SyzBridge: Bridging the Gap in Exploitability Assessment of Linux Kernel Bugs in the Linux Ecosystem

Xiaochen Zou, Yu Hao, Zheng Zhang, Juefei Pu, Weiteng Chen, Zhiyun Qian

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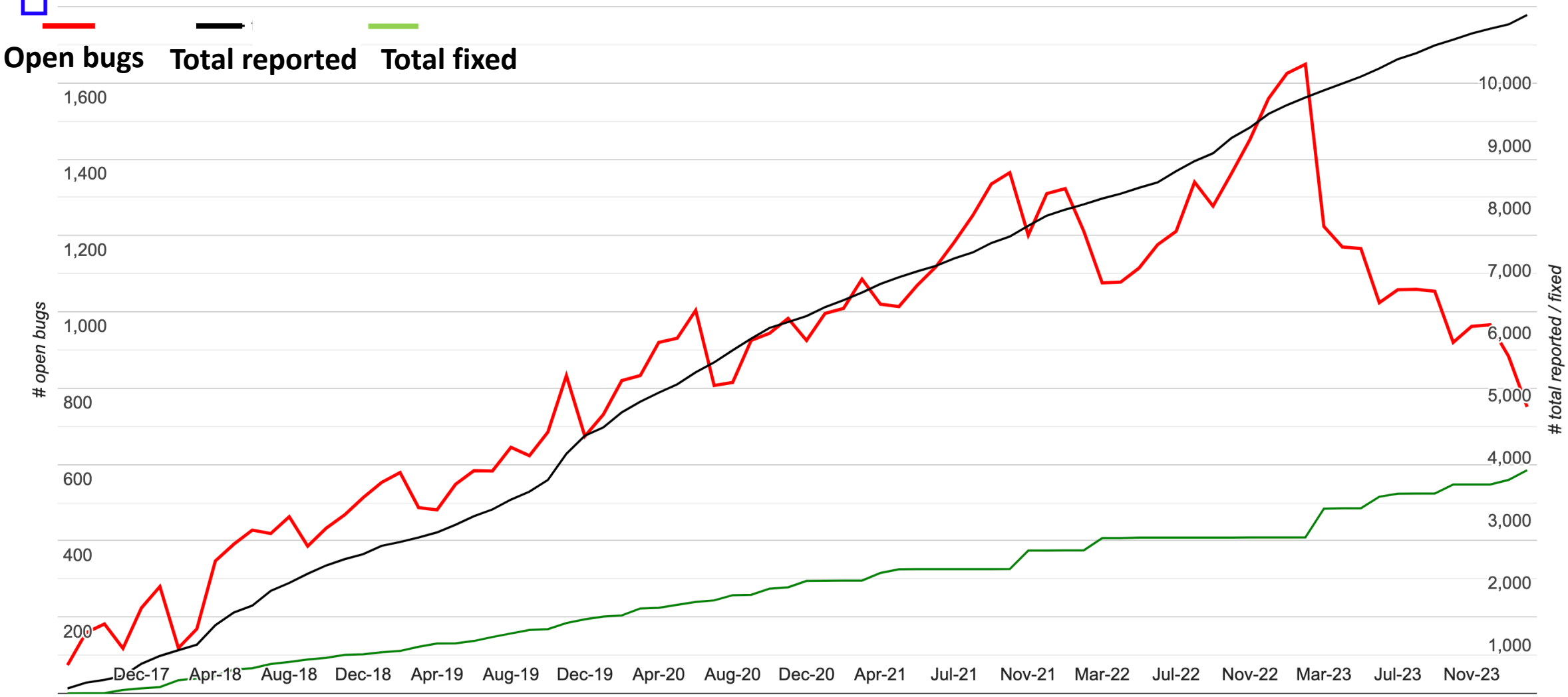
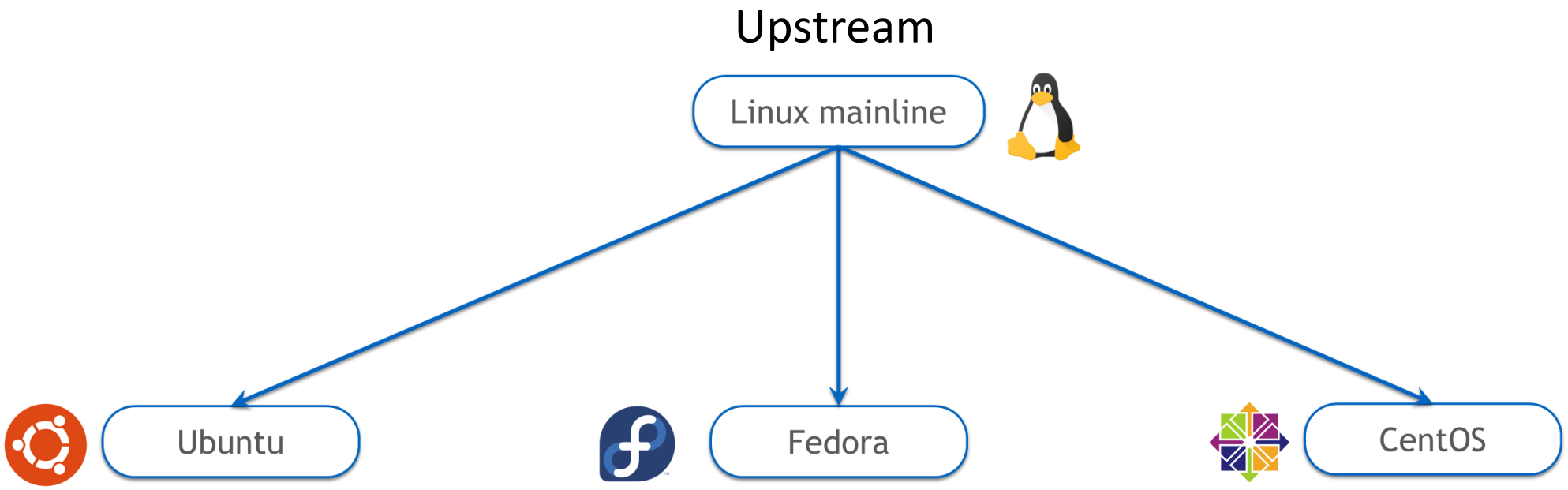
Is Linux kernel safe?

Bugs found by syzbot



Downstream Distros



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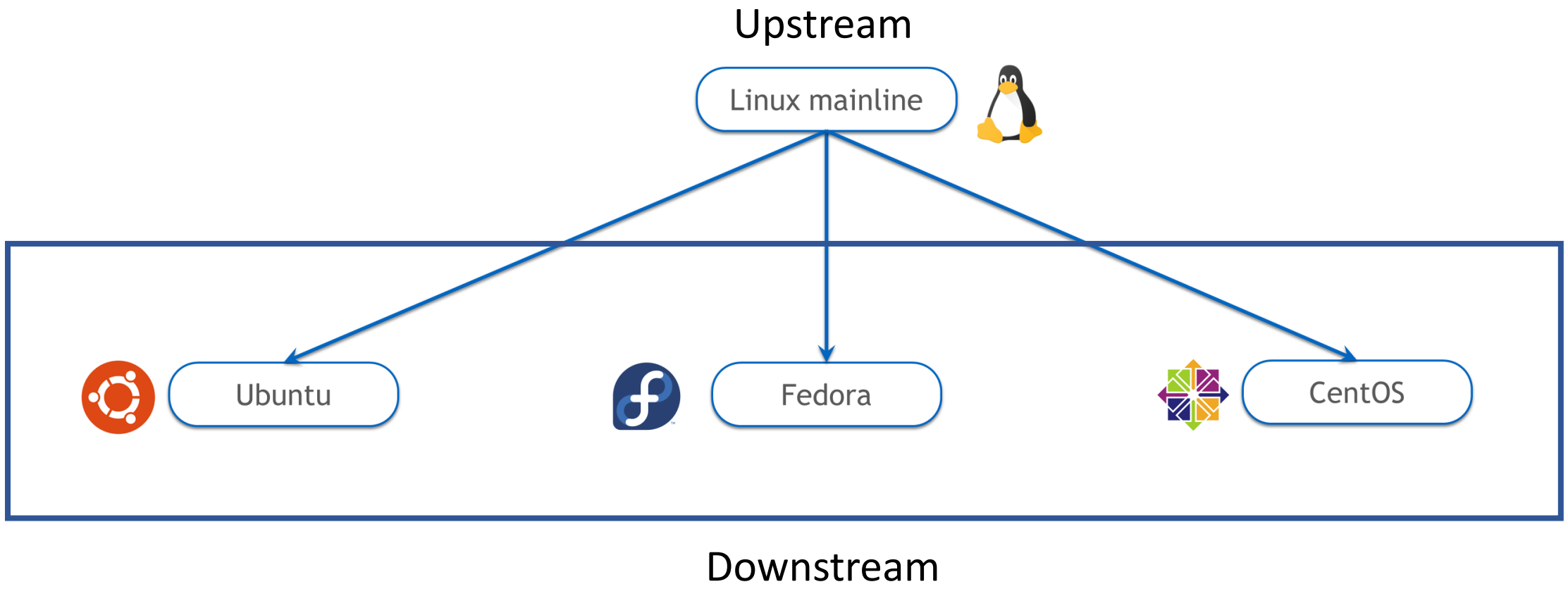

Upstream bugs impact

High-risk upstream bugs: ~183

Valid bugs*	High-risk bugs*
215	17
293	15
202	99
83	4
292	10
85	38
1170	183

Table from {SyzScope: Revealing High-Risk Security Impacts of Fuzzer-Exposed Bugs in Linux kernel} USENIX 2023

Real-world Exploits from syzbot: ~5

CVE-2022-0185
CVE-2021-22600
CVE-2021-22555
CVE-2021-4154
CVE-2021-3715

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High-risk upstream bugs: ~183

Valid bugs*	High-risk bugs*
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15.6% upstream bugs are high-risk

