9. Application/Kernel Interface

- POSIX Essentials
- Implementation

Application/Kernel Interface: System Calls

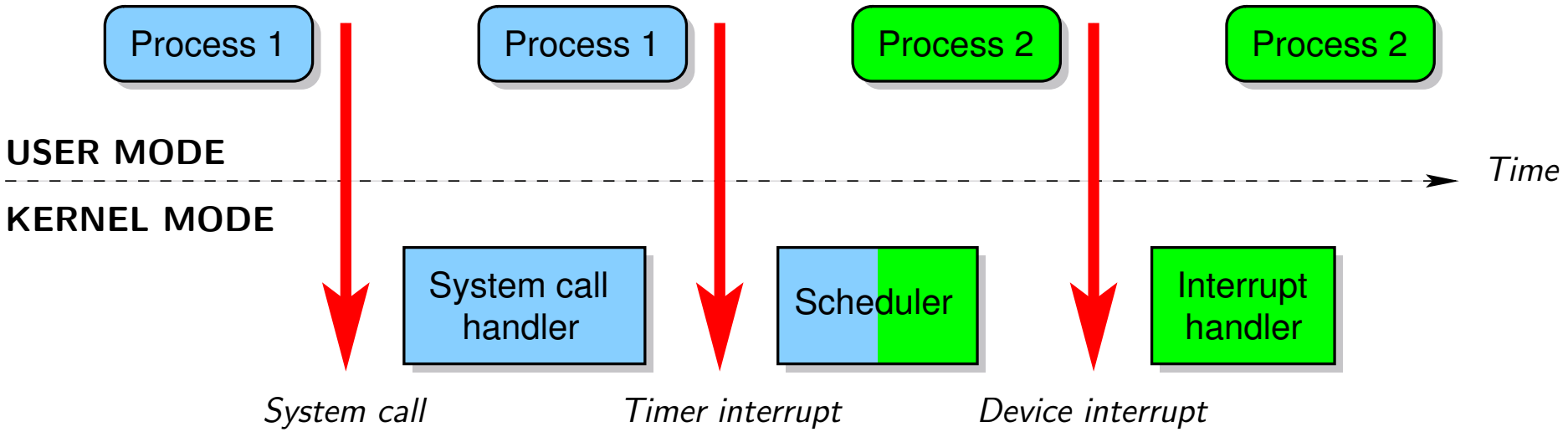
Challenge: Interaction Despite Isolation

- How to isolate processes (in memory)...
- ... While allowing them to request help from the kernel...
- ... To access resources (in compliance with security policies)...
- ... And to interact

System Call Principles

Solution: Privilege Levels

- User and kernel programs run in different priviledge levels, or "modes"
  - *Kernel mode*: no restriction
  - *User mode*: restricted instructions and memory regions
- Processors provide instructions to switch between user and kernel modes
- User processes switch to kernel mode when requesting a service provided by the kernel: *system call*



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POSIX Standard

Portable Operating System Interface

- IEEE POSIX 1003.1 and ISO/IEC 9945 (latest standard: 2004)
- Many subcommittees

Portability Issues

- POSIX is portable and does not evolve much,
- ... but it is still too high level for many OS interactions
  E.g., it does not specify file systems, network interfaces or power management
- C applications deal with portability with
  - C preprocessor: *conditional compilation*
  - Multi-target `Makefile` rules or GNU `configure` scripts to generate `Makefiles`
  - Shell environment variables (`LD_LIBRARY_PATH`, `LD_PRELOAD`), etc.

Should You Care About POSIX?

Modern Operating System Interfaces

- Java takes a different approach
  - A *Virtual Machine* (VM)
  - A *Standard Development Kit* (SDK)
- Yet UNIX commands and shell scripts are also normalized in POSIX
- Besides POSIX, Linux also sets its own "extended standard"
- Note: unlike GNU/Linux, Android is not a typical POSIX/UNIX system, but still uses Linux as a kernel

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System Call Implementation

C Library Wrapper

- All system calls defined in OS-specific header file
  Linux: `/usr/include/sys/syscall.h` (which includes `/usr/include/bits/syscall.h`)
- System call handlers are numbered
- C library wraps processor-specific parts into a plain function

