FUZE: Towards Facilitating Exploit Generation for Kernel Use-After-Free Vulnerabilities

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What are We Talking about?

- Discuss the challenge of exploit development
- Introduce an approach to facilitate exploit development
- Demonstrate how the new technique facilitate mitigation circumvention

Background

- All software contain bugs, and # of bugs grows with the increase of software complexity
  - E.g., Syzkaller/Syzbot reports 800+ Linux kernel bugs in 8 months
- Due to the lack of manpower, it is very rare that a software development team could patch all the bugs timely
  - E.g., A Linux kernel bug could be patched in a single day or more than 8 months; on average, it takes 42 days to fix one kernel bug
- The best strategy for software development team is to prioritize their remediation efforts for bug fix
  - E.g. based on its influence upon usability
  - E.g., based on its influence upon software security
  - E.g., based on the types of the bugs
  - … …

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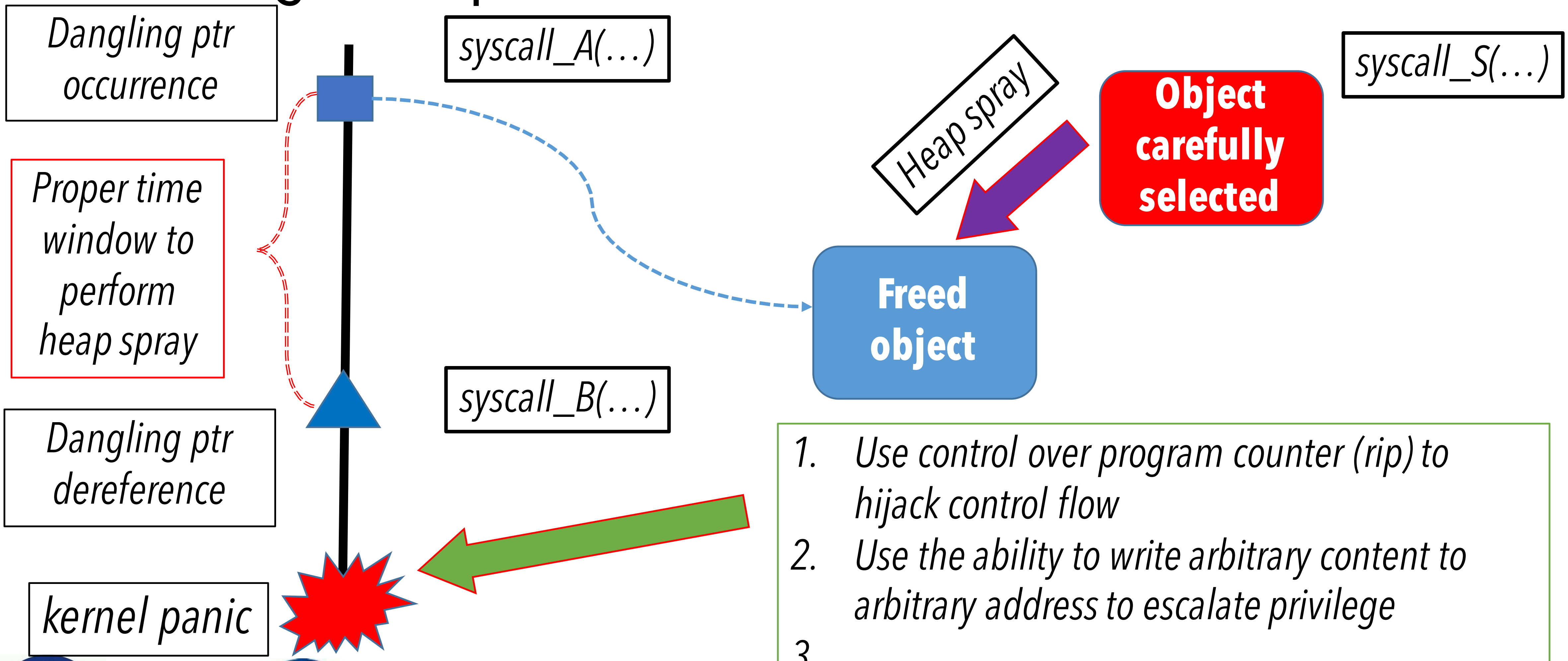
Background (cont.)

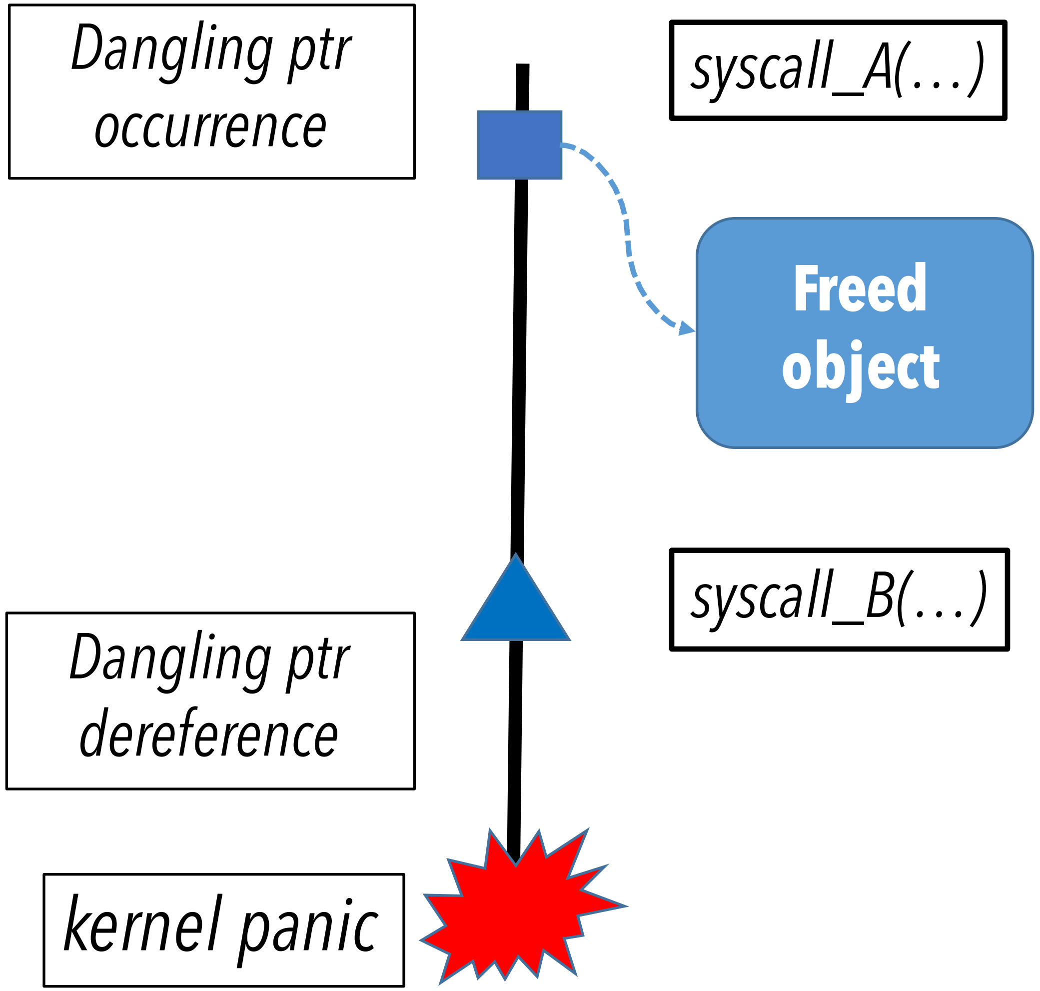
- Most common strategy is to fix a bug based on its exploitability
- To determine the exploitability of a bug, analysts generally have to write a working exploit, which needs
  1) Significant manual efforts
  2) Sufficient security expertise
  3) Extensive experience in target software

