Effectiveness Analysis of System call Sequence-based Container Security Mechanism

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Rapid Growth in Cloud Adaption and Security Concern

- The total volume of data that will be stored in the cloud by 2025, which accounts for **50%** of all the data in the world

– ArcServe, 2020 [1]

- According to 74% of global IT decision-makers, **95%** of all workload will be in the cloud within the next five years

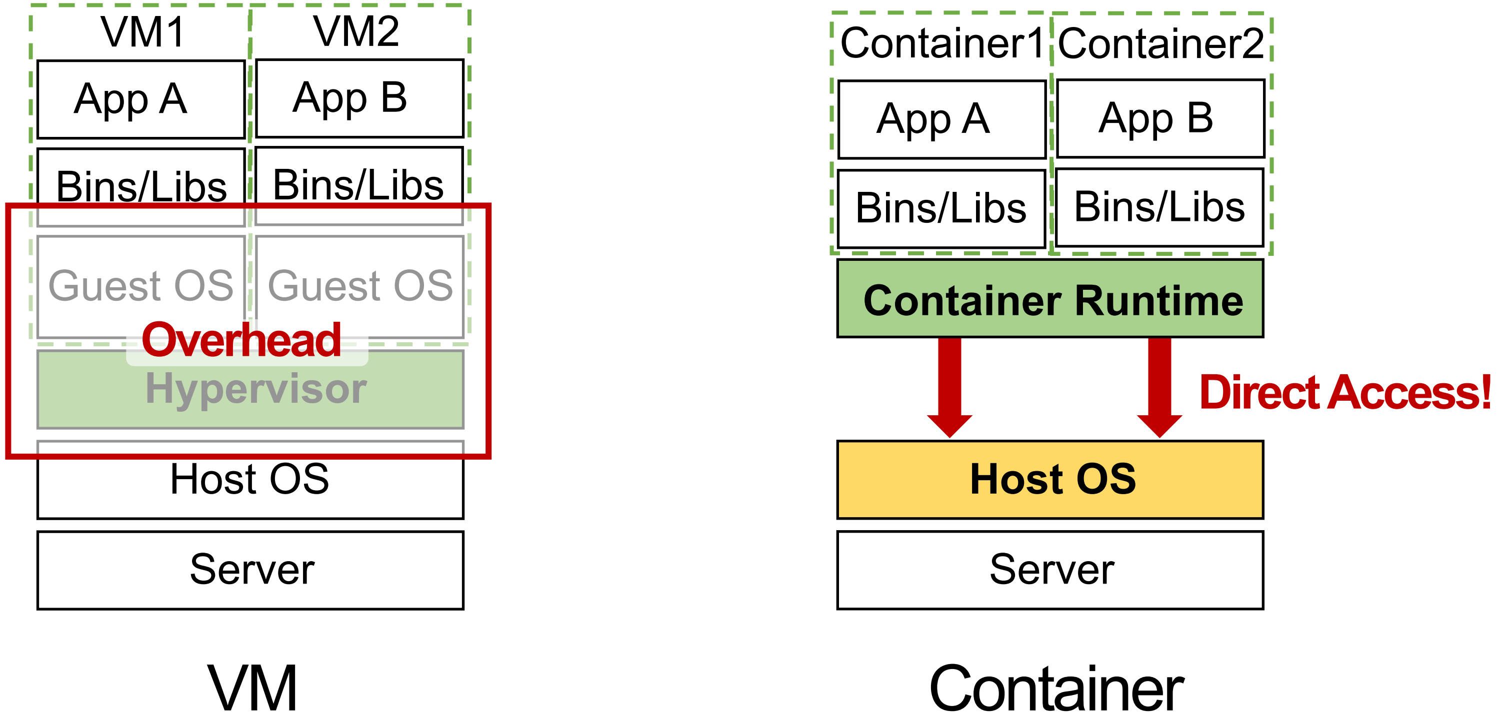
– LogicMonitor, 2020 [1]

- **75%** of enterprises and **90%** of cyber security experts agree that **security is their top concern**

– ArcServe, 2020 [1]

Container Security in Cloud Native Environment

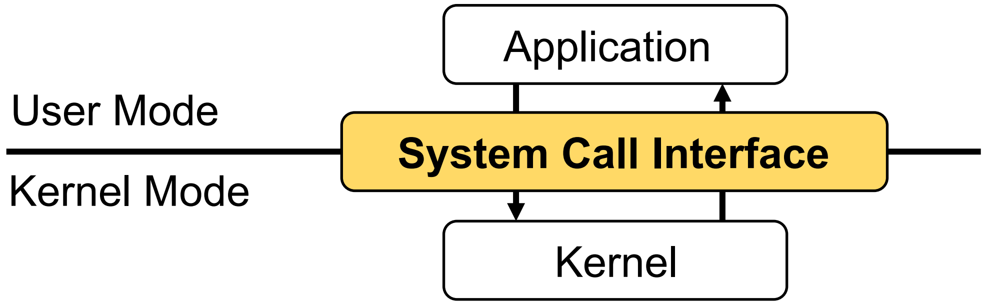
- Containers are a **key virtualization technology** in cloud computing



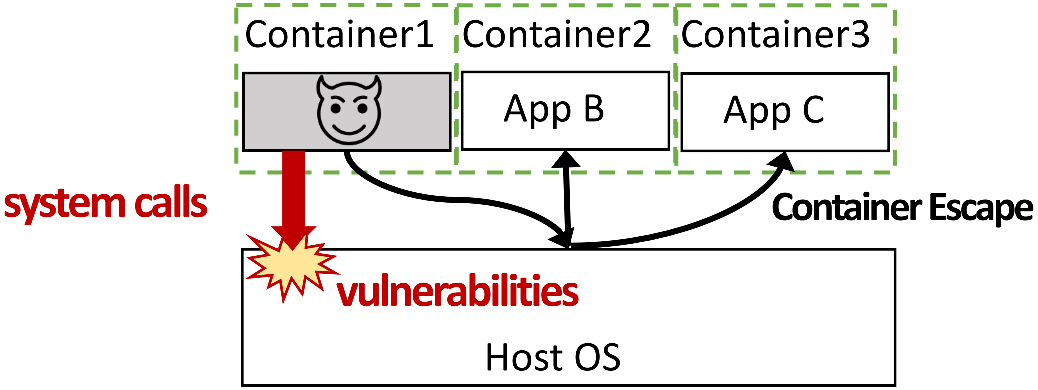
Containers **share** a Host OS!