Real-world Exploits from syzbot: ~5

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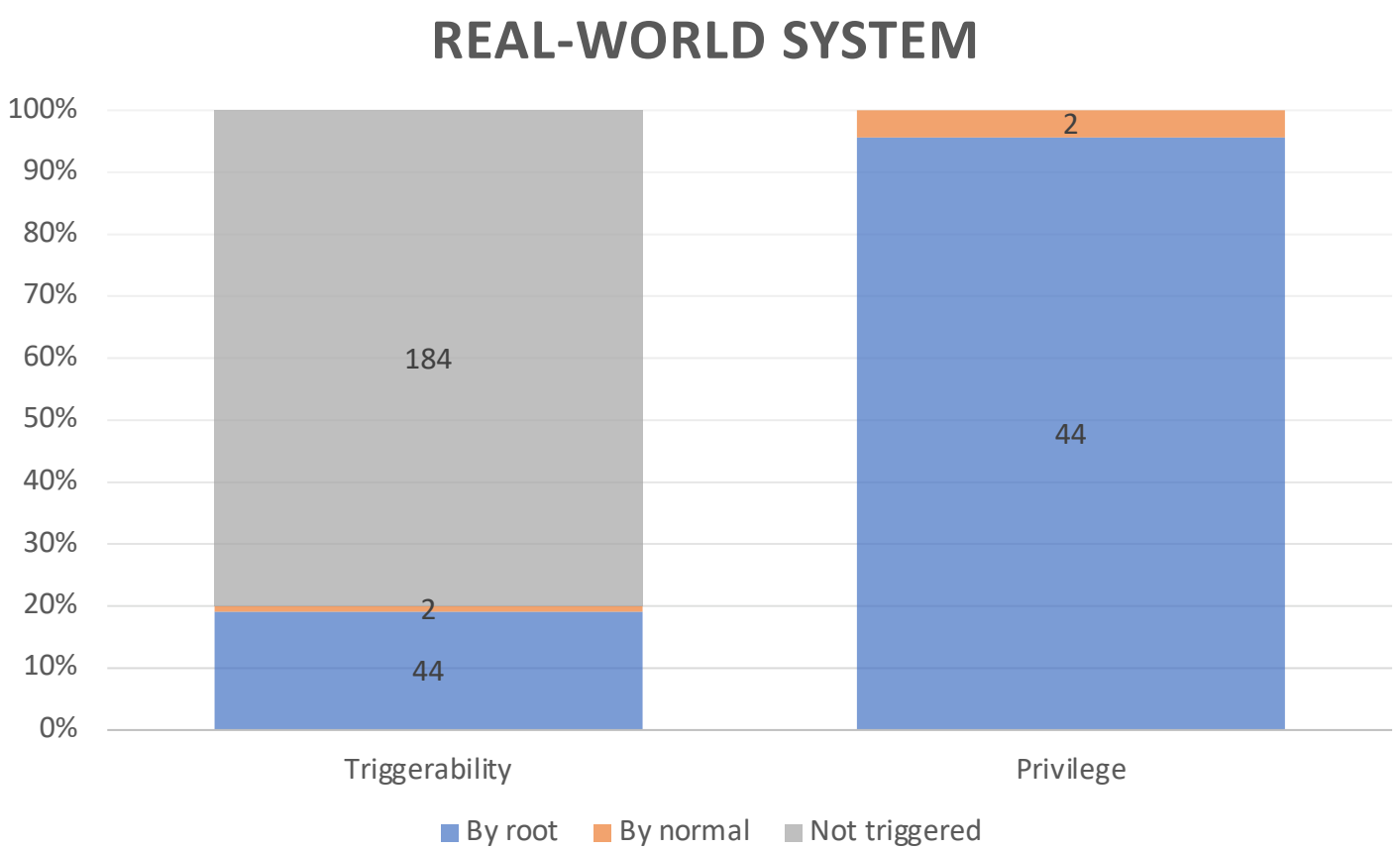
Upstream V.S. Downstream



230 upstream bugs

43 downstream distros

Triggered by root: 19.1%

Triggered by normal: 0.9%

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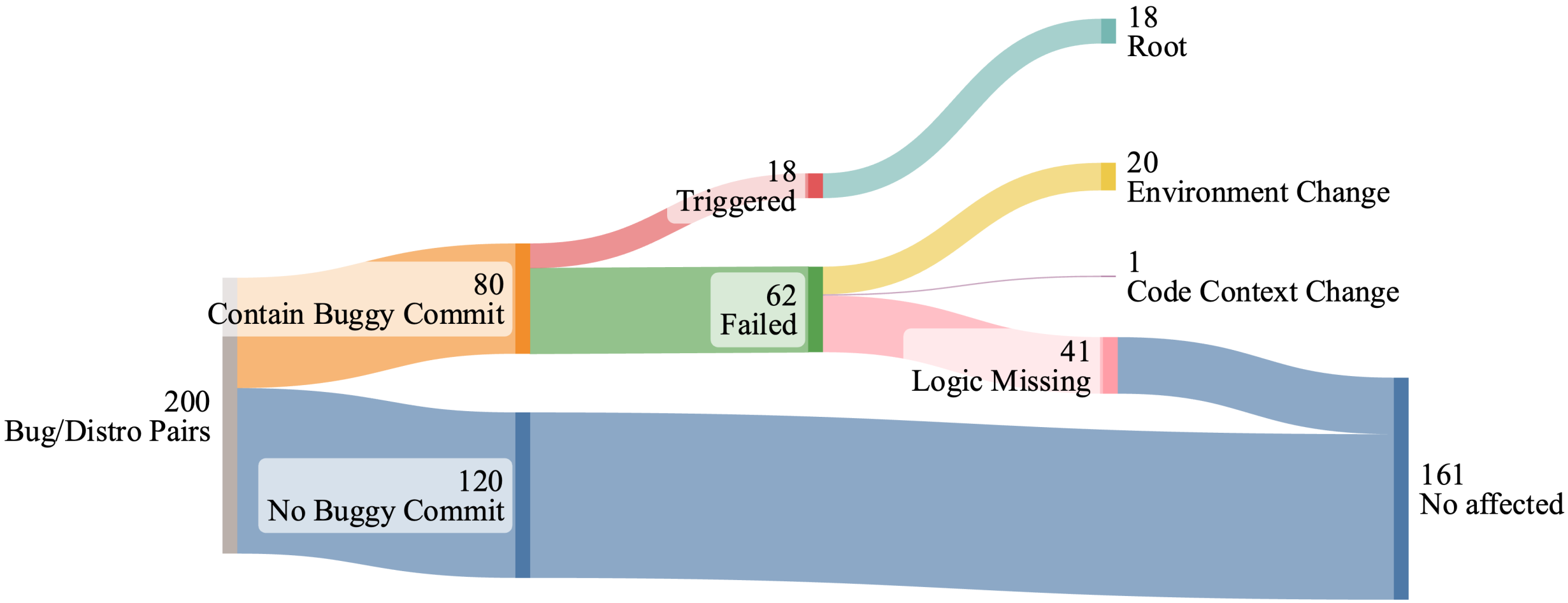
Exploratory Experiment Results



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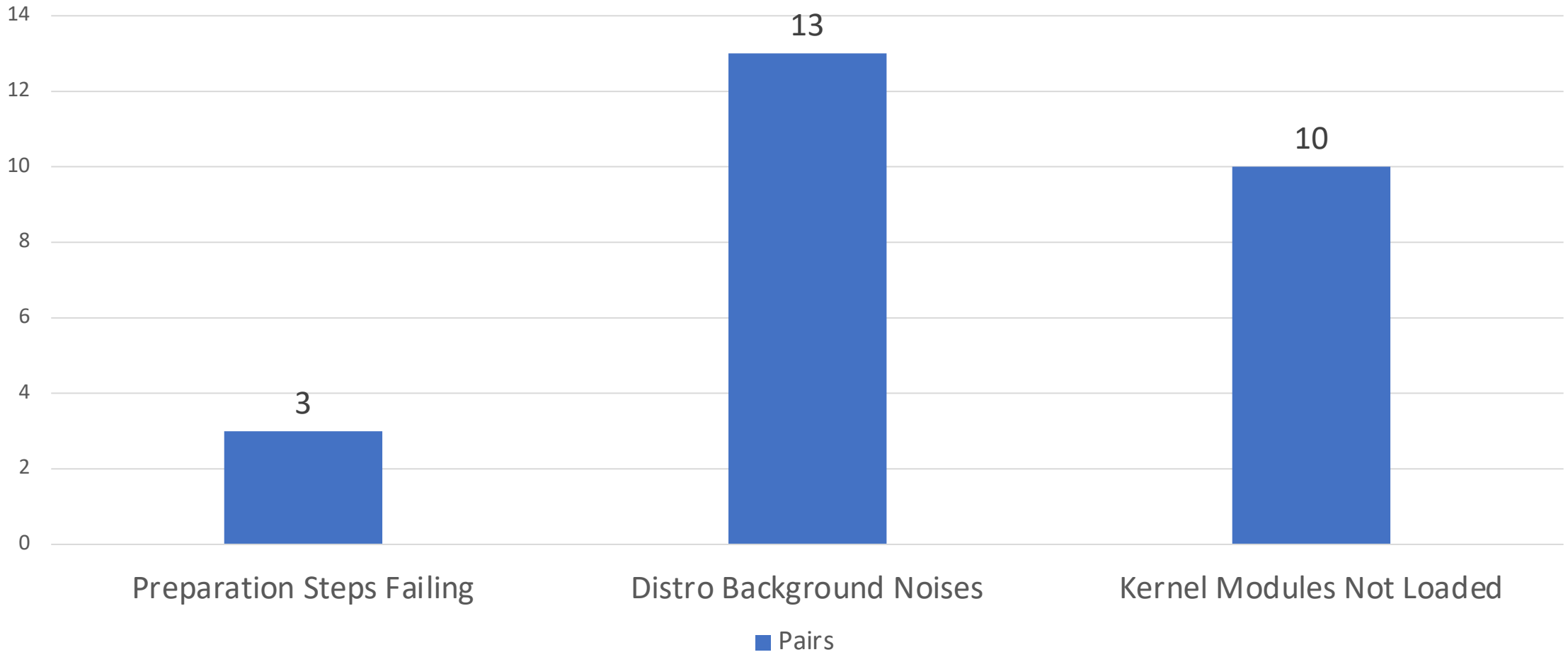
Root Cause – Environment Change



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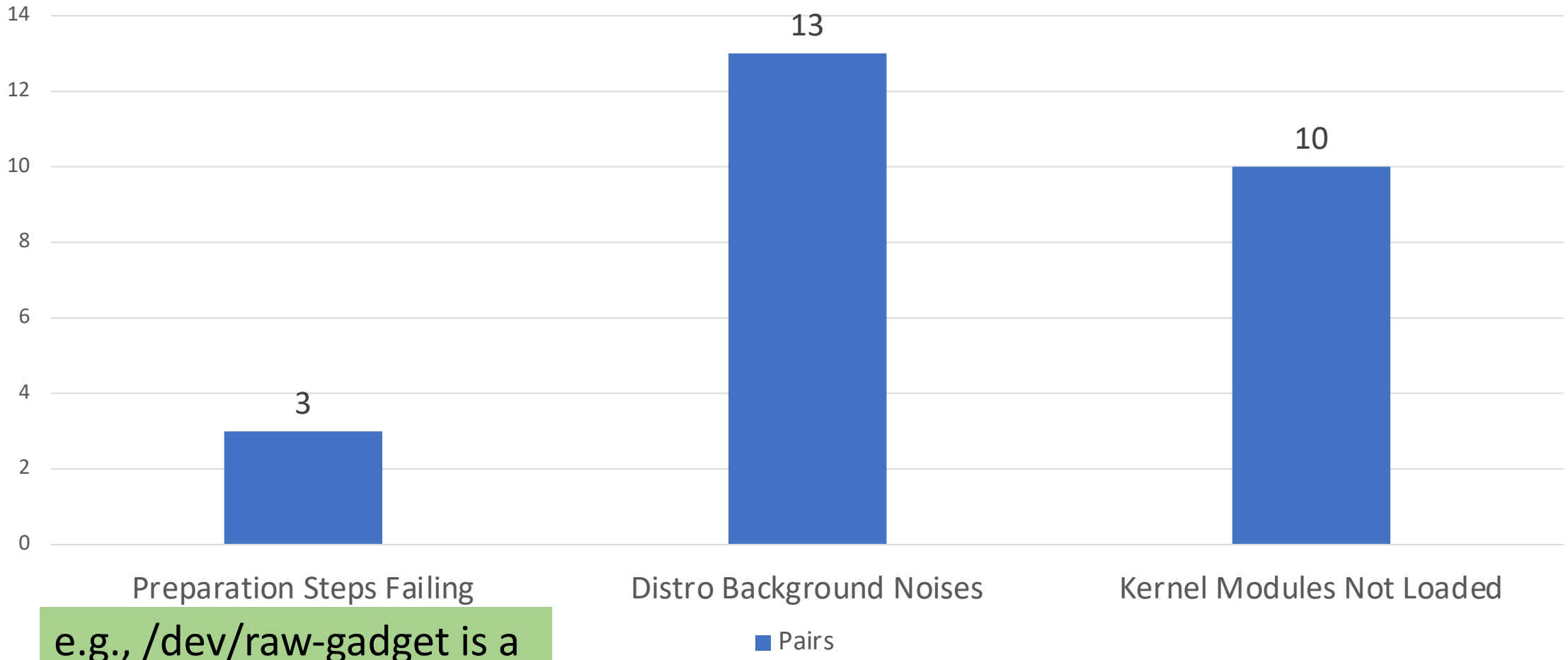