Crafting an Exploit for Kernel Use-After-Free



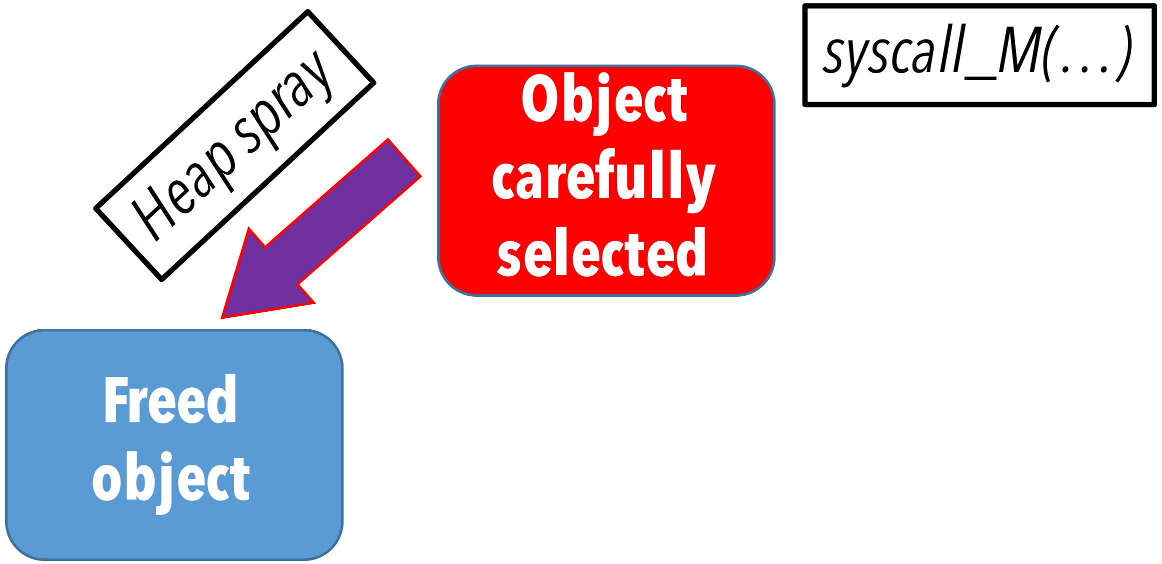
Challenge 1: Needs Intensive Manual Efforts

- Analyze the kernel panic
- Manually track down
  1. The site of dangling pointer occurrence and the corresponding system call
  2. The site of dangling pointer dereference and the corresponding system call



Challenge 2: Needs Extensive Expertise in Kernel

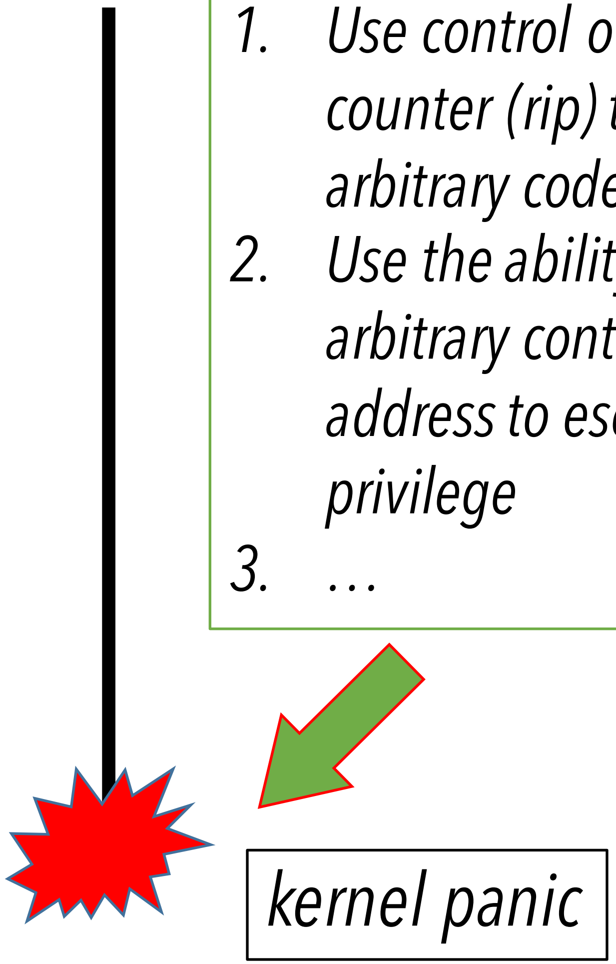
- Identify all the candidate objects that can be sprayed to the region of the freed object
- Pinpoint the proper system calls that allow an analyst to perform heap spray
- Figure out the proper arguments and context for the system call to allocate the candidate objects