Container Escape through System Call

- System Call



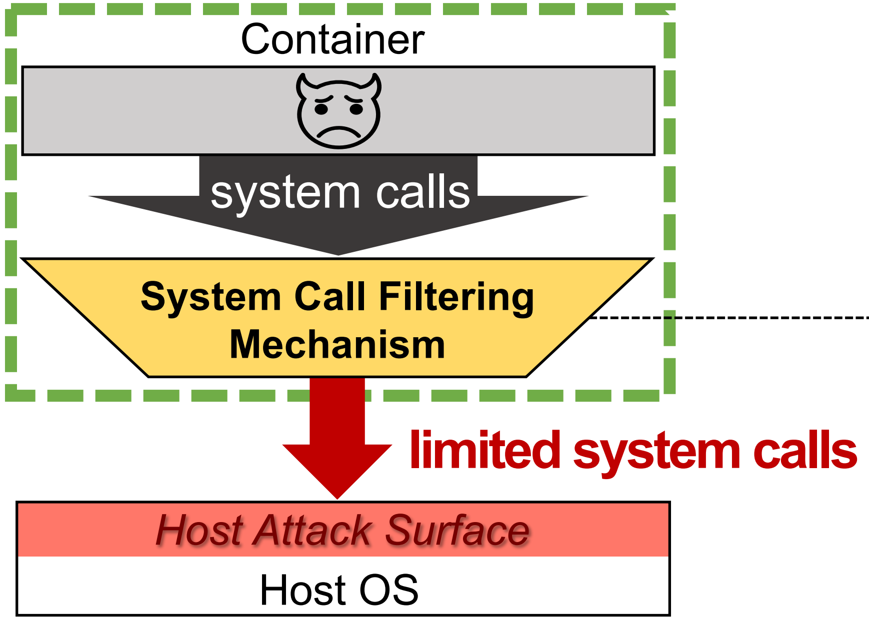
- Container Escape
  - Exploitation of Host kernel vulnerabilities through carefully **crafted system calls**



- Dirty COW Docker Escape (CVE-2016-5195)
- Runc Container Escape (CVE-2019-5736)
- Kubernetes Container Escape (CVE-2022-0185)
- Dirty Pipe Container Escape (CVE-2022-0847)
- DirtyCred Container Escape (CVE-2022-2588)

System Call Filtering Protection Mechanism

The fewer system calls, the more secure!

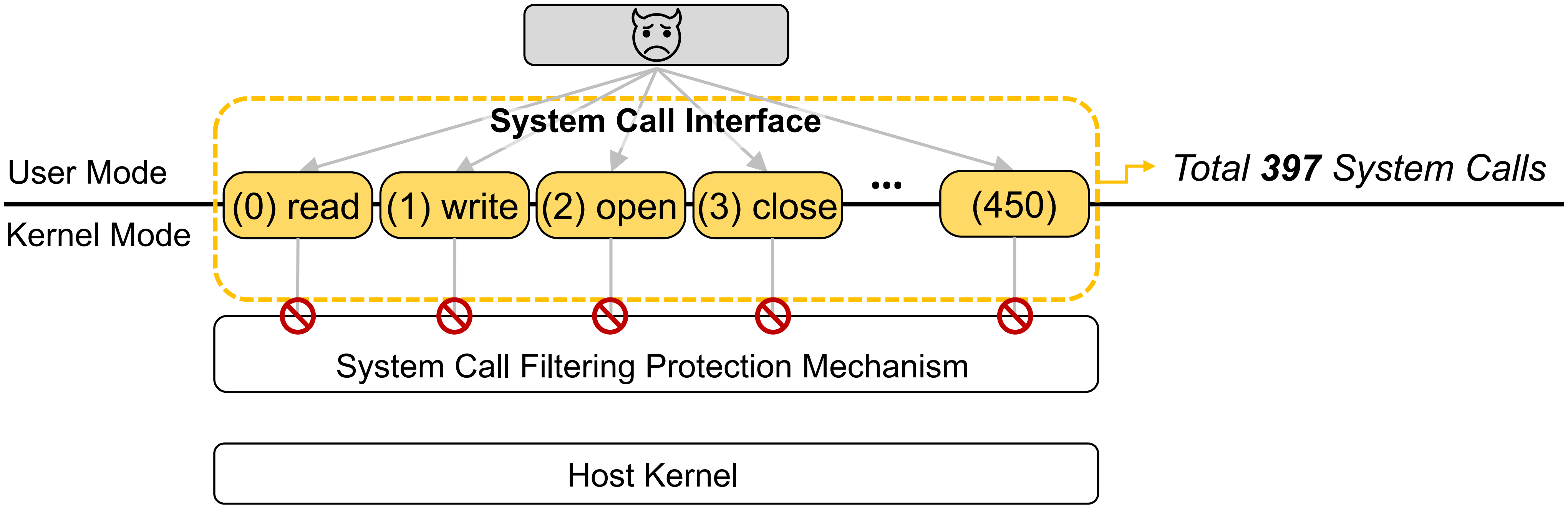


Seccomp (Secure Computing mode)

- Linux kernel feature
- Blocks the system calls
- Restrict a Container’s system calls

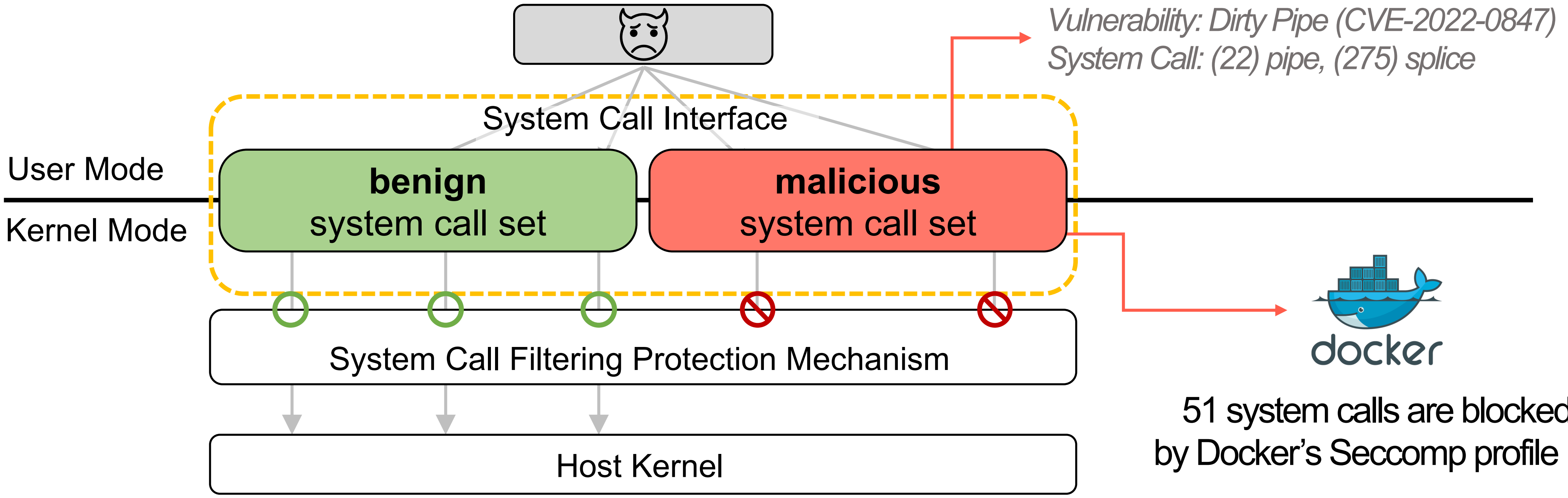
System Call Filtering Protection Mechanism