e.g., /dev/raw-gadget is a debug feature, does not exist in production kernel

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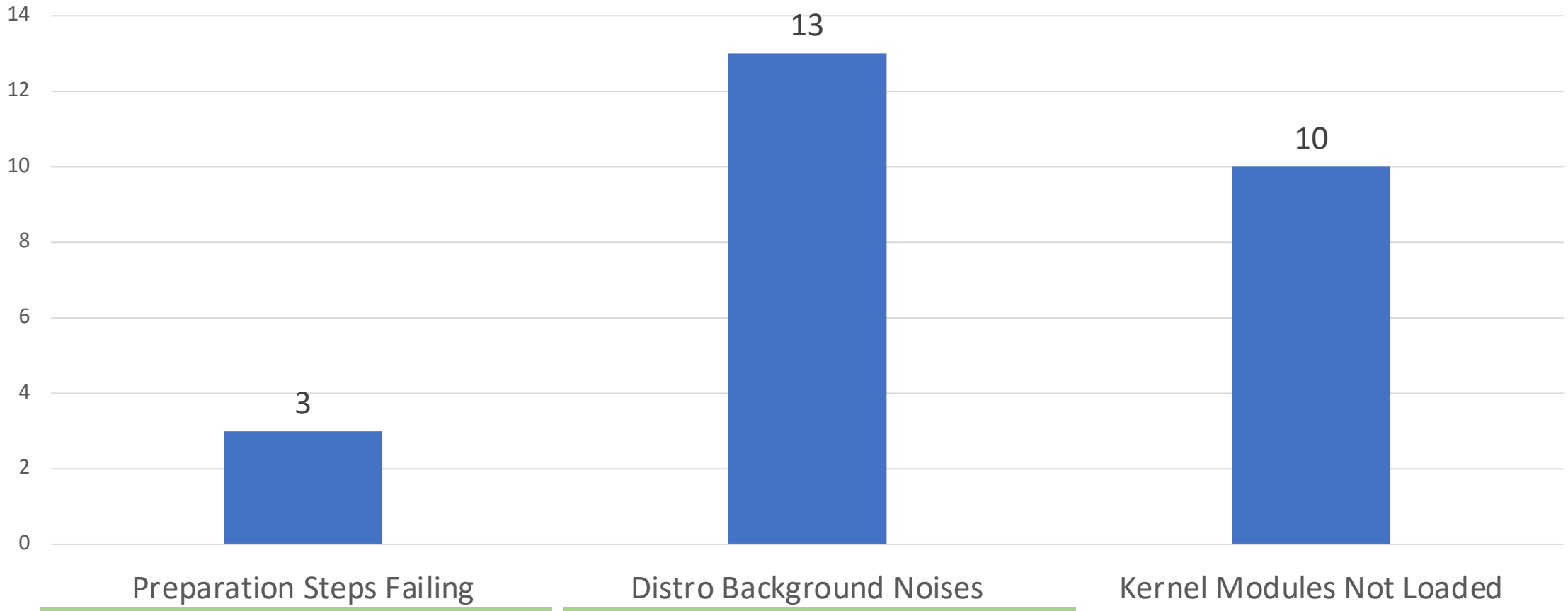

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e.g., Race-condition bugs require more resources (time and cores) to trigger

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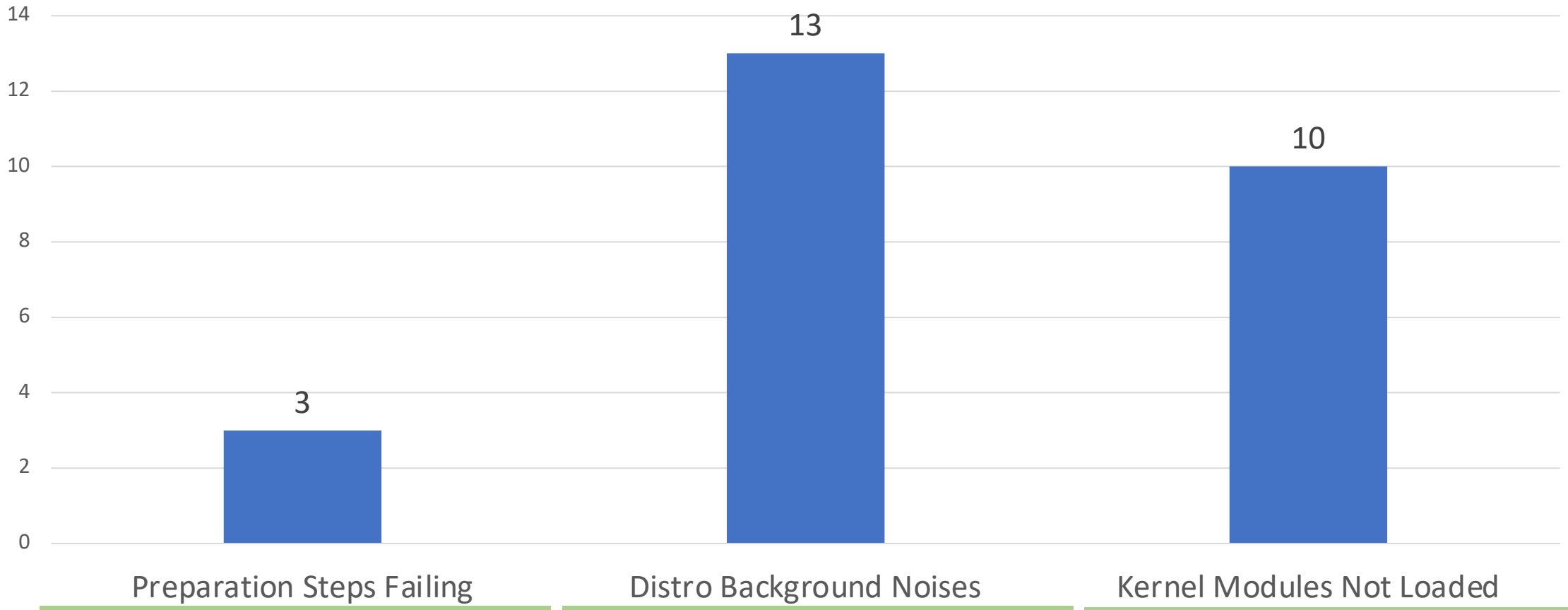

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Kernel modules not loaded

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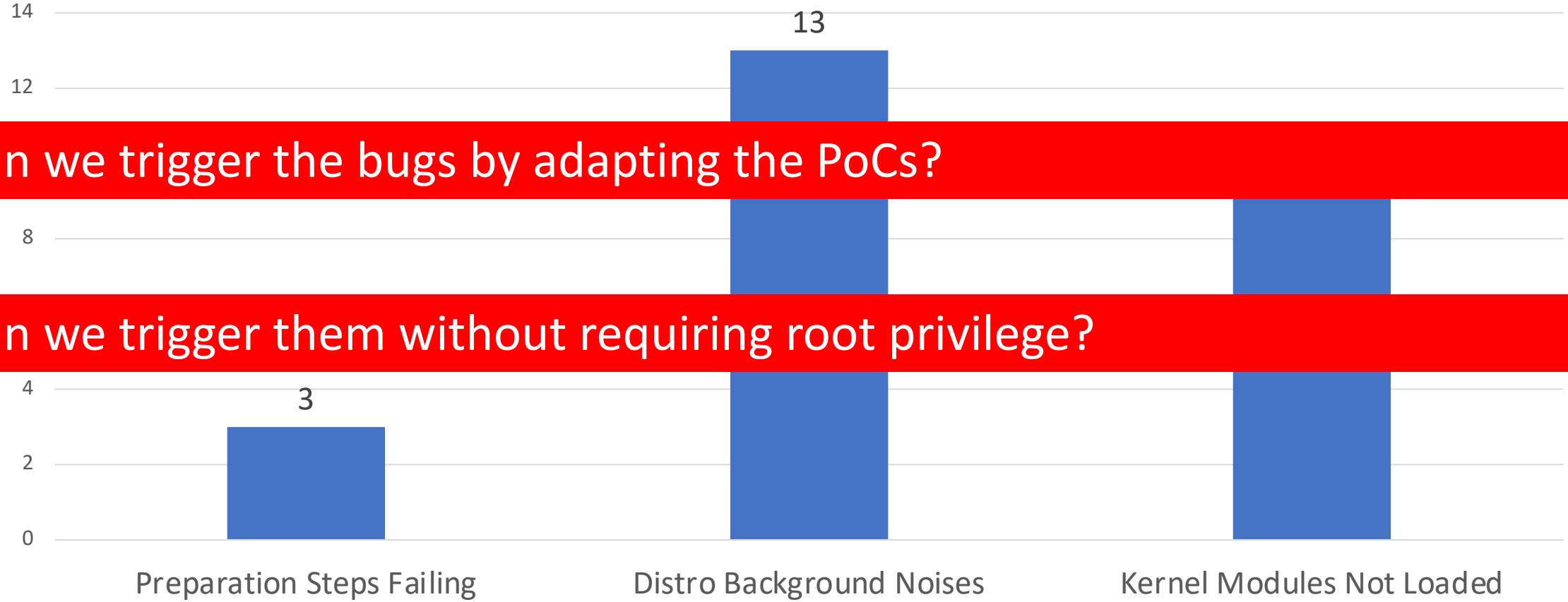

Can we trigger the bugs by adapting the PoCs?