Challenge 3: Needs Security Expertise

- Find proper approaches to accomplish arbitrary code execution or privilege escalation or memory leakage
  - E.g., chaining ROP
  - E.g., crafting shellcode
  - …

1. *Use control over program counter (rip) to perform arbitrary code execution*
2. *Use the ability to write arbitrary content to arbitrary address to escalate privilege*
3. *…*



Some Past Research Potentially Tackling the Challenges

- Approaches for Challenge 1
  - Nothing I am aware of, but simply extending KASAN could potentially solve this problem
- Approaches for Challenge 2
  - [Blackhat07] [CCS' 16] [USENIX-SEC18],...
- Approaches for Challenge 3
  - [NDSS'11] [S&P16], [S&P17],...

[NDSS11] Avgerinos et al., AEG: Automatic Exploit Generation.
[CCS 16] Xu et al., From Collision To Exploitation: Unleashing Use-After-Free Vulnerabilities in Linux Kernel.
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Problem unsolved.

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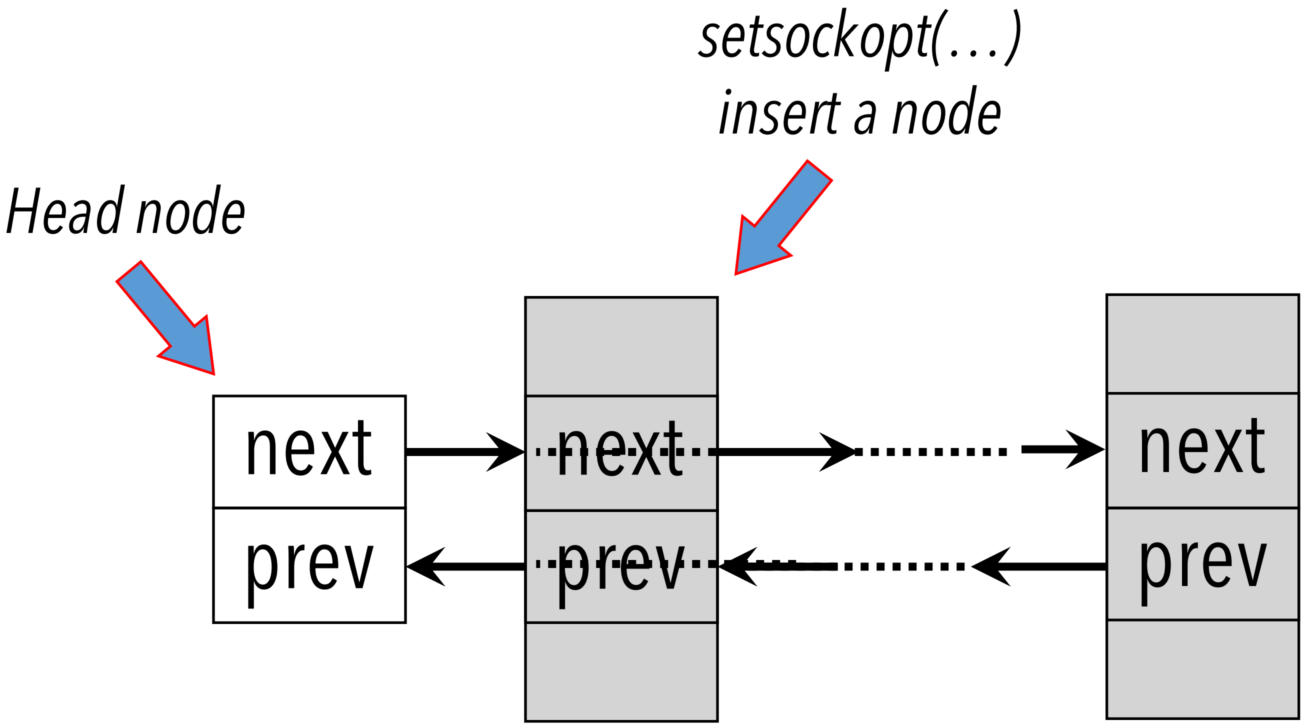
Roadmap

- Unsolved challenges in exploitation facilitation
- Our techniques -- FUZE
- Evaluation with real-world Linux kernel vulnerabilities
- Conclusion