- "Which System Call should be **allowed/blocked**?"



System Call Filtering Protection Mechanism

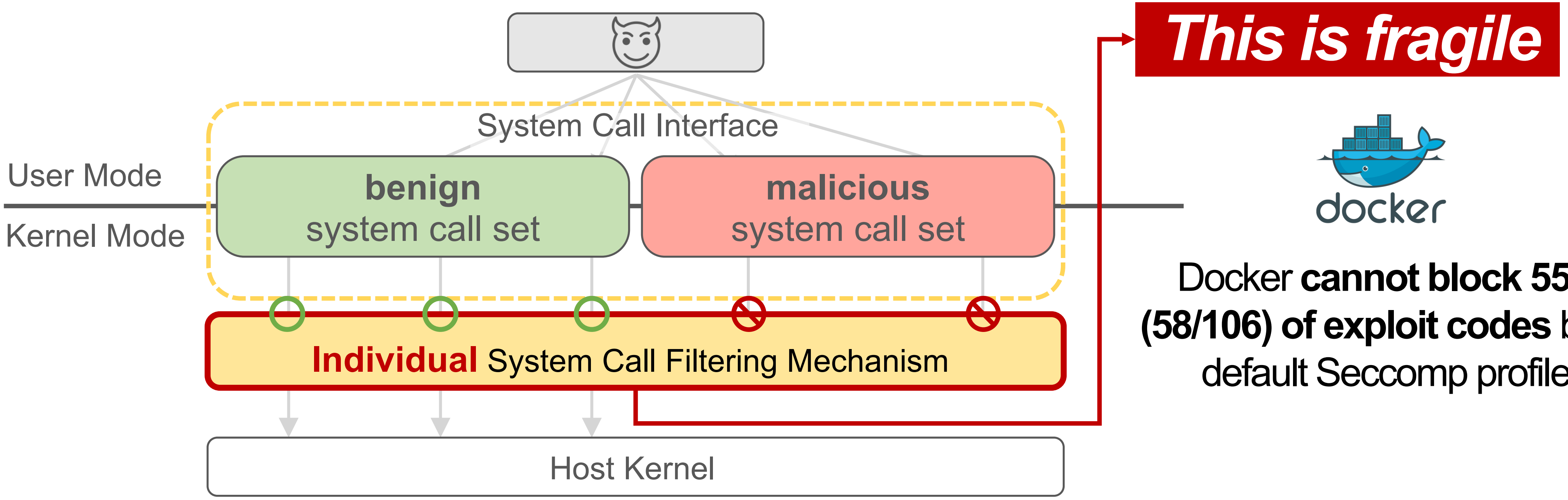
- “Which System Call should be allowed/blocked?”
  - **Which System Call is benign/malicious?**



51 system calls are blocked
by Docker’s Seccomp profile [2]

Problem

- Limitation in Individual System call Filtering Protection Mechanism



Docker **cannot block 55% (58/106) of exploit codes** by its default Seccomp profile.

Our Intuition and Approach

- System call Filtering Method: ***system call sequence***
  - without the risk of blocking normal application operations
  - It can thwart exploits that cannot be blocked by individual syscall-based filtering

- Syscall sequence blocking can mitigate Dirty Pipe vulnerability

  → Docker’s default Seccomp profile with an individual syscall blocking cannot defend it

Syscall Sequence Policy
(generated by analyzing the exploit codes)