Can we trigger them without requiring root privilege?

e.g., /dev/raw-gadget is a debug feature, does not exist in production kernel

e.g., Race-condition bugs require more resources (time and cores) to trigger

Kernel modules not loaded

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PoC Adaptation

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Preparation Steps Failing

- Rule out unnecessary preparation steps

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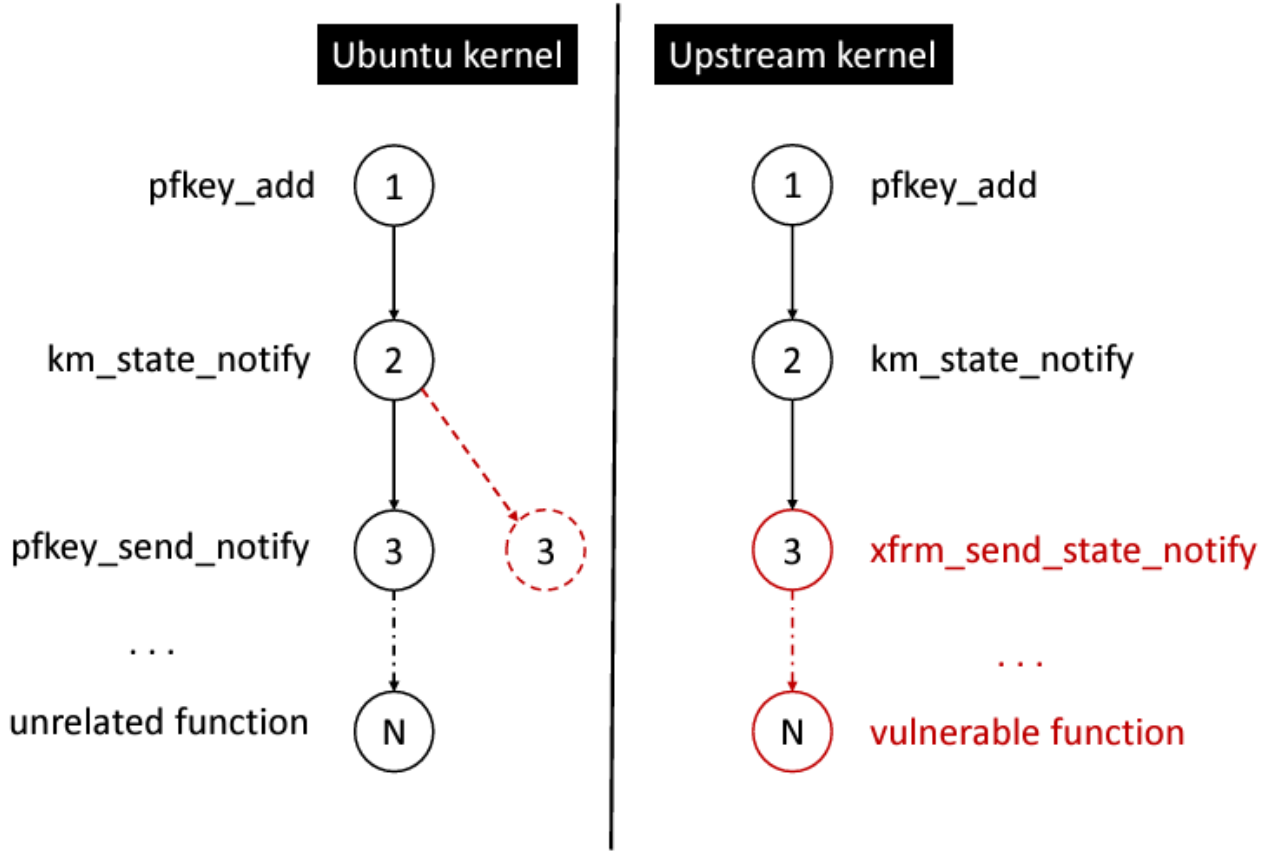
Distro Background Noises

- Force to free occupied resources and enable “for loop” in PoC for data collision

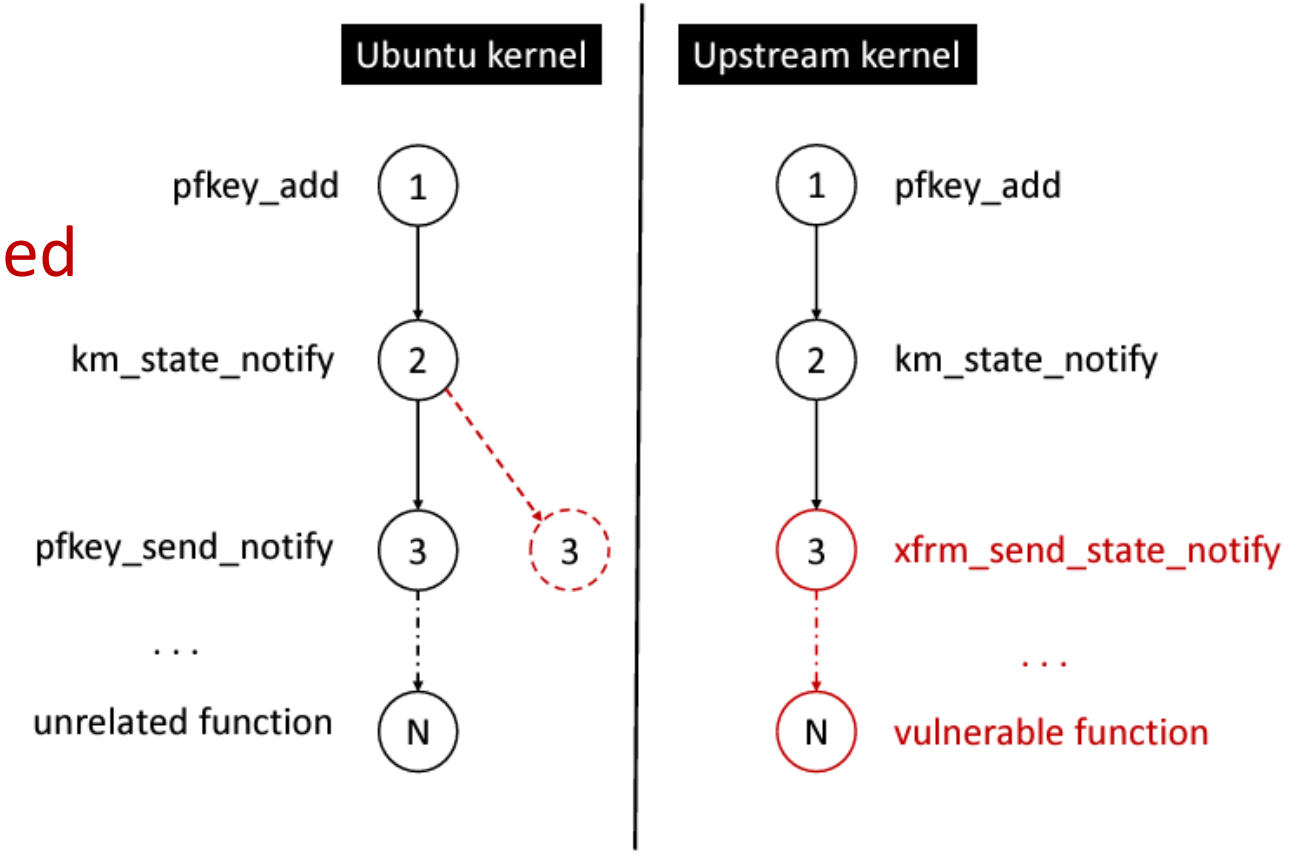
PoC Adaptation



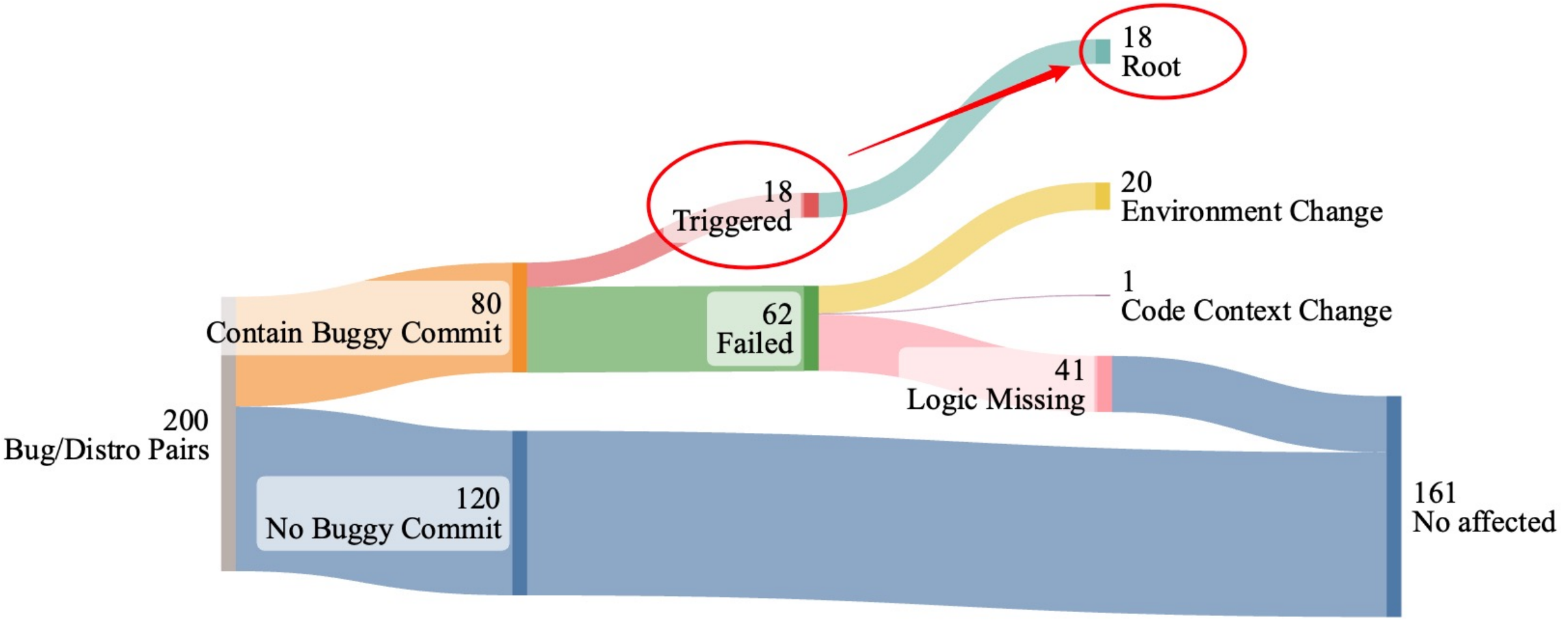
PoC Adaptation

Necessary Kernel Modules Not Loaded

- Using kernel trace to identify the missing kernel modules
- Load the missing modules by *modprobe*



Privilege Downgrading



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Privilege Downgrading

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Kernel Internal Privilege Check

- *kernel capability check*

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1. Monitoring ns_capable function

2. Force PoC using namespace

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Kernel Privileged Operation

- *Releasing occupied resources*
- *Mounting filesystem*
- *Using modprobe to load kernel modules*

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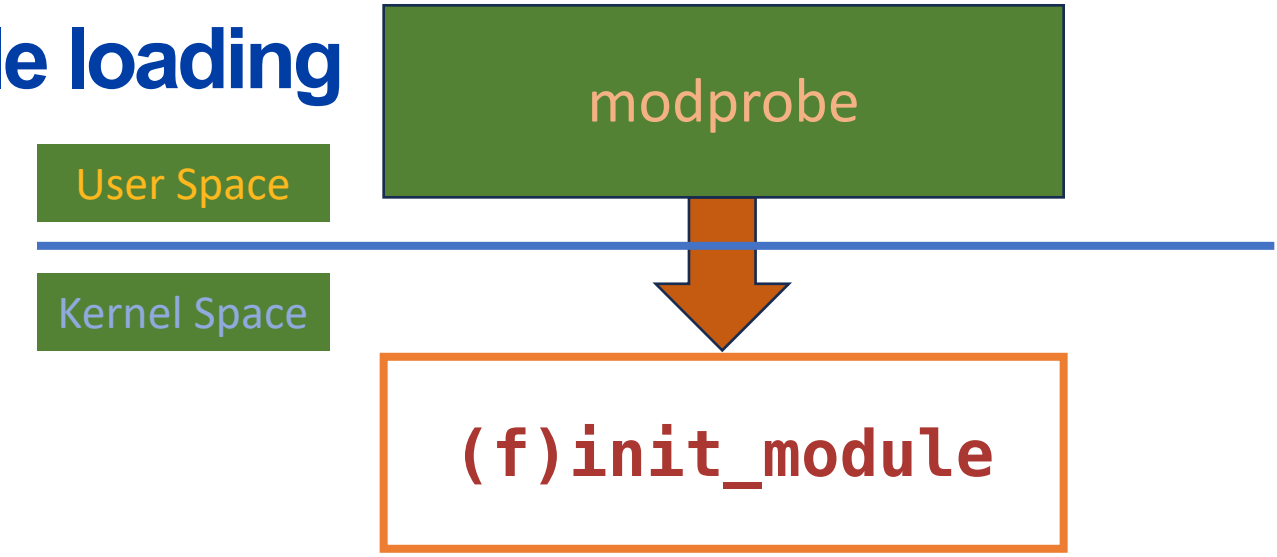
Is modprobe the only way to load kernel modules?