A Real-World Example (CVE-2017-15649)




```c
void *task1(void *unused) {
  ...
  int err = setsockopt(fd, 0x107, 18,
      ↪ ..., ...);
}

void *task2(void *unused) {
  int err = bind(fd, &addr, ...);
}

void loop_race() {
  ...
  while(1) {
    fd = socket(AF_PACKET, SOCK_RAW,
        ↪ htons(ETH_P_ALL));
    ...
    //create two racing threads
    pthread_create (&thread1, NULL,
        ↪ task1, NULL);
    pthread_create (&thread2, NULL,
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    pthread_join(thread1, NULL);
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    close(fd);
  }
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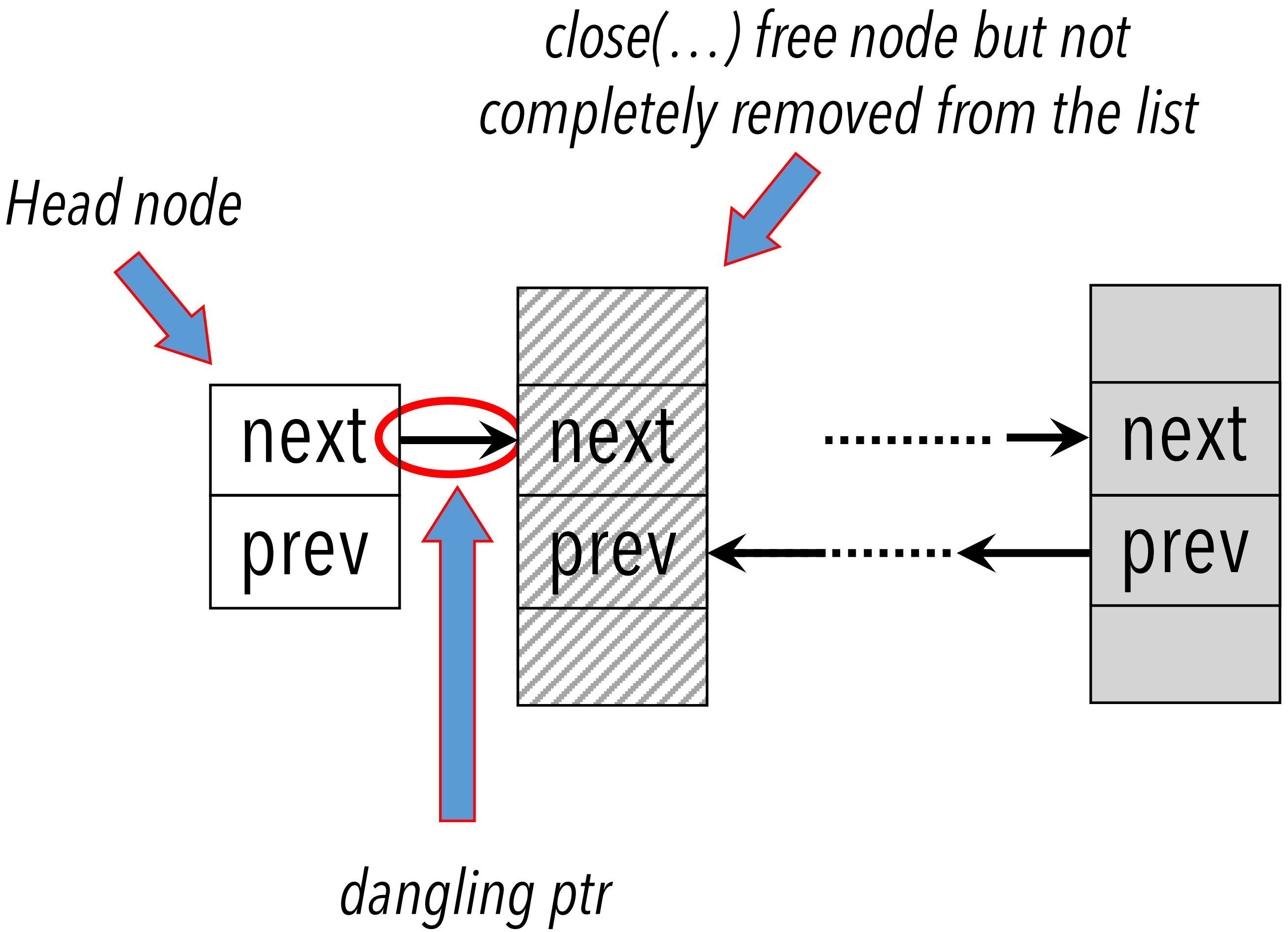


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    close(fd);
  }
}
```
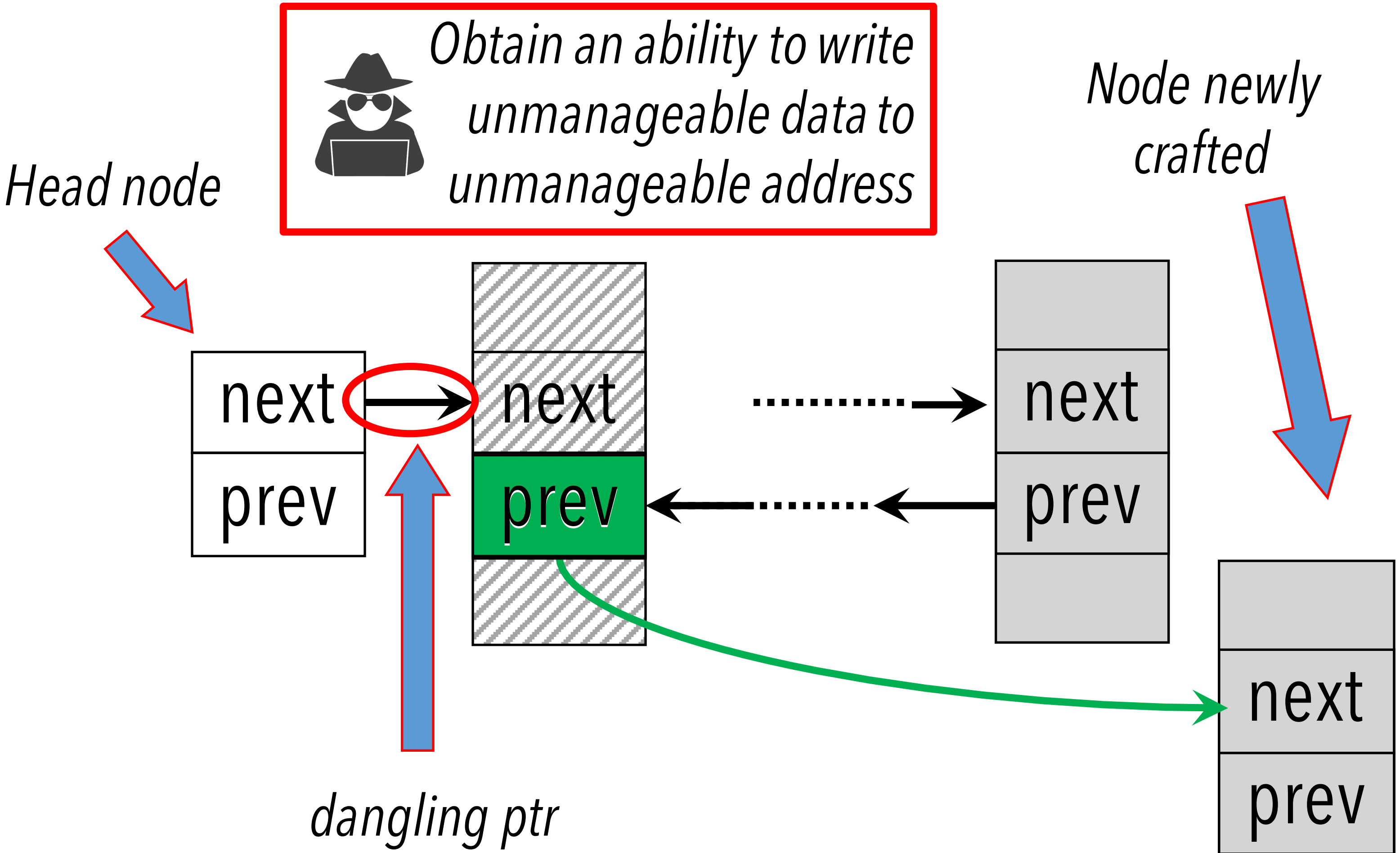