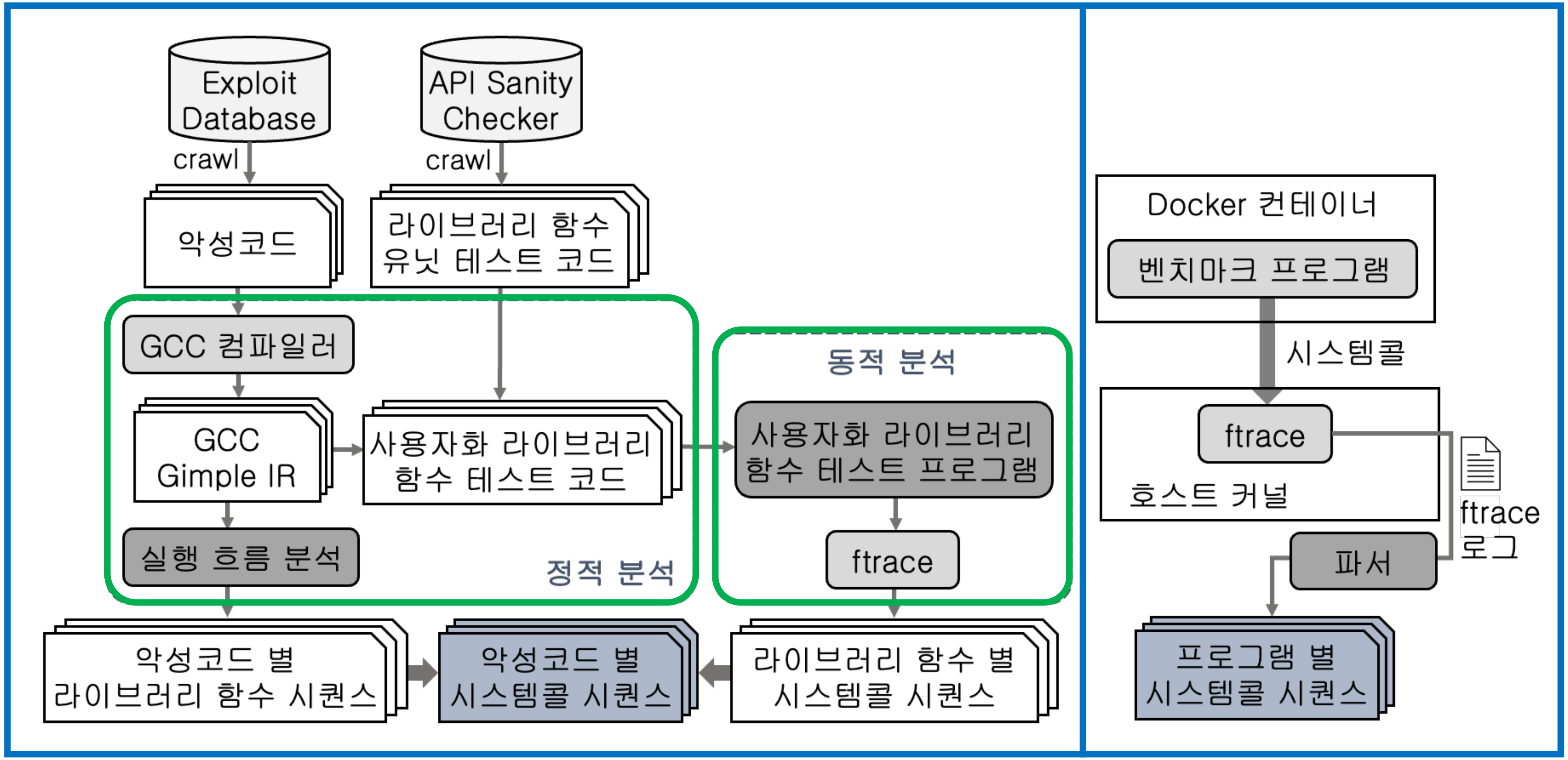
openat → fstat → pipe → fcntl → write → read → splice → write → close

Observed Syscall Sequence
(on the host when the exploit code is executed in Docker)

openat → fstat → pipe → fcntl → write → read → splice → write → close

- Goal
  1) To analyze limitations of individual system call-based filtering mechanism
  2) To evaluate the security of system call sequence-based filtering mechanism

Approach Overview: Syscall Sequence Analysis



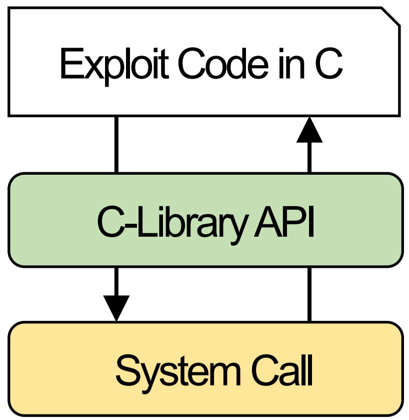
(1) Exploit Code Analysis **(2) Application Analysis**

Exploit Code Analysis Methodology

- Goal: To investigate the system calls that the exploit codes invoke

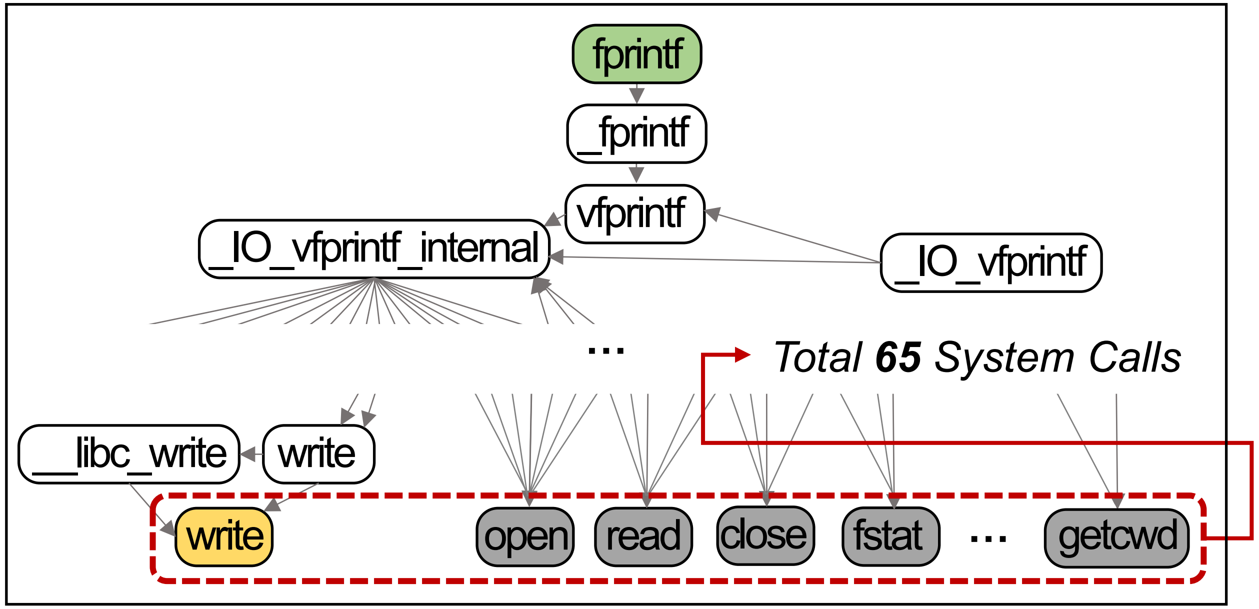
- Only Dynamic Analysis [8,9,10]
  - Method of tracing system calls while directly executing the exploit codes
  - \+ Upon successful execution, complete information can be obtained
  - – It is very difficult to set up the environment to run the exploit code

- Only Static Analysis [4,5,6,7]
  - Method of analyzing the source code/binary without executing the exploit codes
  - \+ Automated Large-scale analysis is possible
  - – C language makes static analysis difficult
    - The indirect call caused by a function pointer, and deeply nested macro code



