System Calls

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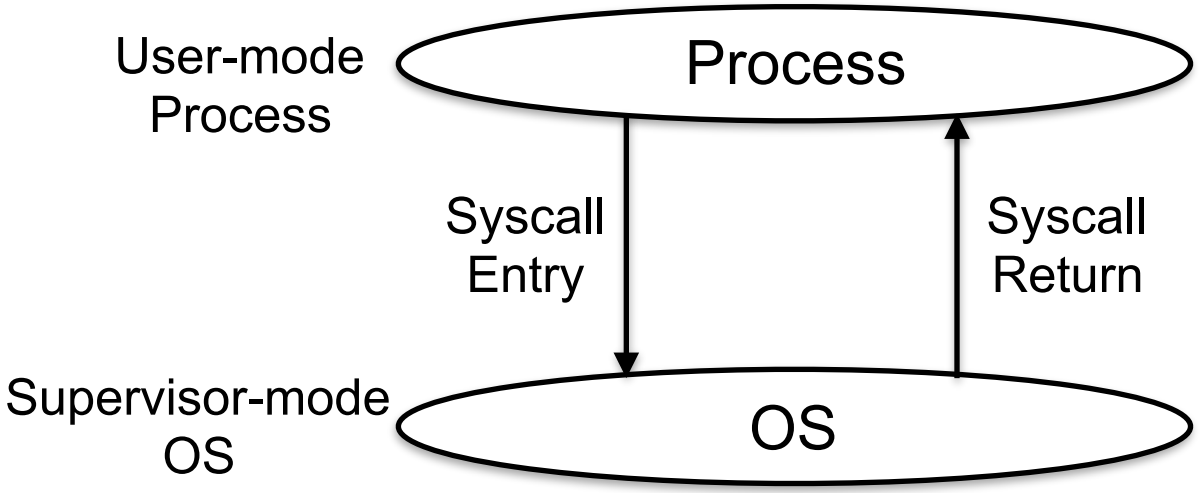
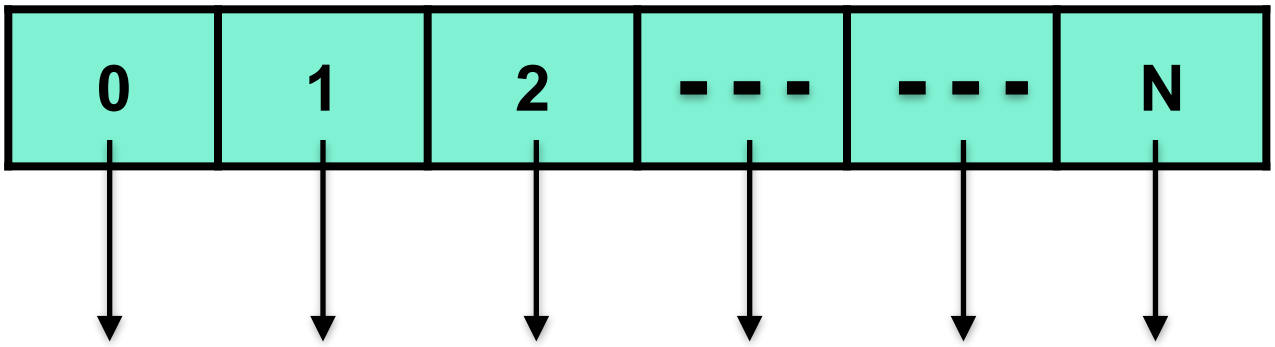
System Calls

- Modern CPUs support at least two levels of privileges:
  - User mode – application execute at this level
  - Supervisor mode – OS (kernel) code executes at this level
- System calls
  - Interface to allow User-level processes to safely invoke OS routines for privileged operations.
  - Safely transfer control from lower privilege level (user mode) to higher privilege level (supervisor mode), and back.



System Call table

- Protected entry points into the kernel for each system call
  - We don't want application to randomly jump into any part of the OS code.
- Syscall table is usually implemented as an array of function pointers, where each function implements one system call
- Syscall table is indexed via system call number



System call invocation

1. System call is invoked via a special CPU instruction
   - Such as SYSENTER/int 0x80/lcall7/lcall27 etc.
   - The system call number and arguments passed via CPU registers and optionally stack.
2. CPU saves process execution state
3. CPU switches to higher privilege level
   - Jumps to an entry point in OS code.
4. OS indexes the system call table using the system call number
5. OS invokes the system call via a function pointer in the system call table.
   - For performance reasons, the system call usually executes in the execution context of the calling process, but in privileged mode.
   - Some operating systems may execute the system call in a separate execution context for better security.
6. If the syscall involves blocking I/O, the calling process may block while the I/O completes.
7. When syscall completes, the calling process is moved to ready state.
8. The saved process state is restored
9. Processor switches back to lower (user) privilege level using SYSEXIT/iret instructions
10. Process returns from the system call and continues.