Challenge 4: No Primitive Needed for Exploitation

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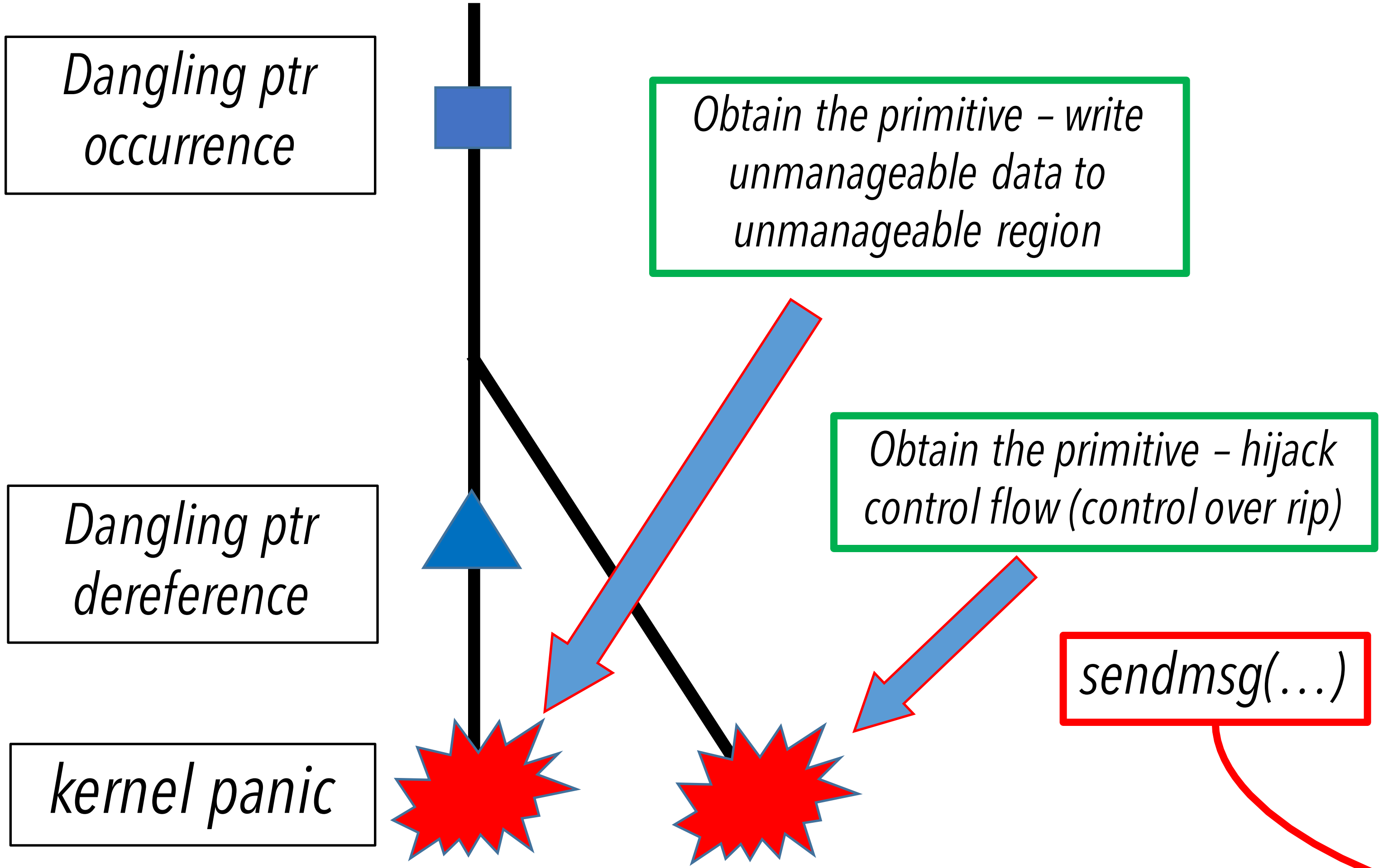
```

No Useful Primitive == Unexploitable??

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  ...
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}

void *task2(void *unused) {
  int err = bind(fd, &addr, ...);
}

void loop_race() {
  ...
  while(1) {
    fd = socket(AF_PACKET, SOCK_RAW,
      htons(ETH_P_ALL));
    ...
    //create two racing threads
    pthread_create (&thread1, NULL,
      task1, NULL);
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    pthread_join(thread1, NULL);
    pthread_join(thread2, NULL);

    close(fd);
  }
}
```