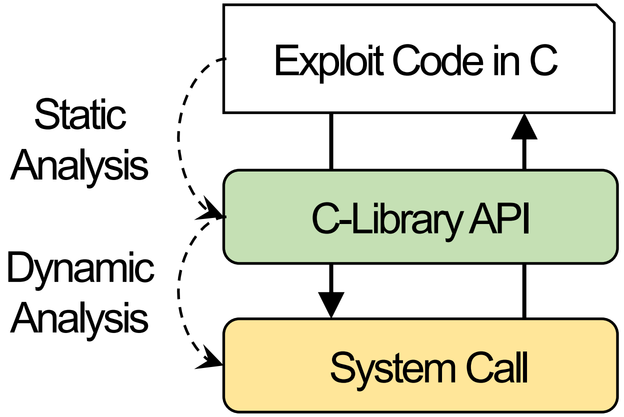
Problems in Precedent Researches

- Challenge in **Static Analysis**
  - Confine [4] (RAID '20) : built libc-to-syscall call graph
    - ► ***boating reachable system calls***



Exploit Code Analysis Methodology

- Hybrid Analysis
  - Combine static analysis and dynamic analysis to generate a system call sequence corresponding to each exploit code
  - **Static Analysis**: to extract library function sequence on all possible control flows where the exploits can be successfully triggered
  - **Dynamic Analysis**: to build a mapping between library functions and system call sequences



Static Analysis to Map Exploit Code-Glibc function

- Using GCC + GCC GIMPLE IR (Intermediate Representation)
  - Getting info on control flow of glibc function

```
void foo() {
  int i,j;
  do{
    i = getuid();
    j = geteuid();
  } while(i == j);
  bar();
}
```

Example source code

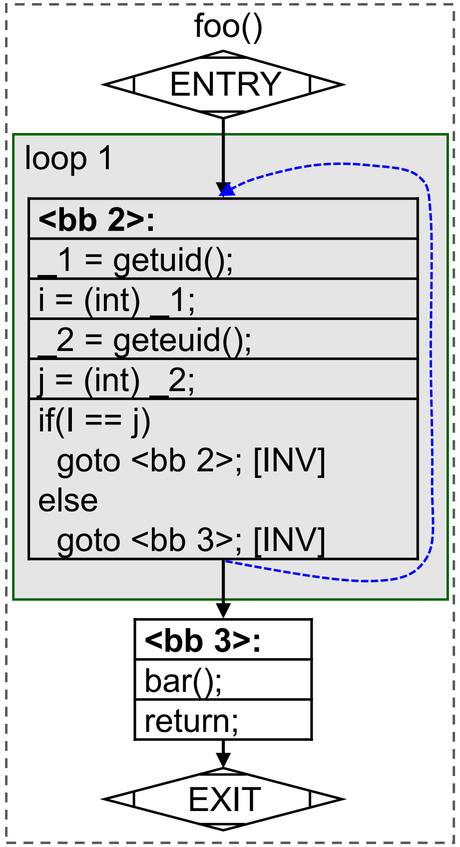
```
foo: getuid-geteuid-getuid-geteuid-getuid-geteuid-bar
```

Library function call sequence(s) for code

```
;; Function foo (…)
            …
;; Loop 1
;;  header 2, latch 2
;;  depth 1, outer 0
;;  nodes: 2
;; 2 succs { 2 3 }
;; 3 succs { 1 }
foo ()
{
             …
 <bb 2> :
 _1 = getuid ();
 i = (int) _1;
 _2 = geteuid ();
 j = (int) _2;
 if (i == j)
   goto <bb 2>; [INV]
 else
   goto <bb 3>; [INV]

 <bb 3> :
 bar ();
 return;
}
```

GCC's GIMPLE IR



Visualization

Dynamic Analysis to Map Glibc function-System Call

- Dynamic Analysis (using API Sanity Checker dataset [11] + ftrace mechanism)

(a) API Sanity Checker Dataset

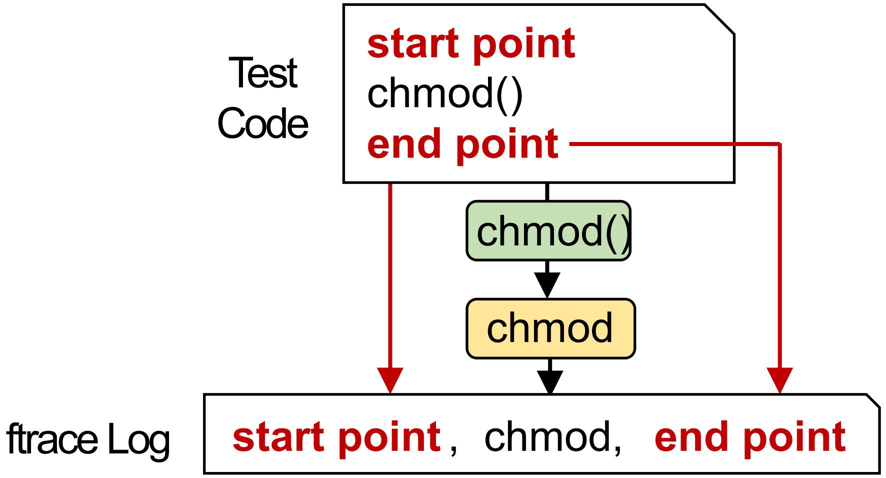
- An automatic generator of basic unit tests for a shared C/C++ library