Privilege Downgrading – module loading



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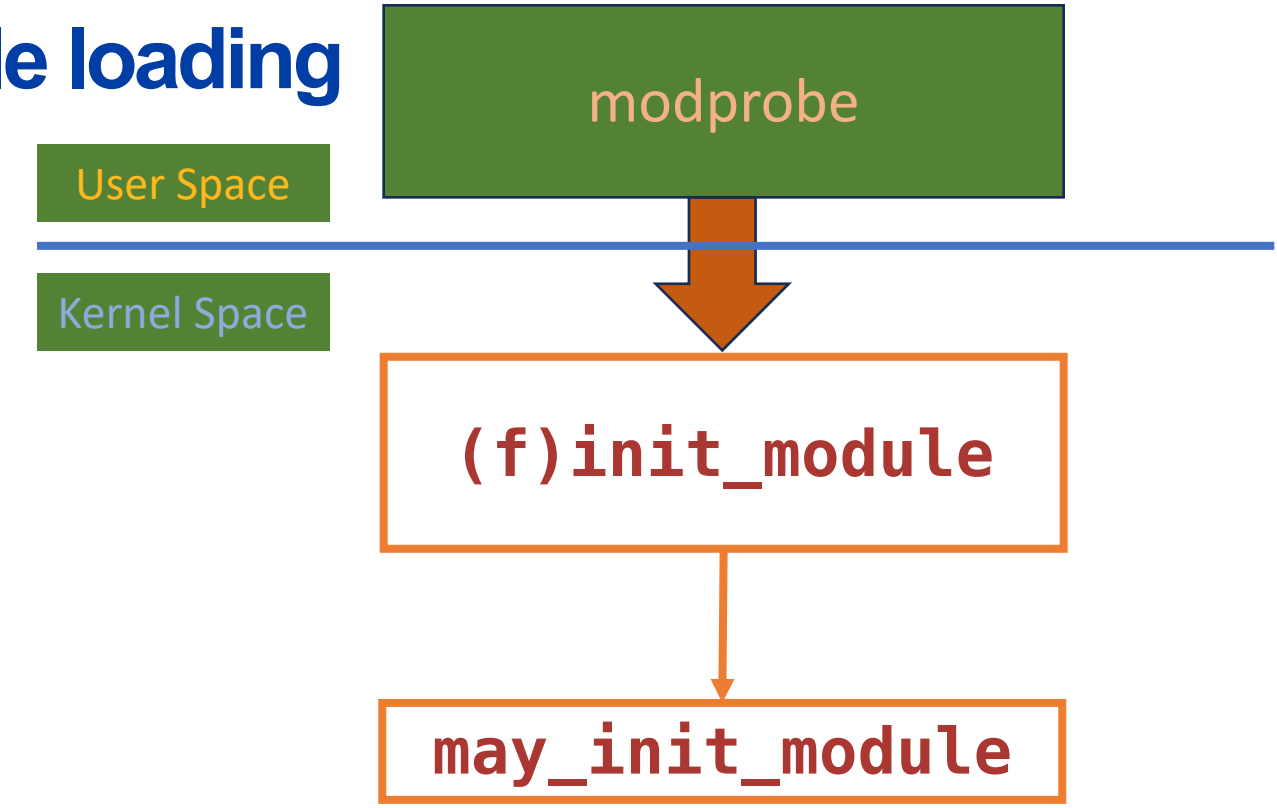

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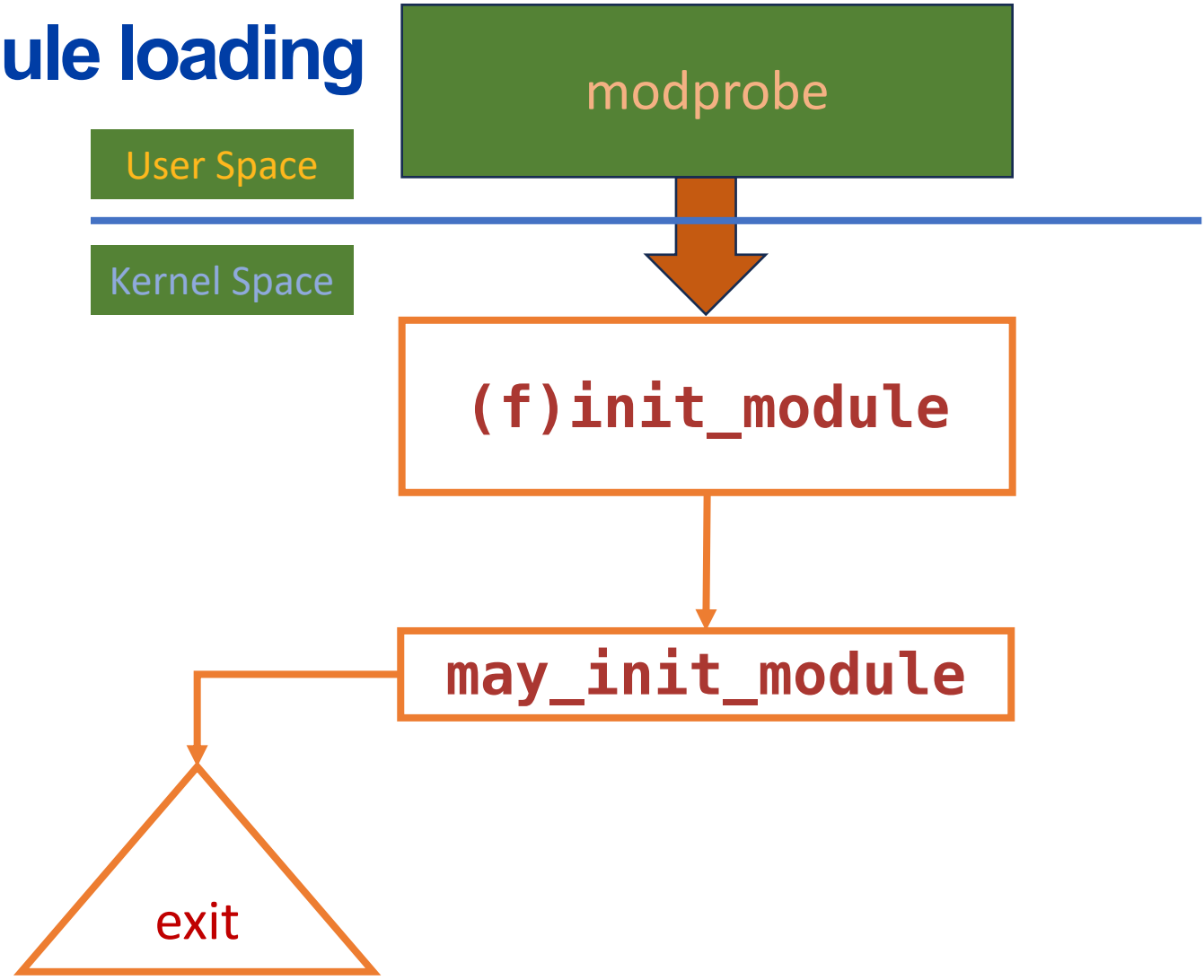

Privilege Downgrading – module loading

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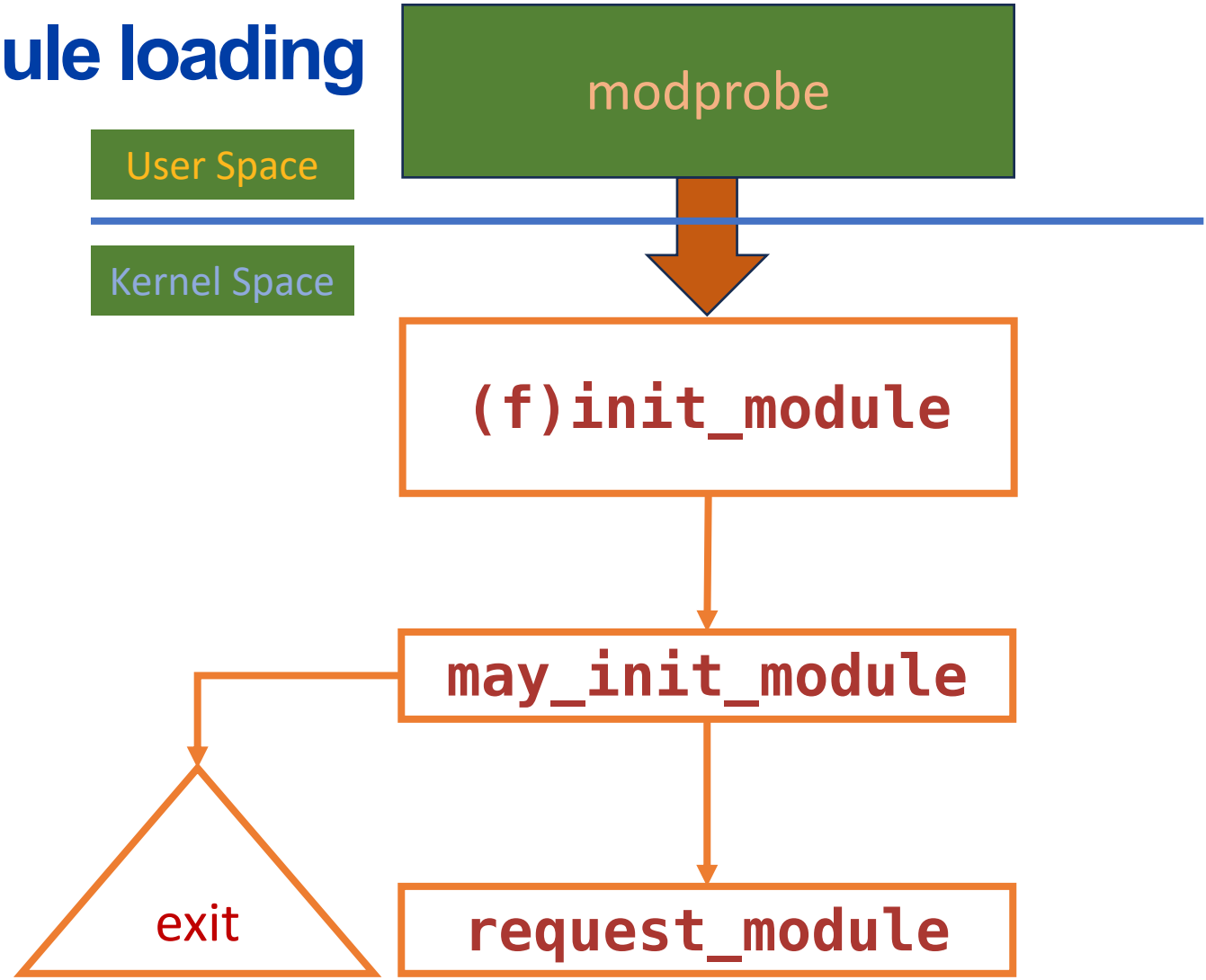