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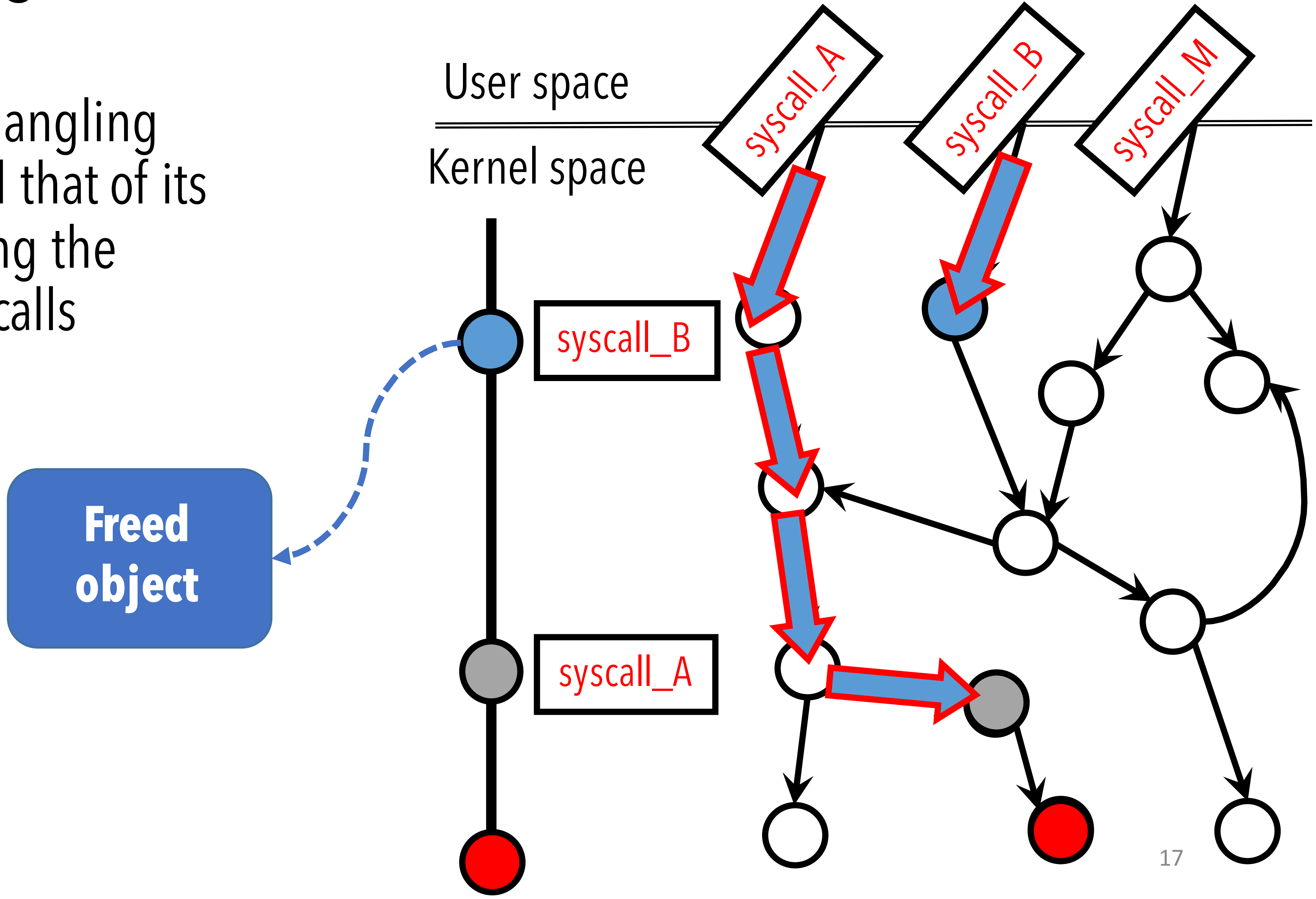
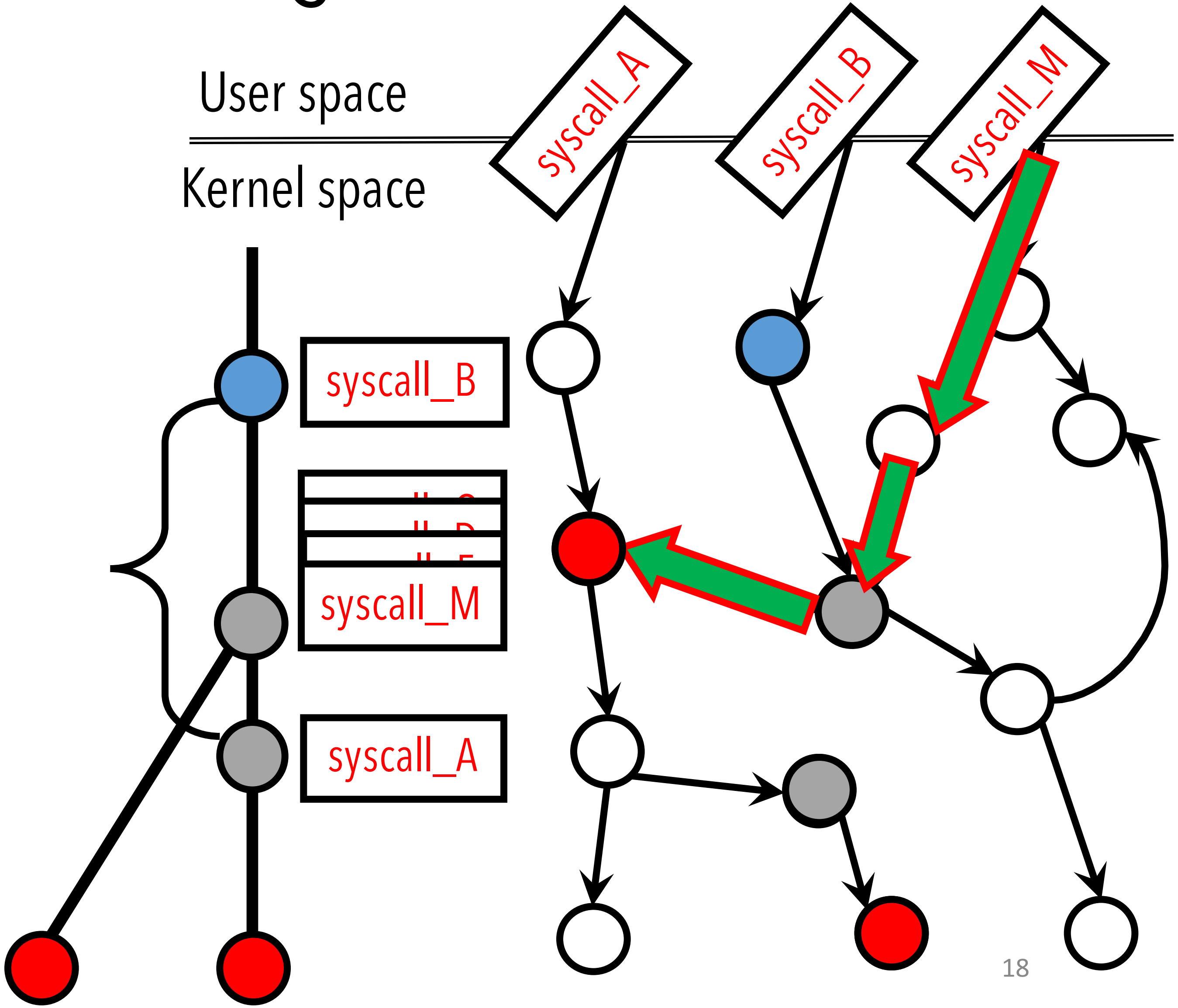
FUZE – Extracting Critical Info.