(b) ftrace mechanism

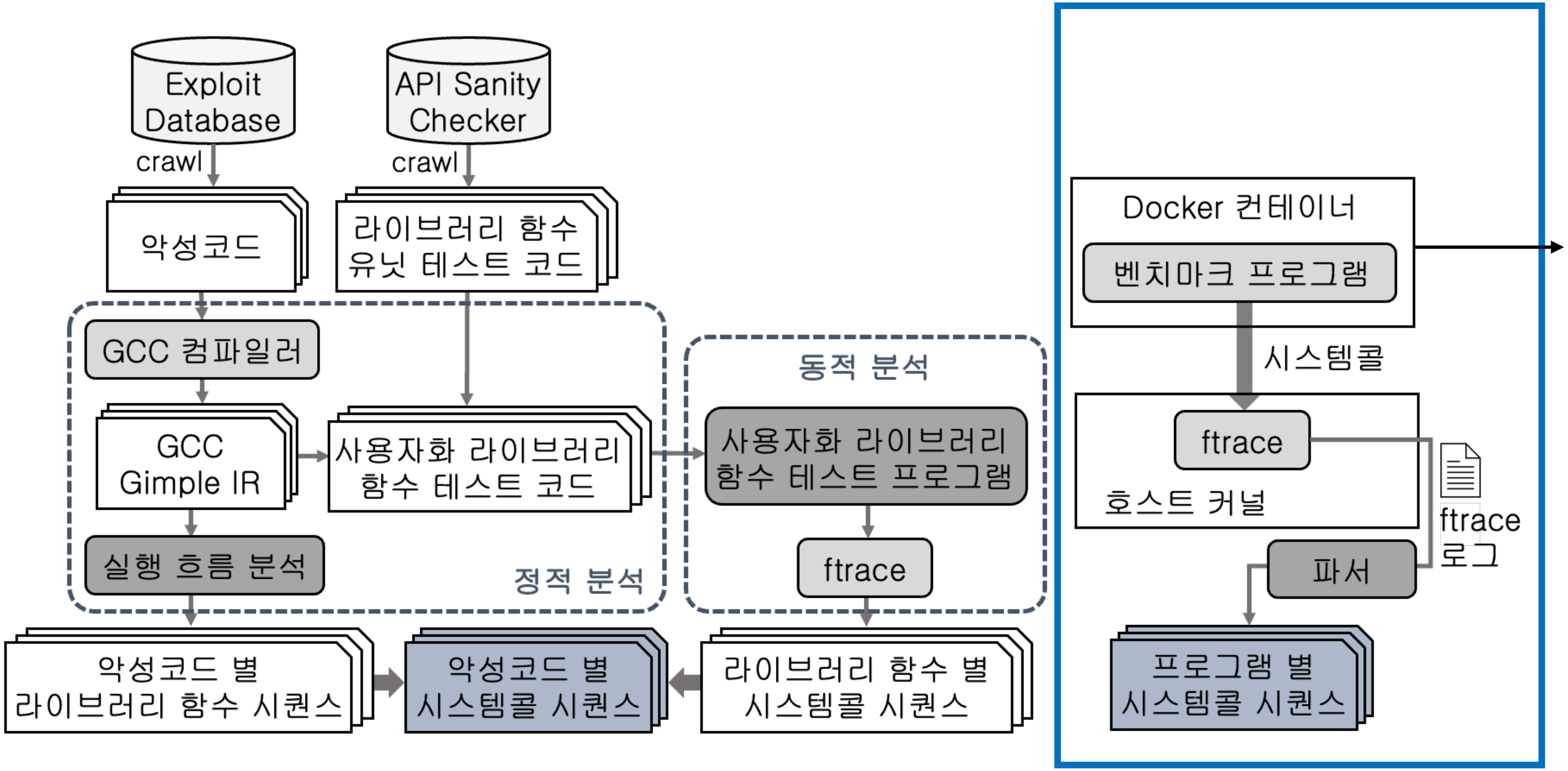
- Tracing tool in Linux kernel
- Possible to write directly to log file

```
#include <rpc/types.h>
#include <sys/stat.h>>

int main(int argc, char *argv[])
{
   __mode_t__mode =umask(0);
   chmod ((const char *) "/proc/self/exec", 3565);
   return 0;
}
```



Approach Overview: Syscall Sequence Analysis



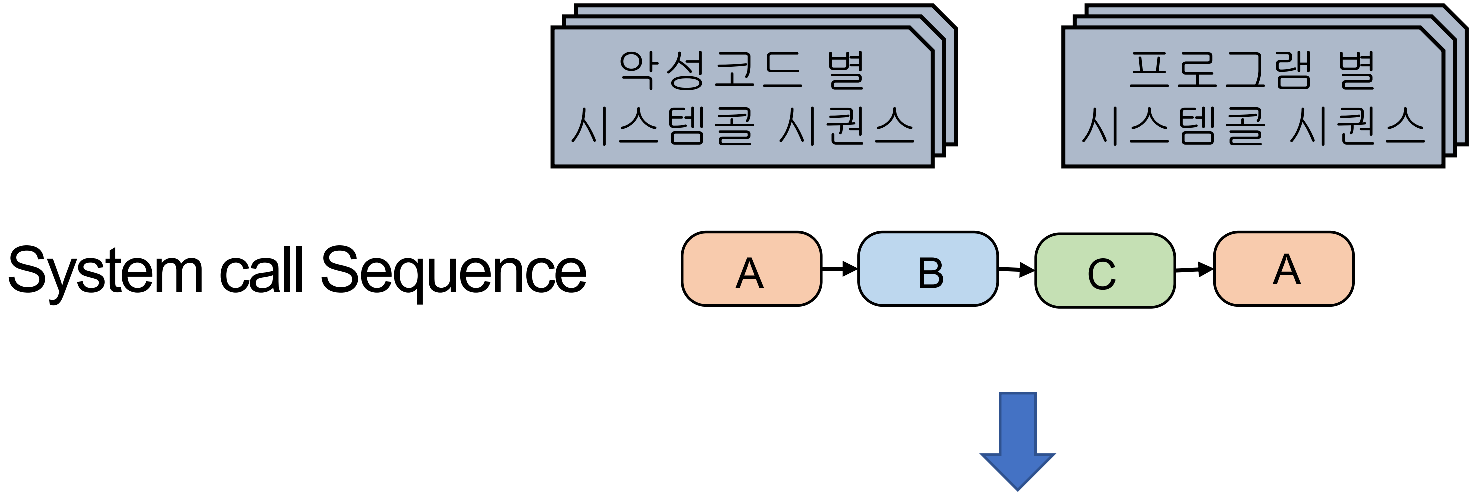
4 Server App
(nginx, httpd, tomcat, node)

