System Calls

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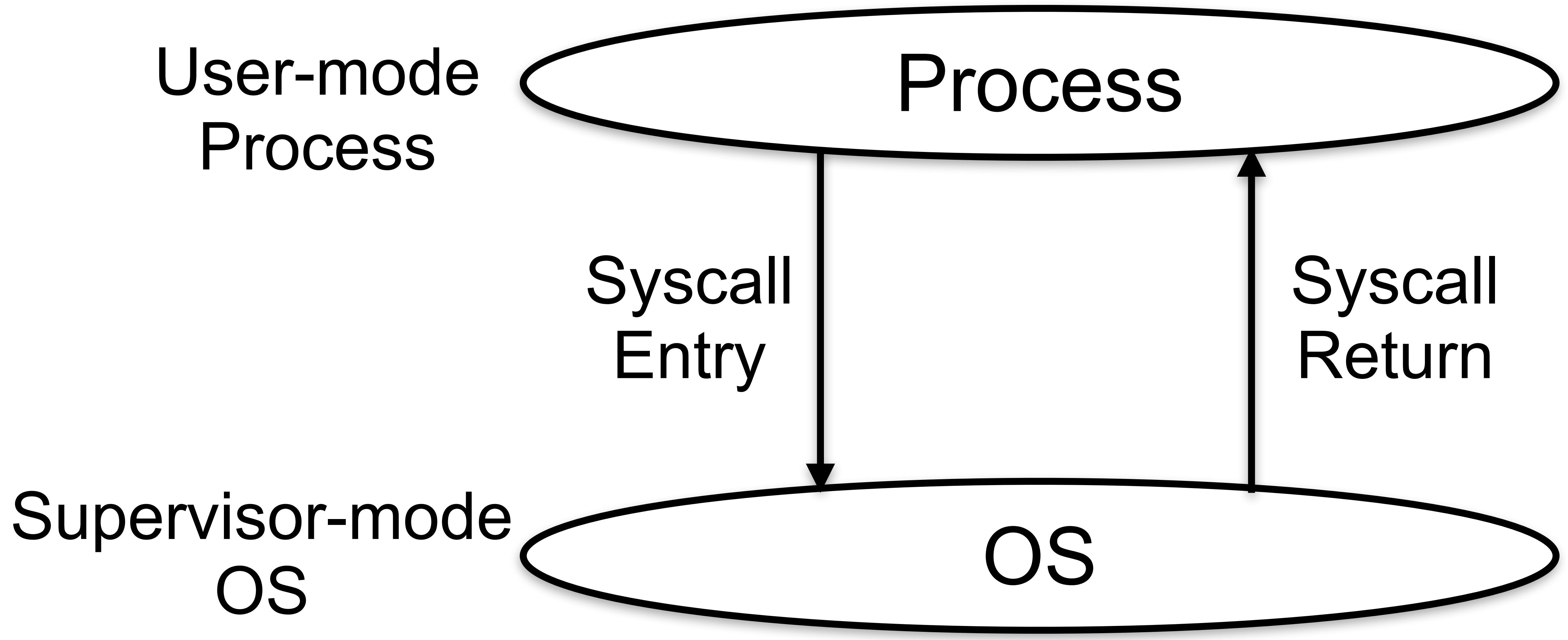
System Calls

- 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.

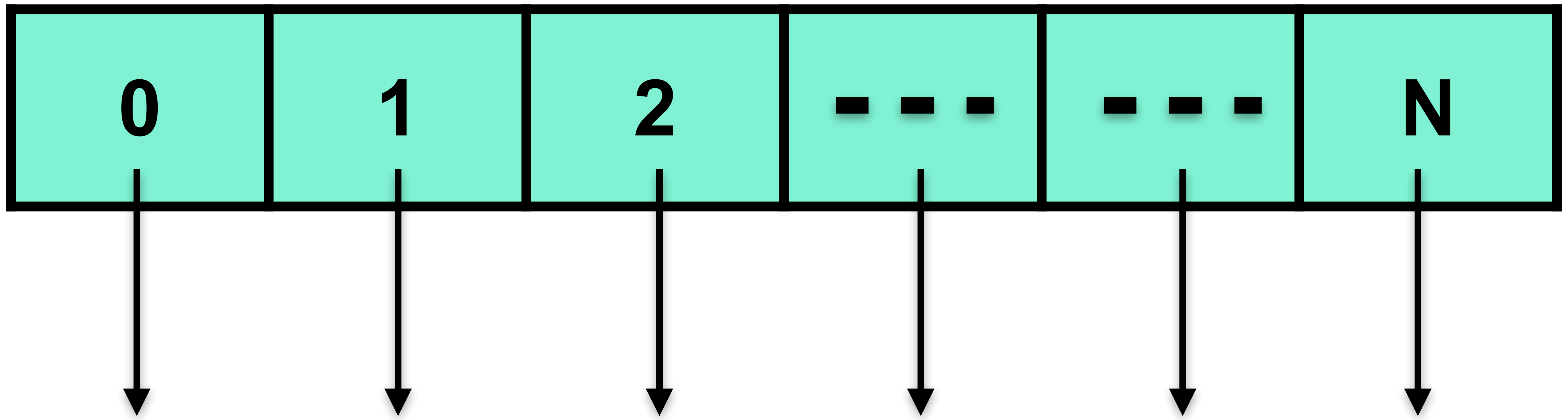


System Call table

- 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



Steps in system call execution

User process	Invoke syscall using, say, SYSENTER instruction (arguments in registers/stack)
CPU	Switch CPU to <u>supervisor</u> mode. Jump to entry point in kernel.
Kernel	Save process state Lookup Syscall table. Invoke syscall.
Kernel	Optionally Block process if it needs to wait for I/O or other events. Return process to ready state when woken.
Kernel	Restore saved process state SYSEXIT
CPU	Switch CPU to <u>user</u> mode Return to user process
User Process	Return from system call. Continue

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

1. 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.

2. 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.

3. Implement a user-level wrapper to invoke your system call
   - 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)

- Syscall table initialized in arch/x86/entry/syscall_64.c
- arch/x86/entry/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

```
SYSCALL_DEFINE0(foo){
printk (KERN ALERT “sys_foo: pid is %d\n”, current->pid);
return current->pid;
}
```

- Syscall with one primitive argument

```
SYSCALL_DEFINE1(foo, int, arg){
printk (KERN ALERT “sys_foo: Argument is %d\n”, arg);
return arg;
}
```

- To see system log:
  - `dmesg`
  - `less /var/log/kern.log`

Step 2: Write the system call handler

- Verifying argument passed by user space

```
SYSCALL_DEFINE1(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.

```
SYSCALL_DEFINE3( read, unsigned int, fd,
                char __user *, buf,  size_t, count)
{
                …

   if( !access_ok( VERIFY_WRITE, buf, count))
                return –EFAULT;
                …
}
```

Step 3: Invoke syscall handler from user space

- 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
  - https://developer.ibm.com/tutorials/l-system-calls/

Step 3: Invoke your new handler from user space

```
#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;
}
```