System Call Implementation

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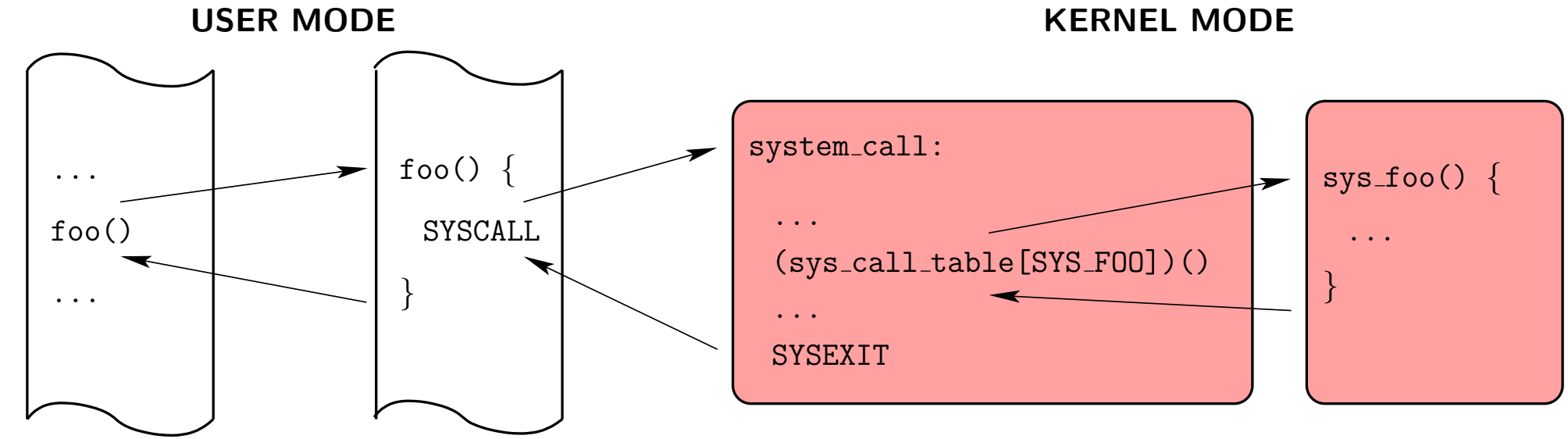

System Call Implementation

Wrapper's Tasks

1. Move parameters from the user stack to processor registers
   Passing arguments through registers is easier than playing with both user and kernel stacks at the same time
2. Switch to kernel mode and jump to the system call handler
   Call processor-specific instruction (`trap`, `sysenter`, ...)
3. Post-process the return value and compute `errno`

Handler's Tasks

1. Save processor registers into the *kernel mode stack*
2. Call the service function in the kernel
   Linux: array of function pointers indexed by system call number
3. Restore processor registers
4. Switch back to user mode
   Call processor-specific instruction (`rti`, `sysexit`, ...)

System Call Implementation

Verifying the Parameters

- Can be call-specific
  E.g., checking a file descriptor corresponds to an open file

- General (coarse) check that the pointer arguments point to user pages
  Linux: less than `PAGE_OFFSET`
- Delay more complex page fault checks until address translation time
  1. Access to non-existent page of the process
     → no error but need to allocate (and maybe copy) a page on demand
  2. Access to a page outside the process space
     → issue a segmentation/page fault
  3. The kernel function itself is buggy and accesses and illegal address
     → call `oops()` (possibly leading to "kernel panic")

Trace of System Calls

```
$  strace ./hello
execve("./hello", ["./hello"], [/* 36 vars */])    = 0
brk(0)                                             = 0x0804a000
...
access("/etc/ld.so.nohwcap", F_OK)                 = -1 ENOENT (No such file or directory)
open("/etc/ld.so.cache", O_RDONLY)                 = 3
fstat64(0x3, 0xffd1c12c)                           = 0
mmap2(NULL, 100777, PROT_READ, MAP_PRIVATE, 3, 0) = 0xf7f2e000
close(3)                                           = 0
...
open("/lib32/libc.so.6", O_RDONLY)                 = 3
read(3, "\177ELF\1\1\1\0\0\0\0\0\0\0\0\3\0\3\0\1\0\0\0\1\000"..., 512) = 512
fstat64(0x3, 0xffd1c1c8)                           = 0
mmap2(NULL, 1336944, PROT_READ|PROT_EXEC, MAP_PRIVATE|MAP_DENYWRITE, 3, 0) = 0xf7de7000
...
close(3)                                           = 0
mmap2(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0xf7de6000
...
munmap(0xf7f2e000, 100777)                         = 0
fstat64(0x1, 0xffd1c9bc)                           = 0
mmap2(NULL, 4096, PROT_READ|PROT_WRITE, MAP_PRIVATE|MAP_ANONYMOUS, -1, 0) = 0xf7f46000
write(1, "Hello world!\n", 13)                     = 13
exit_group(0)                                      = ?
```