4 DB App
(mongodb, mysql, mariadb, redis)

(b) Application Analysis

Approach Overview: Syscall Sequence Analysis

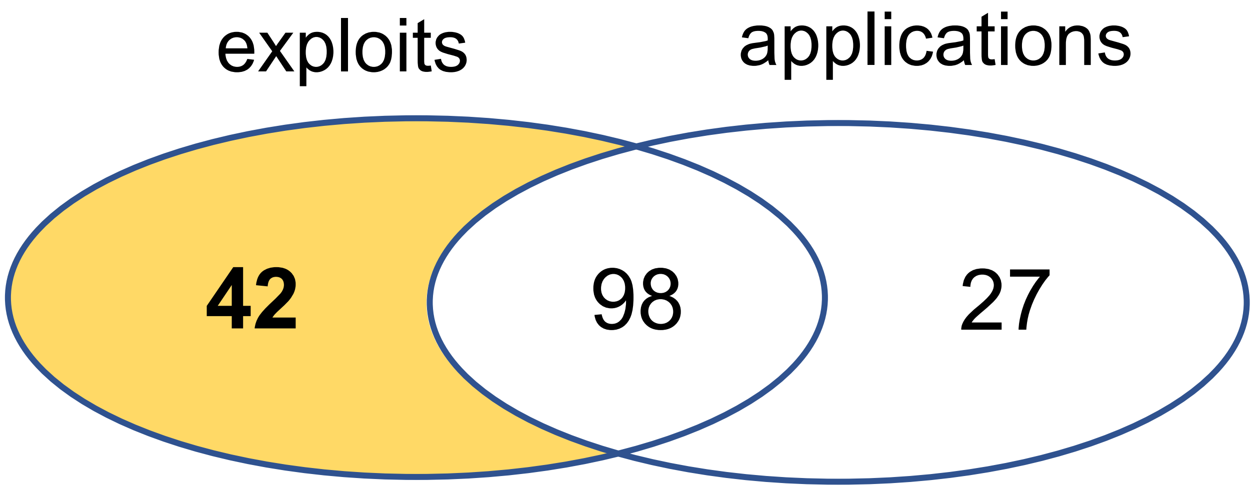
- N-gram Analysis



N	N-gram system call sequence	#
2	A-B, B-C, C-A	3
3	A-B-C, B-C-A	2
4	A-B-C-A	1

Experimental evaluation

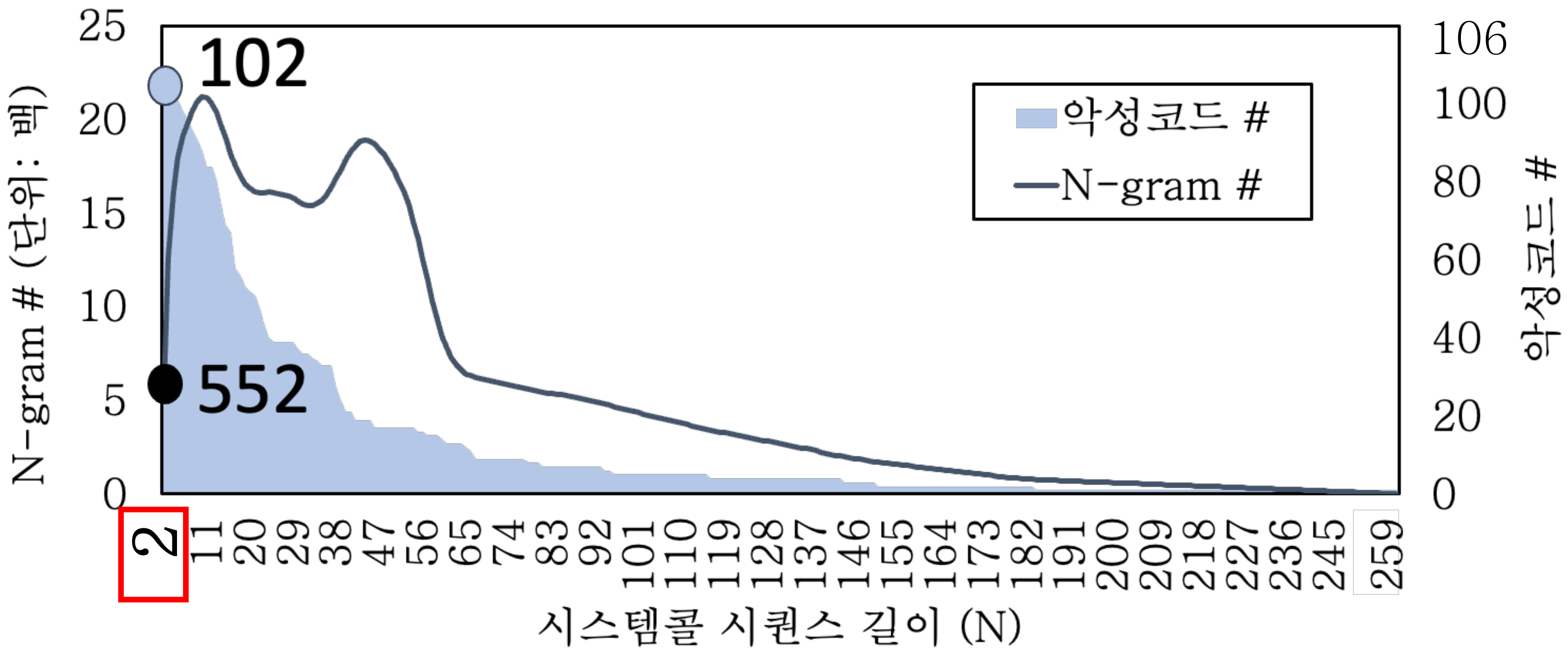
- Evaluation of **individual** system call-based filtering mechanisms



➡ **67 (about 63%)** out of 106 exploit codes could be blocked.

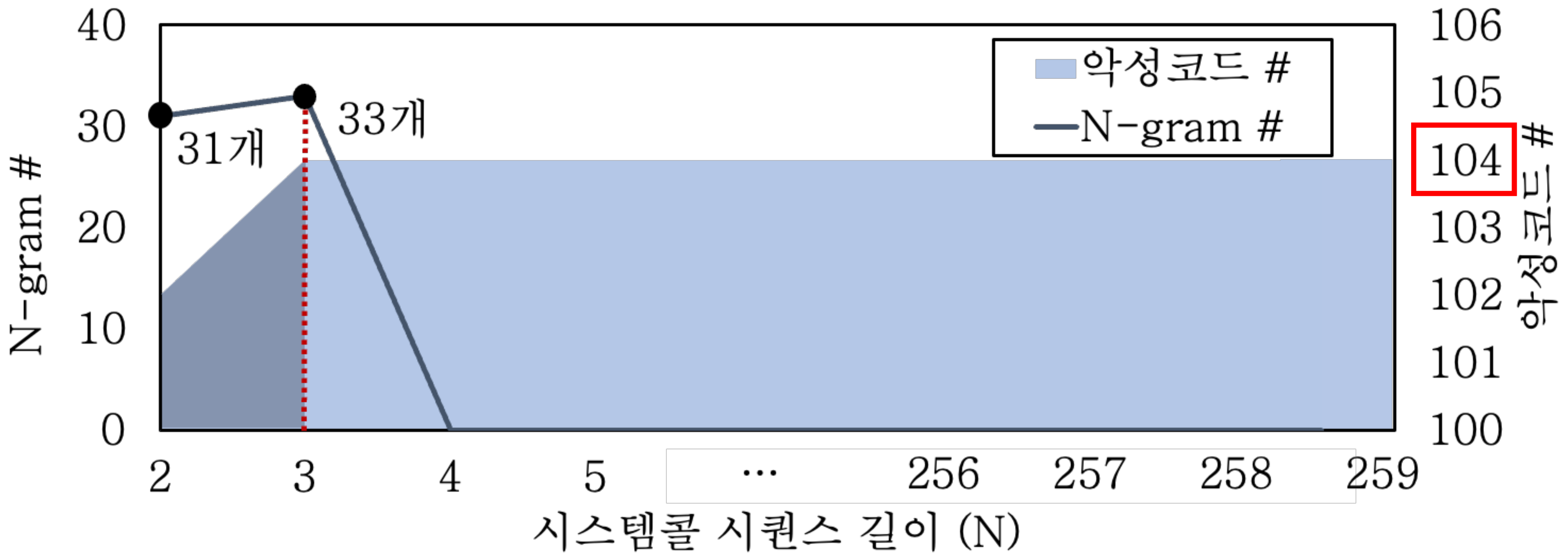
Experimental evaluation

- Evaluation of system call **sequence**-based filtering mechanisms
  - **N-gram set from exploits – N-gram set from applications**



