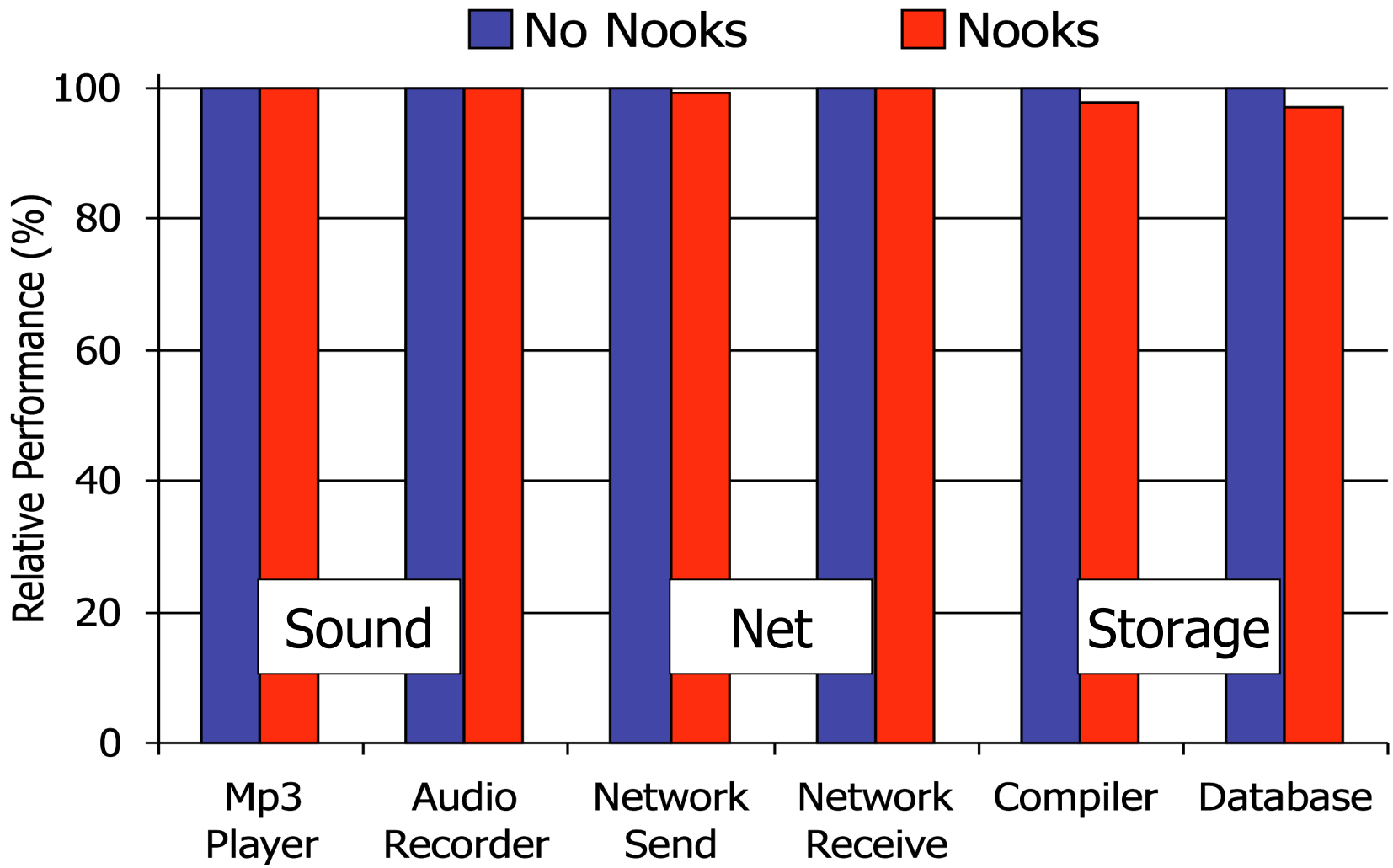


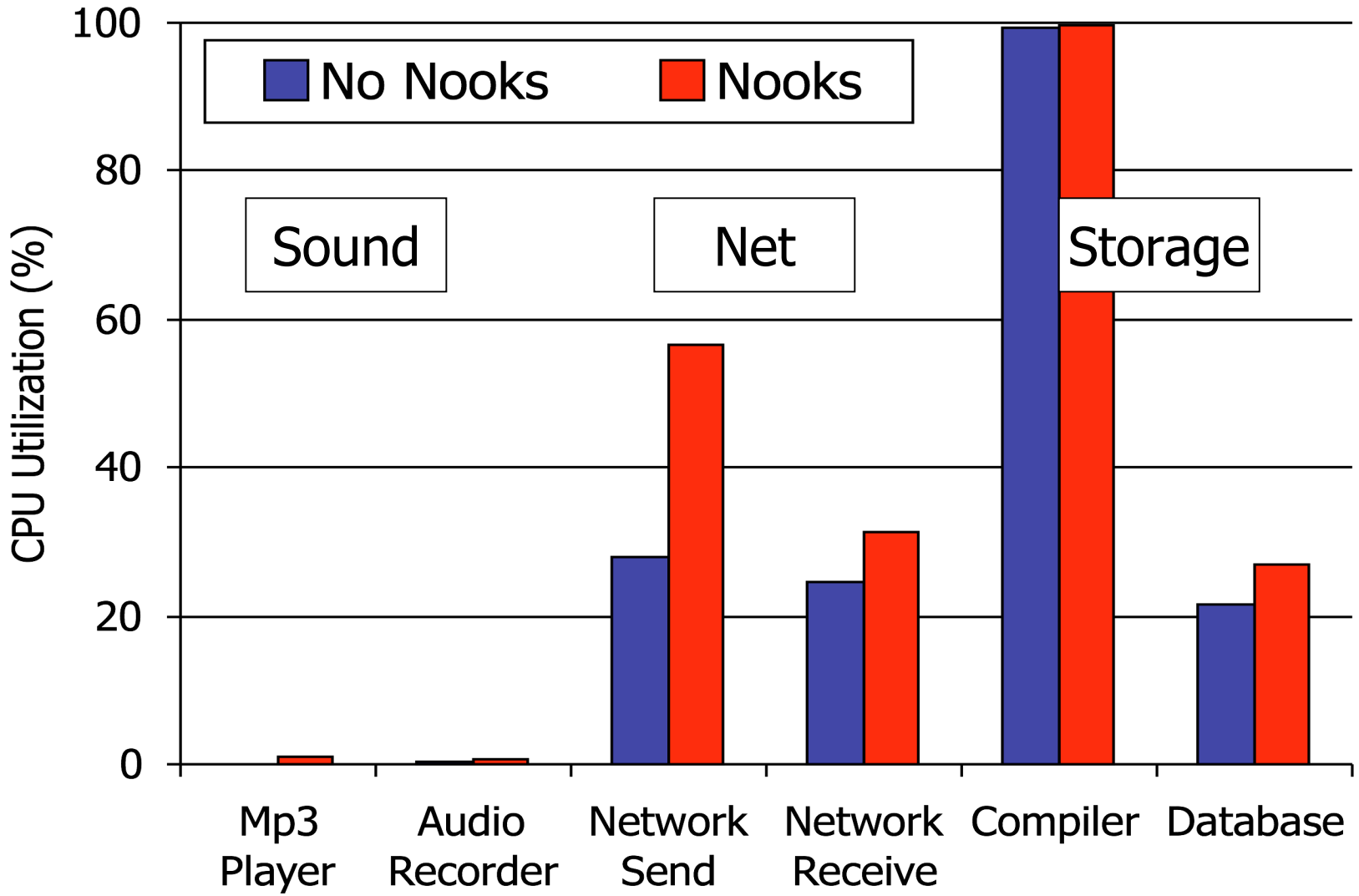
Recovery Works



Relative Performance



CPU Usage


100
80
60
40
20
0
CPU Utilization (%)
No Nooks
Nooks
Sound
Net
Storage
Mp3 Player
Audio Recorder
Network Send
Network Receive
Compiler
Database

Future Work

- Application to virtual machines
  - Apply shadow drivers to Xen
- Fixing drivers
  - Reducing hardware-induced driver failures
  - New driver architectures
  - Testing drivers w/o devices
  - Writing drivers in Python

Conclusion

- Nooks is an architecture and a set of components and techniques for improving system reliability that is:
  - Highly effective at preventing crashes
  - Compatible with existing code
  - Low performance overhead
  - Low implementation cost

Questions?