Privilege Downgrading – request_module

```
request_module
```

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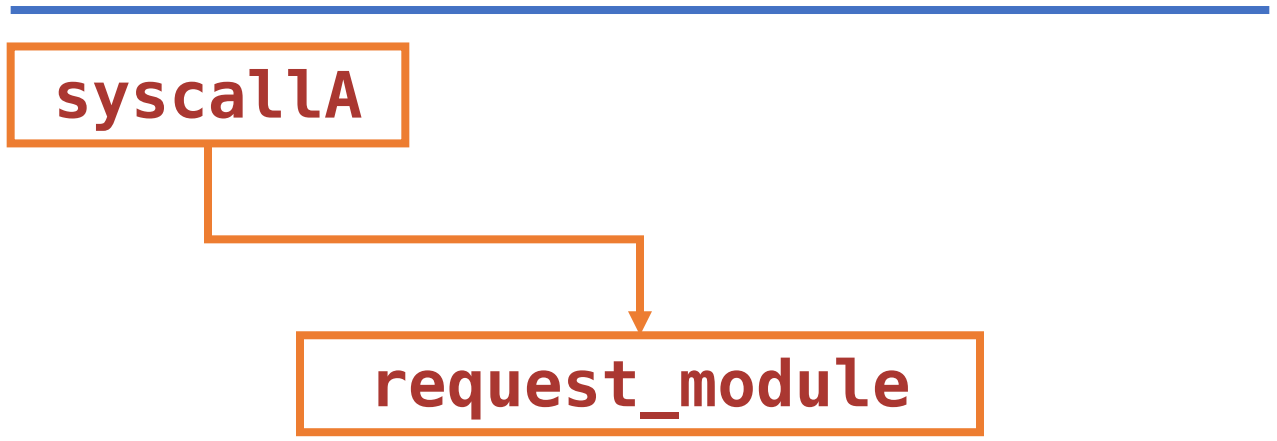

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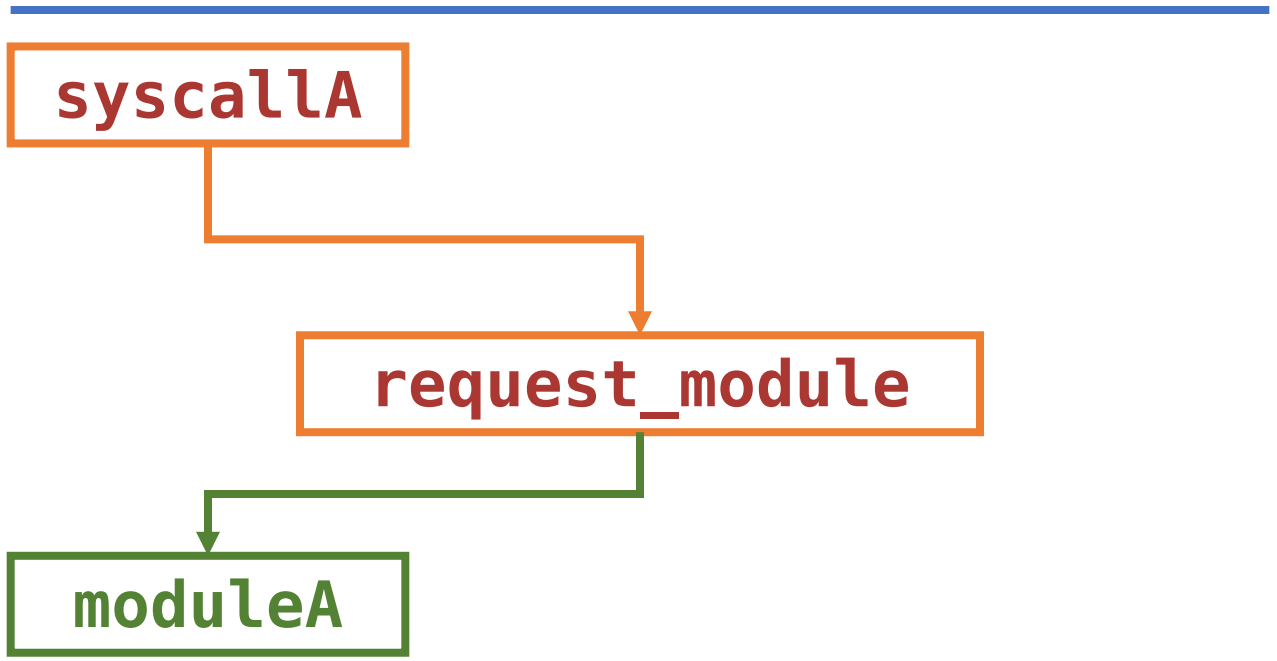

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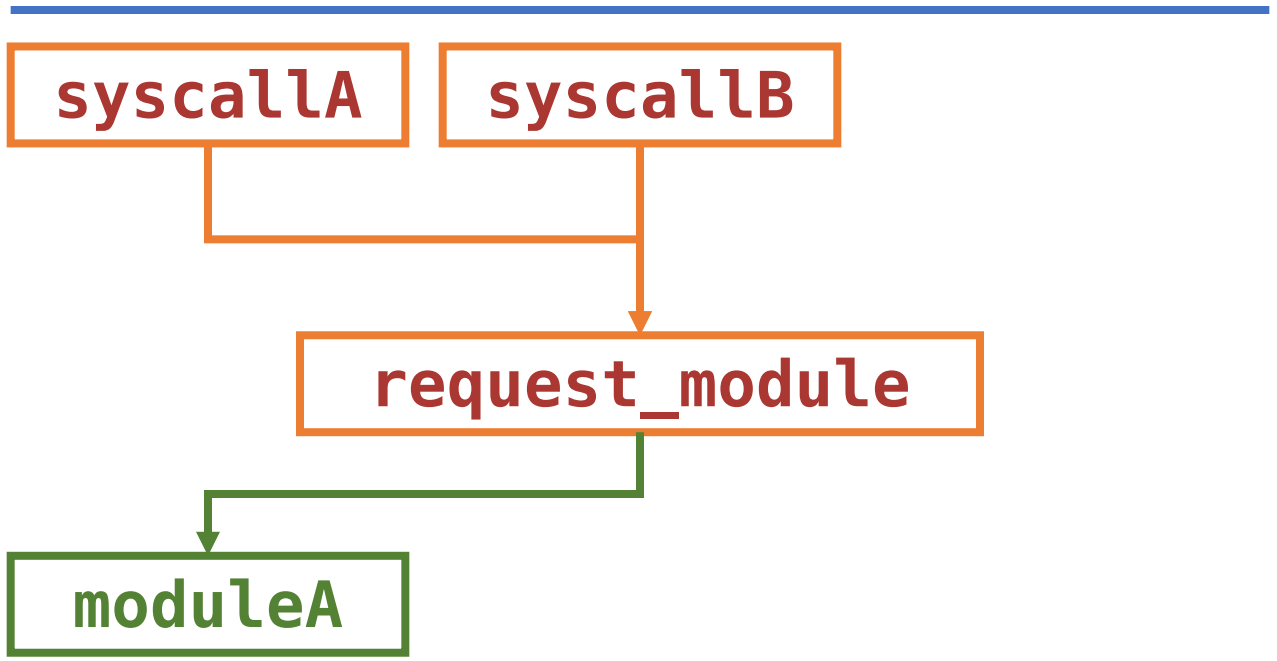

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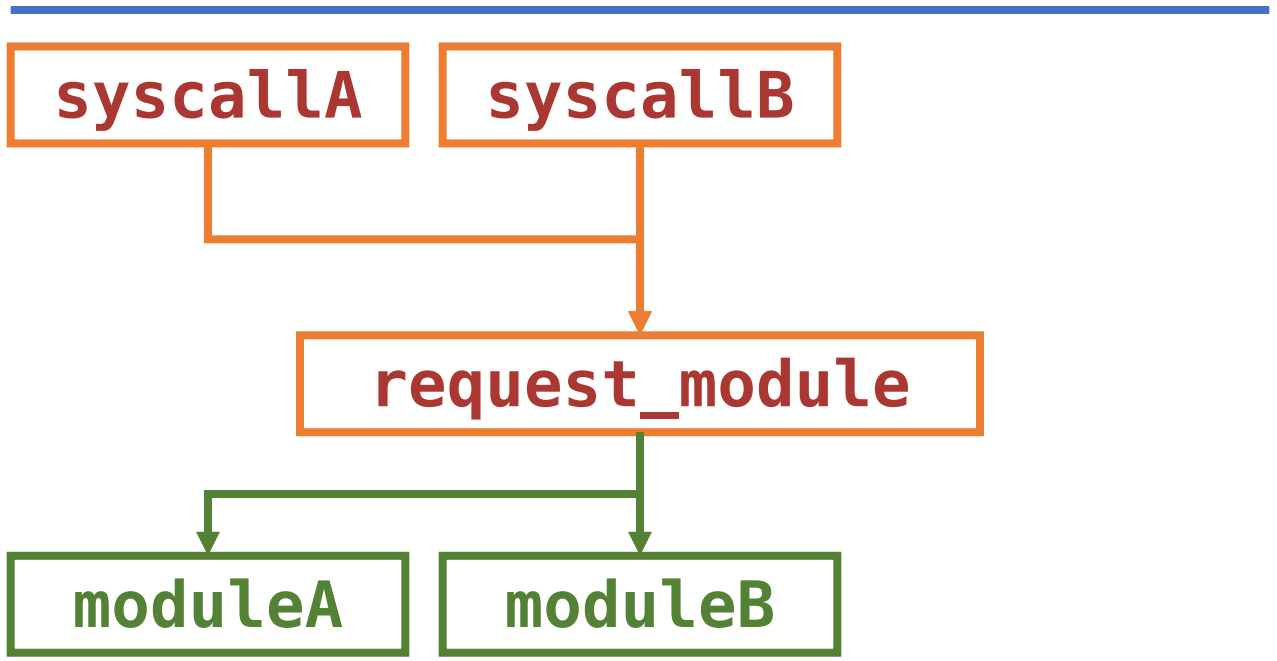