Experimental evaluation

- Evaluation of system call **sequence**-based filtering mechanisms
  - N-gram set from exploits - N-gram set from applications



104 (about 98%) out of 106 exploit codes could be blocked.

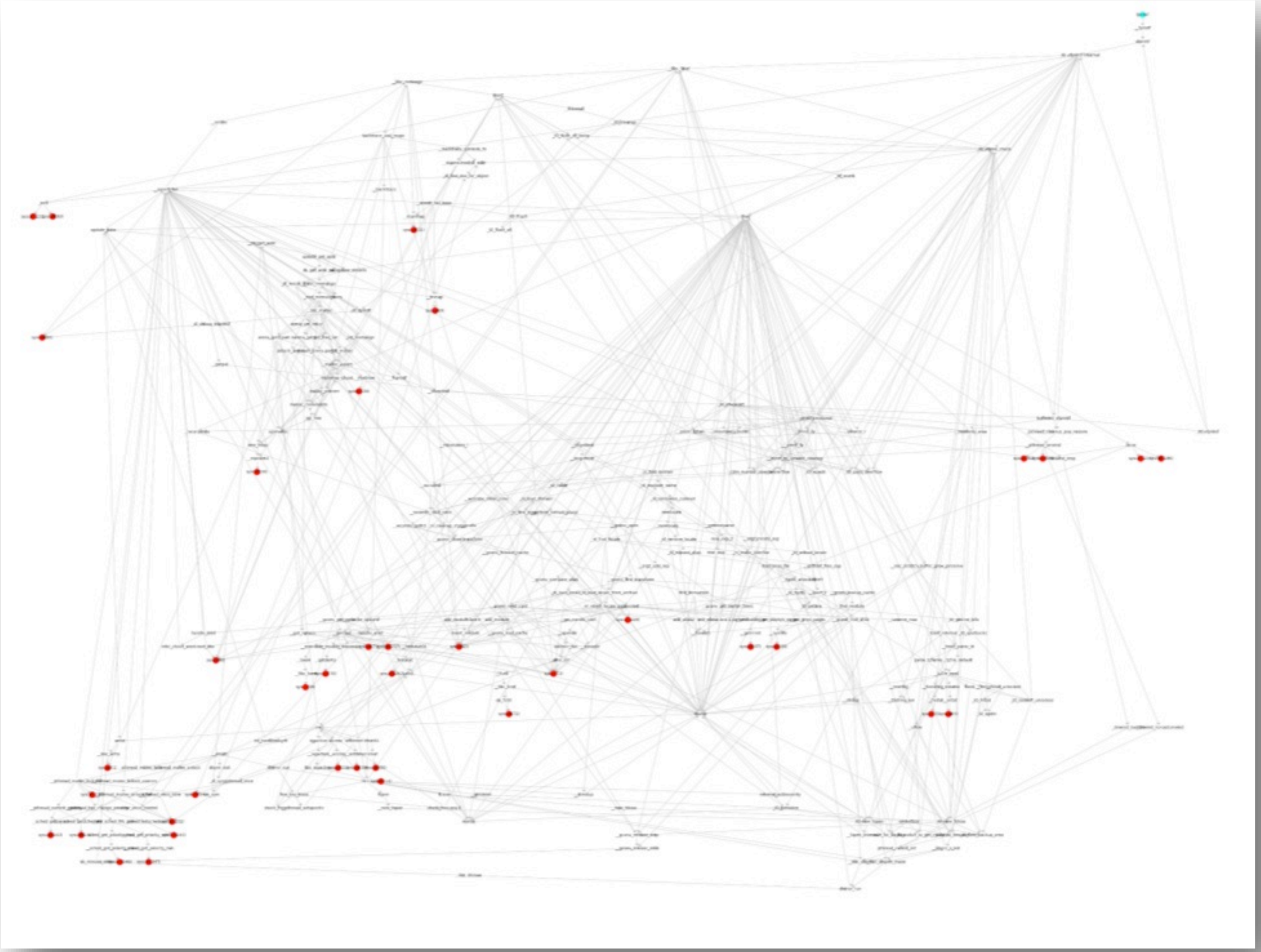
Conclusion

- System call filtering mechanism is important for protection of container environment
  - Attack surface of shared kernel reduction
  - Huge damage caused by container escape
- The current filtering mechanism is fragile and non-scalable solution
  - 67 out of 106 malicious codes (about 63%) were able to be blocked
- System call sequence blocking can compensate for the loopholes in individual system call blocking

Filtering Mechanism	# of Policy	# of exploit codes that can be mitigated (%)
Individual Syscall-based	42	67 (63%)
Syscall Sequence-based	33	104 (98%)

Thank you

Appendix. fprintf glibc library function call graph



in Confine [4]

Appendix. Docker Seccomp Porfile

- Docker uses the Seccomp kernel feature to block container access to 51 system calls
  - Docker's Seccomp profile[2] allows 346 system calls

acct	iopl	personality	swapon
add_key	kcmp	pivot_root	swapoff
bpf	kexec_file_load	process_vm_readv	sysfs
clock_adjtime	kexec_load	process_vm_writev	_sysctl
clock_settime	keyctl	ptrace	umount
clone	lookup_dcookie	query_module	umount2
create_module	mbind	quotactl	unshare
delete_module	mount	reboot	uselib
finit_module	move_pages	request_key	userfaultfd
get_kernel_syms	name_to_handle_at	set_mempolicy	ustat
get_mempolicy	nfsservctl	setns	vm86
init_module	open_by_handle_at	settimeofday	vm86old
ioperm	perf_event_open	stime	

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