The Process Model (2)

Lecture 4, Part 2: Traps and Syscalls in Practice

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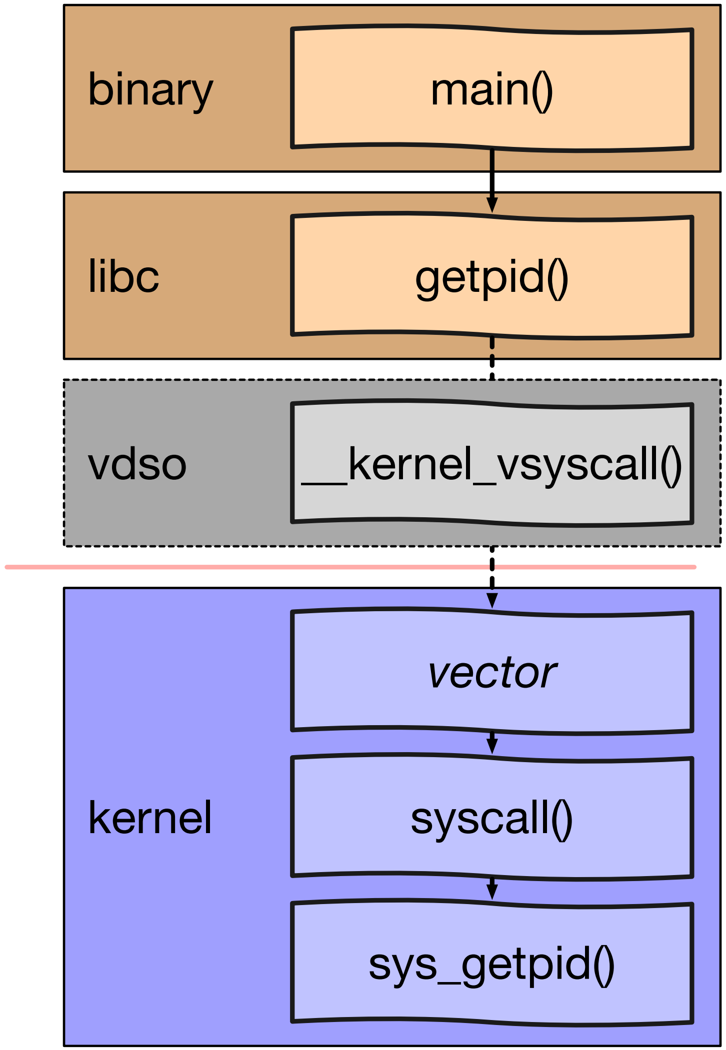
Reminder: System-call invocation



Note: This is something of a mashup of the system-call paths of different operating systems, to illustrate how the ideas compose

- `libc` system-call stubs provide linkable symbols
- Inline system-call instructions or dynamic implementations
  - Linux `vdso`
  - Xen **hypercall page**
- **Machine-dependent trap vector**
- **Machine-independent** function `syscall()`
  - Prologue (e.g., breakpoints, tracing)
  - Actual service invoked
  - Epilogue (e.g., tracing, signal delivery)

System-call entry – `syscallenter`

`cred_update_thread`	Update thread cred from process
`sv_fetch_syscall_args`	ABI-specific `copyin()` of arguments
`ktrsyscall`	`ktrace` syscall entry
`ptracestop`	`ptrace` syscall entry breakpoint
`IN_CAPABILITY_MODE`	Capsicum capability-mode check
`syscall_thread_enter`	Thread drain barrier (module unload)
`systrace_probe_func`	DTrace system-call entry probe
`AUDIT_SYSCALL_ENTER`	Security event auditing
`sa->callp->sy_call`	**System-call implementation! Woo!**
`AUDIT_SYSCALL_EXIT`	Security event auditing
`systrace_probe_func`	DTrace system-call return probe
`syscall_thread_exit`	Thread drain barrier (module unload)
`sv_set_syscall_retval`	ABI-specific return value

Execution order

- That's a lot of tracing hooks – why so many?

getauid: return process audit ID

```
int
sys_getauid(struct thread *td, struct getauid_args *uap)
{
        int error;

        if (jailed(td->td_ucred))
                return (ENOSYS);
        error = priv_check(td, PRIV_AUDIT_GETAUDIT);
        if (error)
                return (error);
        return (copyout(&td->td_ucred->cr_audit.ai_auid, uap->auid,
            sizeof(td->td_ucred->cr_audit.ai_auid)));
}
```

- Arguments: **Current thread** pointer, system-call **argument struct**
- Security: **lightweight virtualisation**, **privilege check**
- Copy value to user address space – can't write to it directly!