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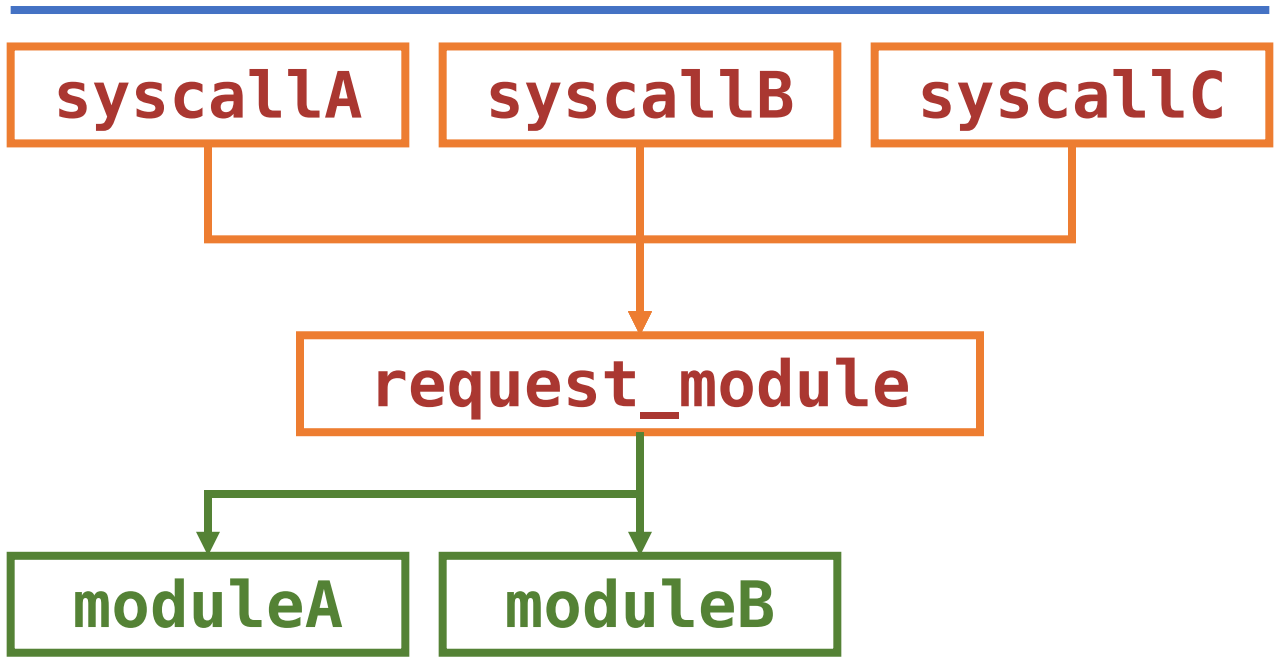

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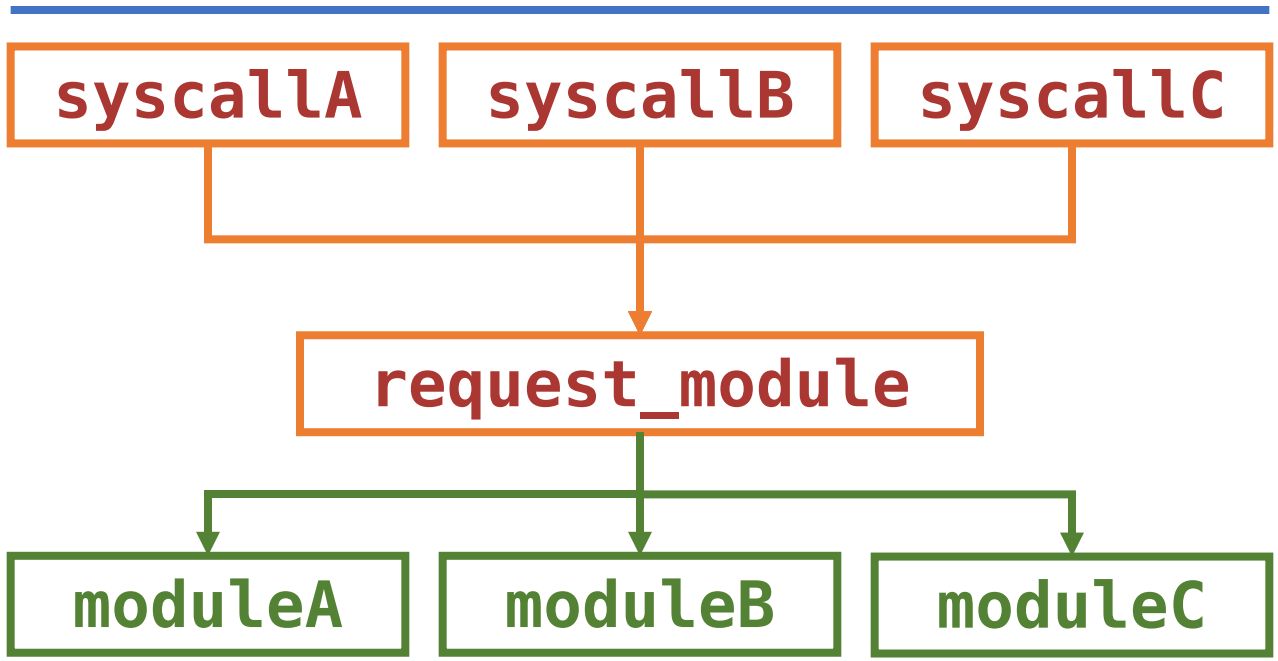

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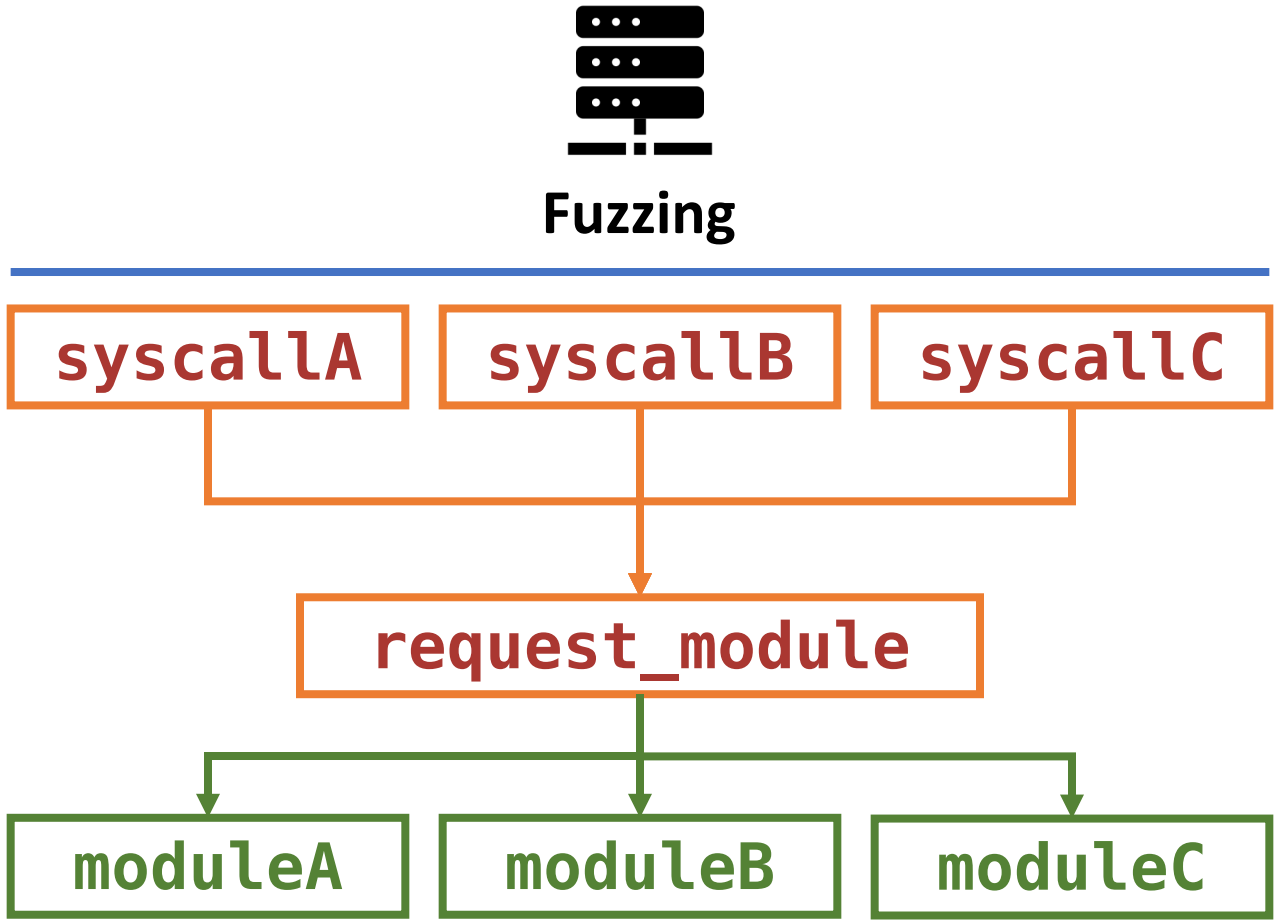

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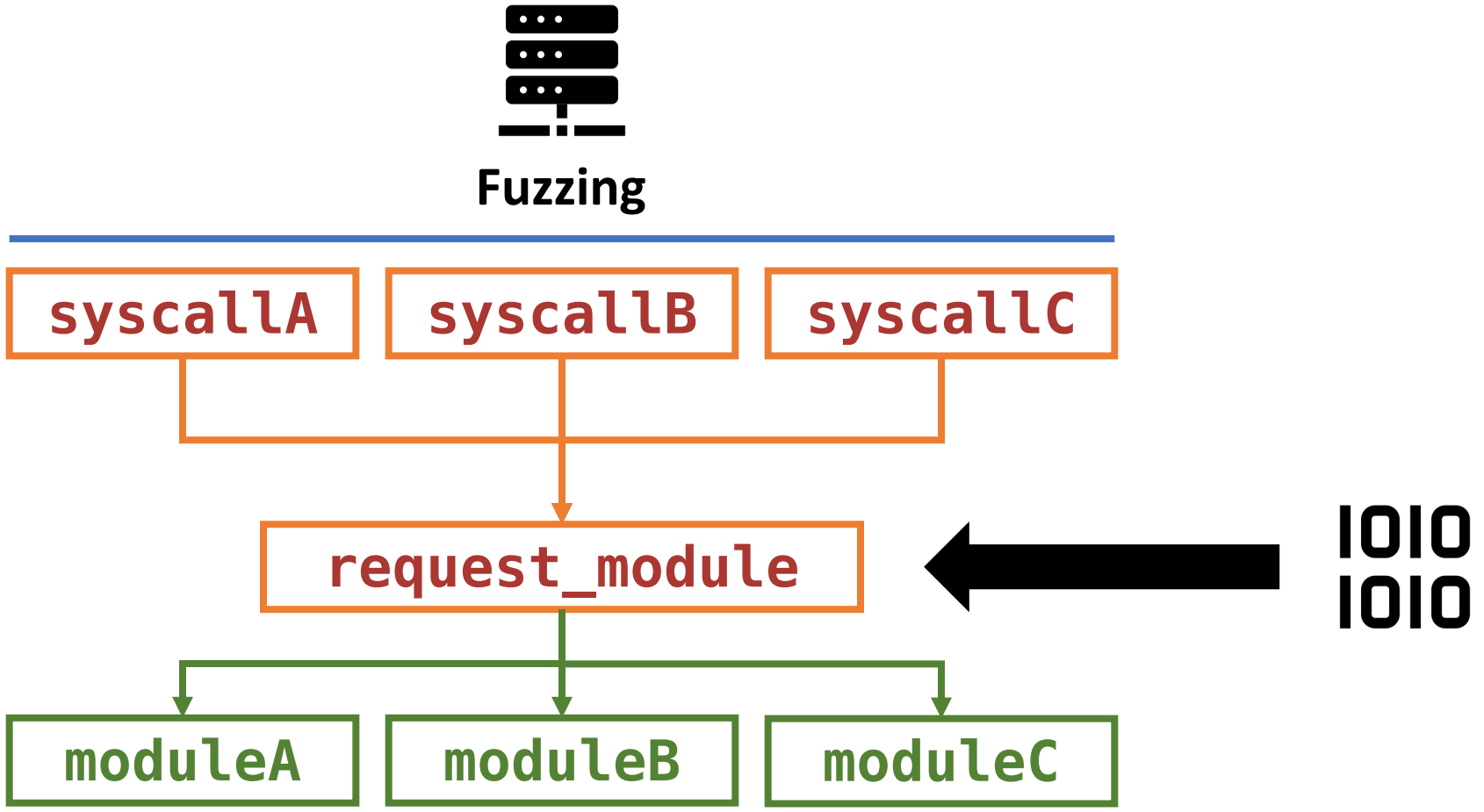