Syscall Usage

- To make it easier to invoke system calls, OS writers normally provide a library that sits between programs and system call interface.
  - Libc, glibc, etc.
- This library provides wrapper routines
- Wrappers hide the low-level details of
  - Preparing arguments
  - Passing arguments to kernel
  - Switching to supervisor mode
  - Fetching and returning results to application.
- Helps to reduce OS dependency and increase portability of programs.

Implementing System Calls

Steps in writing a system call

- Create an entry for the system call in the kernel's syscall_table
  - User processes trapping to the kernel (through SYS_ENTER or int 0x80) find the syscall function by indexing into this table.
- Write the system call code as a kernel function
  - Be careful when reading/writing to user-space
  - Use *copy_to_user()* or *copy_from_user()* routines.
    - These perform sanity checks.
- Generate/Use a user-level system call stub
  - Hides the complexity of making a system call from user applications.
  - See *man syscall*

Step 1: Create a sys_call_table entry (for 64-bit x86 machines)

- arch/x86/syscalls/syscall_64.tbl

```
#
# 64-bit system call numbers and entry vectors
#
# The format is:
# <number> <abi> <name> <entry point>
#
# The abi is "common", "64" or "x32" for this file.
...
309  common       getcpu                  sys_getcpu
310  64           process_vm_readv        sys_process_vm_readv
311  64           process_vm_writev       sys_process_vm_writev
312  common       kcmp                    sys_kcmp
313  common       foo                     sys_foo
```

Step 2: Write the system call handler

- System call with no arguments and integer return value

```
asmlinkage int sys_foo(void) {
        printk (KERN ALERT "I am foo. UID is %d\n", current->uid);
        return current->uid;
}
```

- Syscall with one primitive argument

```
asmlinkage int sys_foo(int arg) {
        printk (KERN ALERT "This is foo. Argument is %d\n", arg);
        return arg;
}
```

- To see log: dmesg, /var/log/kern.log

Step 2: Write the system call handler (cont...)

- Verifying argument passed by user space

```
asmlinkage long sys_close(unsigned int fd)
{
        struct file * filp;
        struct files_struct *files = current->files;
        struct fdtable *fdt;
        spin_lock(&files->file_lock);
        fdt = files_fdtable(files);
        if (fd >= fdt->max_fds)
                goto out_unlock;
        filp = fdt->fd[fd];
        if (!filp)
                goto out_unlock;
        ...
out_unlock:
        spin_unlock(&files->file_lock);
        return -EBADF;
}
```

- Call-by-reference argument
  - User-space pointer sent as argument.
  - Data to be copied back using the pointer.

```
asmlinkage ssize_t sys_read ( unsigned int fd,
        char __user * buf,  size_t count)
{
        ...

        if( !access_ok( VERIFY_WRITE, buf, count))
                return -EFAULT;

        ...
}
```

Example syscall implementation

```
asmlinkage int sys_foo(void) {
        static int count = 0;
        printk(KERN_ALERT "Hello World! %d\n", count++);
        return -EFAULT; // what happens to this return value?
}

EXPORT_SYMBOL(sys_foo);
```

Step 3: Invoke your new handler with syscall

- Use the **syscall(...) library function**.
  - Do a "man syscall" for details.
- For instance, for a no-argument system call named foo(), you'll call
  - ret = syscall(__NR_sys_foo);
  - Assuming you've defined __NR_sys_foo earlier
- For a 1 argument system call named foo(arg), you call
  - ret = syscall(__NR_sys_foo, arg);
- and so on for 2, 3, 4 arguments etc.
- For this method, check
  - http://www.ibm.com/developerworks/linux/library/l-system-calls/

Step 3: Invoke your new handler with syscall (cont...

```
#include <stdio.h>
#include <errno.h>
#include <unistd.h>
#include <linux/unistd.h>
// define the new syscall number. Standard syscalls are defined in linux/unistd.h
#define __NR_sys_foo 333
int main(void)
{
        int ret;
          while(1) {
         // making the system call
                        ret = syscall(__NR_sys_foo);
                        printf("ret = %d errno = %d\n", ret, errno);
                        sleep(1);
       }
          return 0;
}
```