- Identifying the site of dangling pointer occurrence, and that of its dereference; pinpointing the corresponding system calls



FUZE – Performing Kernel Fuzzing

- Identifying the site of dangling pointer occurrence, and that of its dereference; pinpointing the corresponding system calls
- Performing kernel fuzzing between the two sites and exploring other panic contexts (i.e., different sites where the vulnerable object is dereferenced)

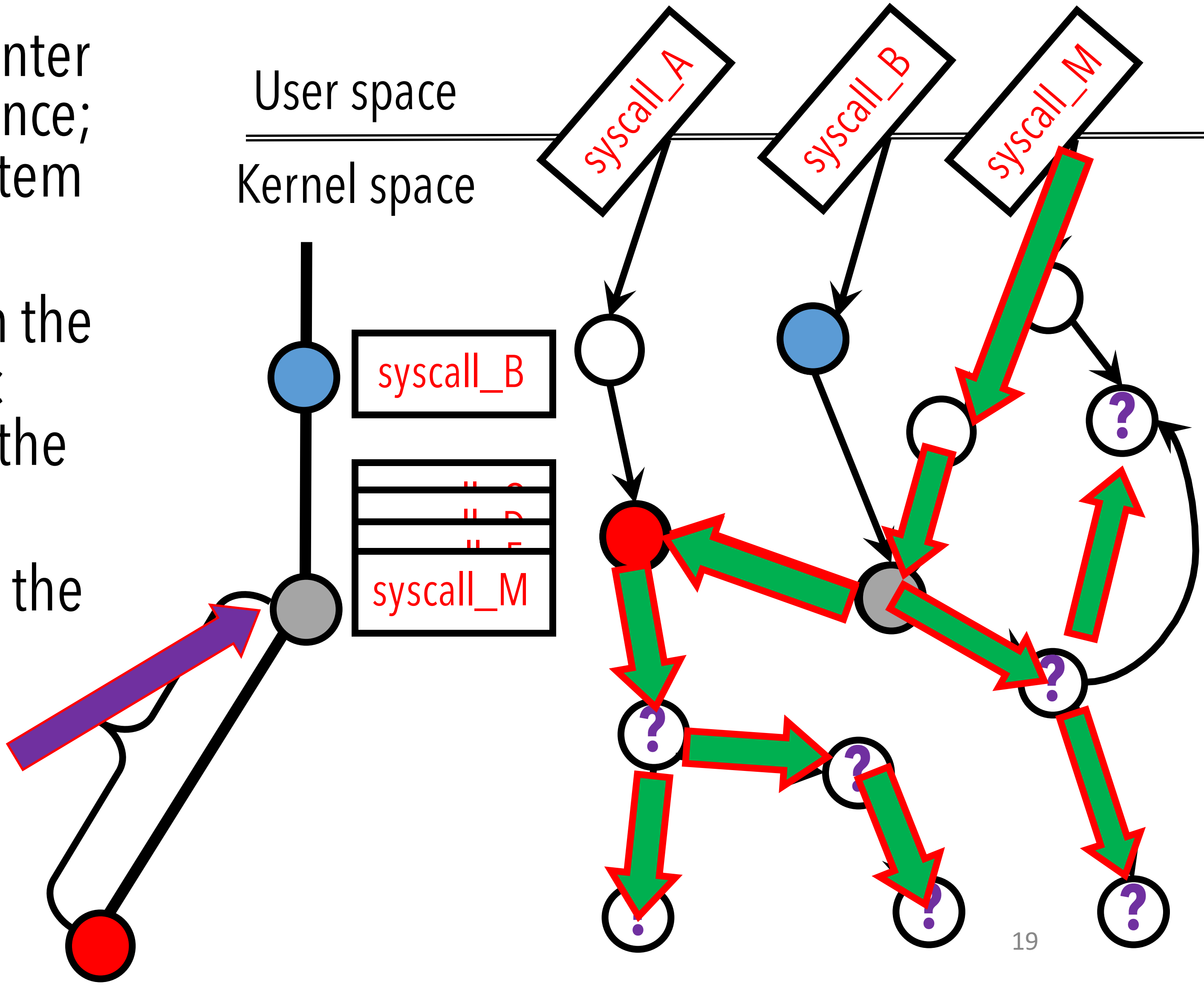


FUZE – Performing Symbolic Execution

- Identifying the site of dangling pointer occurrence, and that of its dereference; pinpointing the corresponding system calls
- Performing kernel fuzzing between the two sites and exploring other panic contexts (i.e., different sites where the vulnerable object is dereferenced)
- Symbolically execute at the sites of the dangling pointer dereference

Freed object

Set symbolic value for each byte



Useful primitive identification

- Unconstrained state
  - state with symbolic Instruction pointer
  - symbolic callback
- double free
  - e.g. `mov rdi, uaf_obj; call kfree`
- write-what-where
  - e.g. write arbitrary value write

```
mov rax, qword ptr[evil_ptr]
call rax
```

stack pivot gadget:

```
xchg eax, esp; ret
```

SMAP disable gadget:

```
mov cr4, rdi ; ret
```

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Case Study

- 15 real-world UAF kernel vulnerabilities
- Only 5 vulnerabilities have demonstrated their exploitability against SMEP
- Only 2 vulnerabilities have demonstrated their exploitability against SMAP

CVE-ID	# of public exploits		# of generated exploits	
	SMEP	SMAP	SMEP	SMAP
2017-17053	0	0	1	0
2017-15649*	0	0	3	2
2017-15265	0	0	0	0
2017-10661*	0	0	2	0
2017-8890	1	0	1	0
2017-8824*	0	0	2	2
2017-7374	0	0	0	0
2016-10150	0	0	1	0
2016-8655	1	1	1	1
2016-7117	0	0	0	0
2016-4557*	1	1	4	0
2016-0728*	1	0	3	0
2015-3636	0	0	0	0
2014-2851*	1	0	1	0
2013-7446	0	0	0	0
overall	5	2	19	5