- No explicit synchronisation as fields are thread-local
- Does it matter how fresh the credential pointer is?

System-call return – `syscallret`

`userret`	Complicated things, like signals
→ `KTRUSERRET`	`ktrace` syscall return
→ `g_waitidle`	Wait for disk probing to complete
→ `addupc_task`	System-time profiling charge
→ `sched_userret`	Scheduler adjusts priorities
	… various debugging assertions…
`p_throttled`	`racct` resource throttling
`ktrsysret`	Kernel tracing: syscall return
`ptracestop`	`ptrace` syscall return breakpoint
`thread_suspend_check`	Single-threading check
`P_PPWAIT`	`vfork` wait

Execution order

- That is a lot of stuff that largely **never happens**
- The trick is making all of this nothing fast – e.g., via per-thread flags and globals that remain in the data cache

System calls in practice: dd (1)

```
root@rpi4-000:/data # time dd if=/dev/zero of=/dev/null bs=10m count=1
status=none
0.000u 0.035s 0:00.03 100.0%         26+176k 0+0io 0pf+0w
```

```
  __sysctl                                                          0
  cap_enter                                                         0
  cap_fcntls_limit                                                  0
  cap_ioctls_limit                                                  0
  cap_rights_limit                                                  0
  close                                                             0
  fstat                                                             0
  fstatat                                                           0
  ioctl                                                             0
  issetugid                                                         0
  munmap                                                            0
  open                                                              0
  openat                                                            0
  pread                                                             0
  readlink                                                          0
  sigaction                                                         0
  sigfastblock                                                      0
  write                                                             0
  mmap                                                         997784
  mprotect                                                    1017154
  read                                                       25010967
          27025905
```

Zero execution times probably reflect coarse-grained DTrace timer granularity on FreeBSD/arm64

System calls in practice: dd (2)

```
root@rpi4-000:/data # time dd if=/dev/zero of=/dev/null bs=1000m count=1
status=none
0.000u 2.838s 0:02.83 100.0%  23+154k 0+0io 0pf+0w
```

```
profile:::profile-997 /execname == "dd"/ {
        @traces[stack()] = count();
}
```

The two most frequent kernel stack traces

```
…
kernel`uiomove_faultflag+0x14c
kernel`uiomove_faultflag+0x148
kernel`zero_read+0x3c
kernel`devfs_read_f+0xd0
kernel`dofileread+0x7c
kernel`sys_read+0xbc
kernel`do_el0_sync+0x448
kernel`handle_el0_sync+0x90
527
```

Trace taken while copying zeros from kernel to user buffer

```
kernel`vm_fault+0xb64
kernel`vm_fault+0xb60
kernel`vm_fault_trap+0x60
kernel`data_abort+0xf4
kernel`handle_el1h_sync+0x78
kernel`uio
kernel`zero_read+0x3c
kernel`devfs_read_f+0xd0
kernel`dofileread+0x7c
kernel`sys_read+0xbc
kernel`do_el0_sync+0x448
kernel`handle_el0_sync+0x90
783
```

Trap from kernel to kernel

Trap from user to kernel

Trace taken while processing a VM fault during memory copy to userspace

```
static void
vm_fault_zerofill(struct faultstate *fs)
{

        /*
         * If there's no object left, fill the page in the top
         * object with zeros.
         */
        if (fs->object != fs->first_object) {
                vm_object_pip_wakeup(fs->object);
                fs->object = fs->first_object;
                fs->pindex = fs->first_pindex;
        }
        MPASS(fs->first_m != NULL);
        MPASS(fs->m == NULL);
        fs->m = fs->first_m;
        fs->first_m = NULL;

        /*
         * Zero the page if necessary and mark it valid.
         */
        if ((fs->m->flags & PG_ZERO) == 0) {
                pmap_zero_page(fs->m);
        } else {
                VM_CNT_INC(v_ozfod);
        }
        VM_CNT_INC(v_zfod);
        vm_page_valid(fs->m);
}
```

What have we learned?

- Our benchmark was synthetic (and quite artificial):
  - Read 1GB of zeros from /dev/zero
  - Write 1GB of read zeroes to /dev/null
- Observations:
  - The read(2) system call dominates kernel tracing
    - Zeroes are really copied into user memory
  - The write(2) system call doesn't appear at all
    - The /dev/null implementation elides its memory copy
  - Much of the read(2) time was spent in nested traps
    - The VM system was zeroing the 1GB buffer as it was copied to
    - We were zeroing all the memory twice!
- The security and reliability properties of the process model come with a real cost
- To prevent confused deputies, the process abstraction is also maintained for kernel access to user memory
- The VM system performed most of its work lazily