Privilege Downgrading – request_module

Table III: Breakdown of module loading fuzzing results

Distro	crypto	fs	net	tty	other	Sum	Total
Ubuntu	85	58	157	13	3	316	371
Fedora	69	47	106	11	3	236	272
Debian	97	52	132	11	7	299	361
Suse	99	52	145	15	0	311	465

Privilege Downgrading – request_module

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```
modprobe xfrm_user
```

Root

Privilege Downgrading – request_module

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```
modprobe xfrm_user
```

Root

Normal User

```
res = syscall(__NR_socket, AF_NETLINK, SOCK_RAW, NETLINK_XFRM);
```

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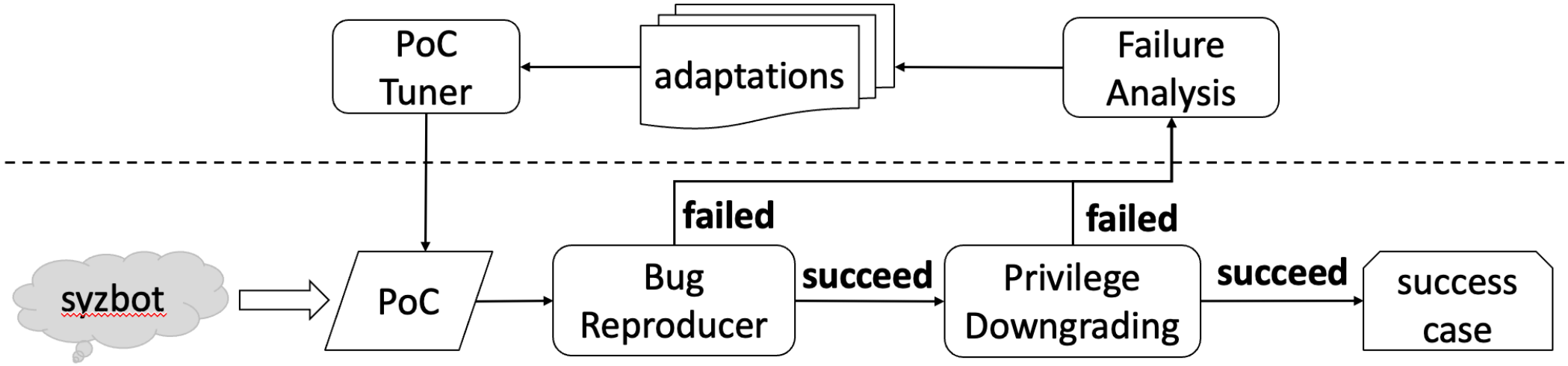
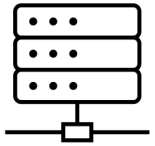
SyzBridge


PoC
Tuner
adaptations
Failure
Analysis
failed
failed
syzbot
PoC
Bug
Reproducer
succeed
Privilege
Downgrading
succeed
success
case

Evaluation – Upstream PoC Adaptations



43 distro major releases

230 upstream KASAN bugs

600 seconds timeout

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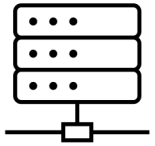
Evaluation – Upstream PoC Adaptations



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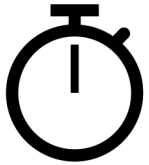

600 seconds timeout

	Root-Triggerable	Normal-User-Triggerable
Ubuntu	55	2
Fedora	58	3
Debian	33	2
Suse	29	1

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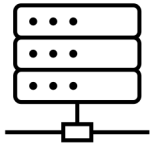
Evaluation – Upstream PoC Adaptations



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	Root-Triggerable			Normal-User-Triggerable		
Ubuntu	55	→	86	2	→	27
Fedora	58	→	77	3	→	46
Debian	33	→	63	2	→	21
Suse	29	→	57	1	→	18

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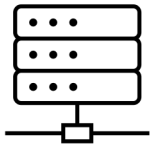
Evaluation – Upstream PoC Adaptations



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	Root-Triggerable				Normal-User-Triggerable			
Ubuntu	55	→	86		2	→	27	
Fedora	58	→	77		3	→	46	
Debian	33	→	63	61%	2	→	21	1300%
Suse	29	→	57		1	→	18	

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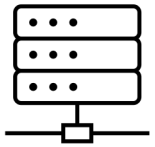
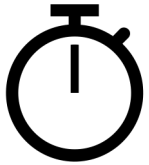
Evaluation – Exploitability Assessment Pipeline.



68 distro major releases

282 upstream high-risk bugs



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5 hours SyzScope

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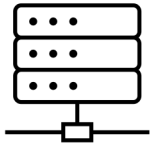

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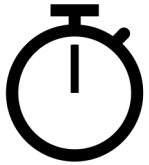

600 seconds timeout
5 hours SyzScope

	Root-Triggerable	Normal-User-Triggerable
Ubuntu	54	1
Fedora	48	3
Debian	47	3
Suse	27	1

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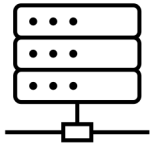
Evaluation – Exploitability Assessment Pipeline.



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600 seconds timeout
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	Root-Triggerable			Normal-User-Triggerable		
Ubuntu	54	→	82	1	→	35
Fedora	48	→	82	3	→	50
Debian	47	→	84	3	→	31
Suse	27	→	42	1	→	9

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Evaluation – Exploitability Assessment Pipeline.

Table VI: High-risk bugs from experiment II

Bug	Bug Primitive	Affect	Before Adaptation		Environment Adaptation			Privilege Adaptation		After Adaptation	
			root	normal	EA1	EA2	EA3	PA1	PA2	root	normal
CVE-2022-27666*	OOB W	UFD	F	-	-	UD	UD	UD	UFD	-	UFD
CVE-2022-0185	OOB W	UFD	UFD	-	-	-	-	-	UFD	-	UFD
CVE-2021-22600	DF	UFD	UFD	-	-	-	-	-	UFD	-	UFD
CVE-2021-22555	OOB W	UFD	F	-	-	UD	UD	UD	UFD	-	UFD
CVE-2021-4154	CFH	UFD	UFD	-	-	-	-	-	UFD	-	UFD
CVE-2021-3715	UAF W	U	U	-	-	-	-	-	U	-	U
cf7393b*	UAF W	UFD	UFD	-	-	-	-	-	UF	D	UF
4b0830a	UAF W	UFD	U	D	-	-	F	-	F	U	FD
e67f2fc	UAF W	UFD	-	-	-	UFD	-	-	UFD	-	UFD
2389bfc*	CFH	UFD	UFD	-	-	-	-	-	F	UD	F
403eb21	CFH	UFS	UF	-	S	-	-	-	UF	S	UF
f4c90f2*	OOB W	UFDS	UFDS	-	-	-	-	-	UFS	D	UFS
380acd1*	DF	UF	UF	-	-	-	-	-	UF	-	UF
b53aed2	OOB W	UFD	UFD	-	-	-	-	-	UFD	-	UFD
e2d0f38	CFH	F	-	-	-	F	-	-	F	-	F
d35e6e8	NPD W	UFD	UFD	-	-	-	-	-	UFD	-	UFD
60e3243	CVW	UFDS	UFDS	-	-	-	-	-	UFDS	-	UFDS
a53b68e	OOB W	UF	F	-	-	U	U	U	UF	-	UF
5ad0e07	NPD W	UF	UF	-	-	-	-	-	UF	-	UF

See the complete table in our paper

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Evaluation – Exploitability Assessment Pipeline.

Table VI: High-risk bugs from experiment II

Bug	Bug Primitive	Affect	Before Adaptation		Environment Adaptation			Privilege Adaptation		After Adaptation	
			root	normal	EA1	EA2	EA3	PA1	PA2	root	normal
CVE-2022-27666*	OOB W	UFD	F	-	-	UD	UD	UD	UFD	-	UFD
CVE-2022-0185	OOB W	UFD	UFD	-	-	-	-	-	UFD	-	UFD
CVE-2021-22600	DF	UFD	UFD	-	-	-	-	-	UFD	-	UFD
CVE-2021-22555	OOB W	UFD	F	-	-	UD	UD	UD	UFD	-	UFD
CVE-2021-4154	CFH	UFD	UFD	-	-	-	-	-	UFD	-	UFD
CVE-2021-3715	UAF W	U	U	-	-	-	-	-	U	-	U
cf7393b*	UAF W	UFD	UFD	-	-	-	-	-	UF	D	UF
4b0830a	UAF W	UFD	U	D	-	-	F	-	F	U	FD
e67f2fc	UAF W	UFD	-	-	-	UFD	-	-	UFD	-	UFD
2389bfc*	CFH	UFD	UFD	-	-	-	-	-	F	UD	F
403eb21	CFH	UFS	UF	-	S	-	-	-	UF	S	UF
f4c90f2*	OOB W	UFDS	UFDS	-	-	-	-	-	UFS	D	UFS
380acd1*	DF	UF	UF	-	-	-	-	-	UF	-	UF
b53aed2	OOB W	UFD	UFD	-	-	-	-	-	UFD	-	UFD
e2d0f38	CFH	F	-	-	-	F	-	-	F	-	F
d35e6e8	NPD W	UFD	UFD	-	-	-	-	-	UFD	-	UFD
60e3243	CVW	UFDS	UFDS	-	-	-	-	-	UFDS	-	UFDS
a53b68e	OOB W	UF	F	-	-	U	U	U	UF	-	UF
5ad0e07	NPD W	UF	UF	-	-	-	-	-	UF	-	UF

See the complete table in our paper

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Takeaway

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Upstream PoCs often fail on downstream OS, but it does not imply the downstream are immune from upstream bugs

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Upstream PoCs can be transformed to downstream-valid PoCs through varied adaptations

A seemingly high-privilege PoCs might be downgraded to low privilege

SyzBridge found >50 syzbot bugs are likely exploitable on at least one downstream distro we tested (whereas only 5 were recognized with CVEs in the past 4 years)

Q&A

Thank you for listening

Access my portfolio

SyzBridge has been open source

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