*: discovered new dereference by fuzzing

Case Study (cont)

- FUZE helps track down useful primitives, giving us the power to
  - Demonstrate exploitability against SMEP for 10 vulnerabilities
  - Demonstrate exploitability against SMAP for 2 more vulnerabilities
  - Diversify the approaches to perform kernel exploitation
    - 5 vs 19 (SMEP)
    - 2 vs 5 (SMAP)

CVE-ID	# of public exploits		# of generated exploits	
	SMEP	SMAP	SMEP	SMAP
2017-17053	0	0	1	0
2017-15649	0	0	3	2
2017-15265	0	0	0	0
2017-10661	0	0	2	0
2017-8890	1	0	1	0
2017-8824	0	0	2	2
2017-7374	0	0	0	0
2016-10150	0	0	1	0
2016-8655	1	1	1	1
2016-7117	0	0	0	0
2016-4557	1	1	4	0
2016-0728	1	0	3	0
2015-3636	0	0	0	0
2014-2851	1	0	1	0
2013-7446	0	0	0	0
overall	5	2	19	5

Discussion on Failure Cases

- Dangling pointer occurrence and its dereference tie to the same system call
- FUZE works for 64-bit OS but some vulnerabilities demonstrate its exploitability only for 32-bit OS
    - E.g., CVE-2015-3636
- Perhaps unexploitable!?
    - CVE-2017-7374 ← null pointer dereference
    - E.g., CVE-2013-7446, CVE-2017-15265 and CVE-2016-7117

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Conclusion

- Primitive identification and security mitigation circumvention can greatly influence exploitability
- Existing exploitation research fails to provide facilitation to tackle these two challenges
- Fuzzing + symbolic execution has a great potential toward tackling these challenges
- Research on exploit automation is just the beginning of the GAME! Still many more challenges waiting for us to tackle…

Thank you!

- Exploits and source code available at:
  - https://github.com/ww9210/Linux_kernel_exploits
- Contact: wuwei@iie.ac.cn

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Questions

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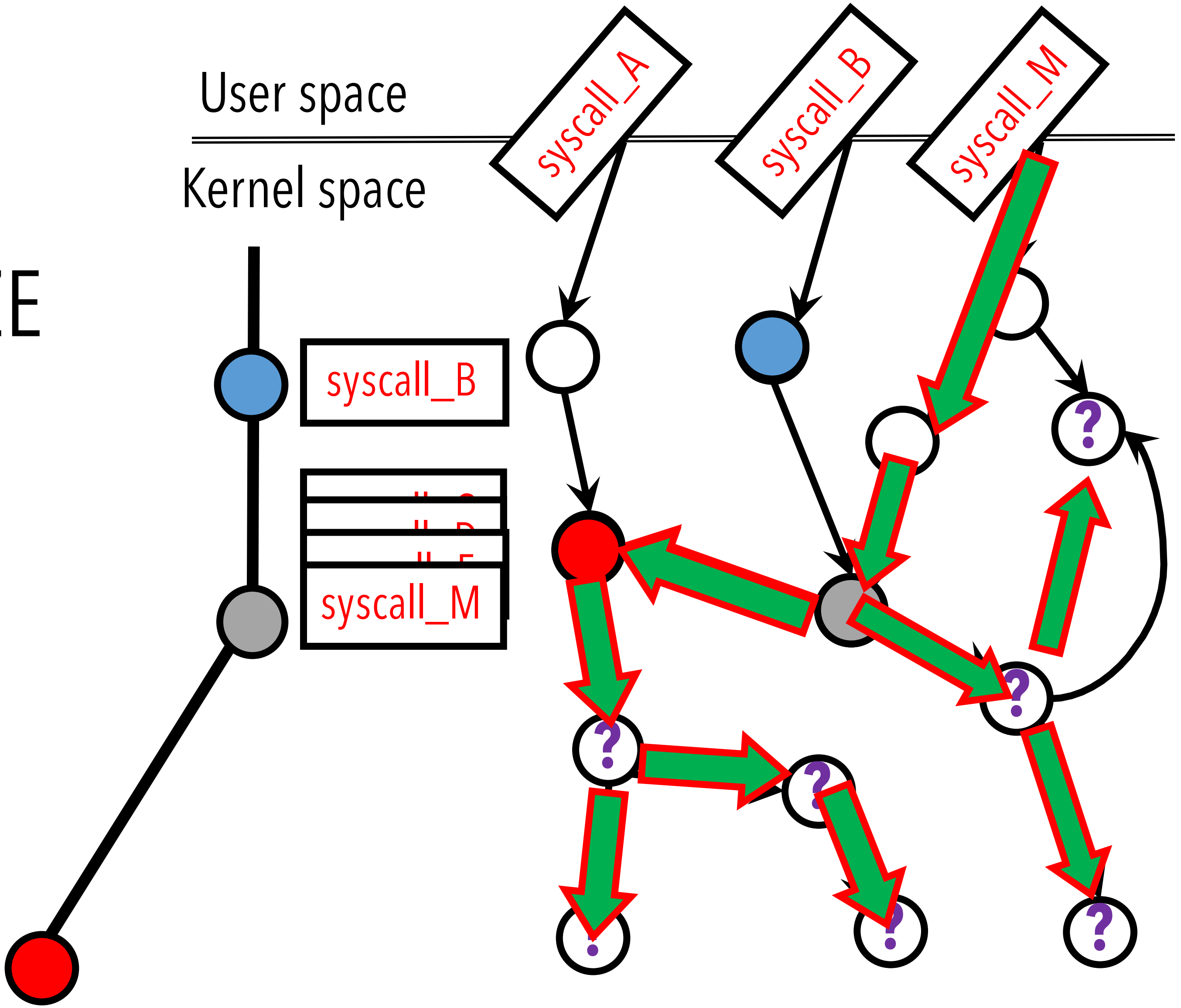

Questions

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