CSE 451: Operating Systems

Section 2

Interrupts, system calls, and project 1

Interrupts

- Interrupt
  - Hardware interrupts caused by devices signaling CPU
- Exception
  - Unintentional software interrupt
  - Ex: divide-by-zero, general protection fault, breakpoints
  - Transfers control to Exception Handler fn
- Trap (software interrupt)
  - Intentional software interrupt
  - Controlled method of entering kernel mode
  - Performed via system calls

Interrupt handling

- Execution of current process halts
- CPU switches from user mode to kernel mode, saving process state (registers, stack pointer, program counter)
  - Context switches: rebuilding a car's transmission at 60mph
  - Pipelining makes this even more complex
- CPU looks up interrupt handler in table and executes it
- When the interrupt handler finishes, the CPU restores the process state, switches back to user mode, and resumes execution

Interrupt handling

- What happens if there is another interrupt during the execution of the interrupt handler?
  - Race conditions
  - The kernel disables interrupts before entering some handler routines (FLIH vs. SLIH)
- What happens when an interrupt arrives and interrupts are disabled?
  - The kernel queues interrupts for later processing

System calls

- Provide userspace applications with controlled access to OS services
- Requires special hardware support on the CPU to detect a certain system call instruction and trap to the kernel
- x86 uses the INT X instruction, X in [0,255]

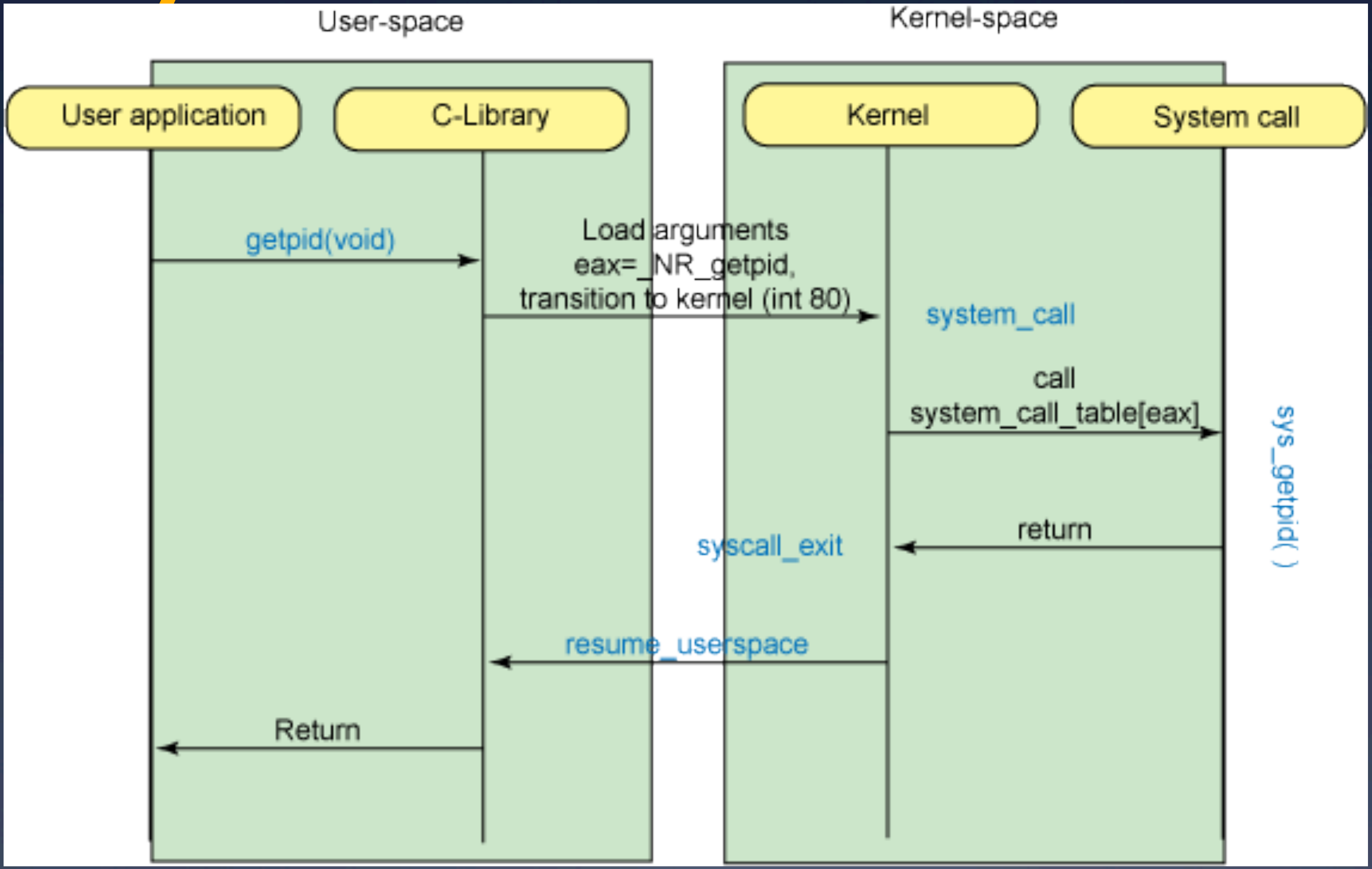
System call control flow

- User application calls a user-level library routine (`gettimeofday()`, `read()`, `exec()`, etc.)
- Invokes system call through stub, which specifies the system call number. From `unistd.h`:

```
#define __NR_getpid 172
__SYSCALL(__NR_getpid, sys_getpid)
```

- This generally causes an interrupt, trapping to kernel
- Kernel looks up system call number in syscall table, calls appropriate function
- Function executes and returns to interrupt handler, which returns the result to the userspace process

System call control flow



- Specifics have changed since this diagram was created, but the idea is still the same

Linux Syscall Specifics

- The syscall handler is generally defined in `arch/x86/kernel/entry_[32|64].S`
- In the Ubuntu kernel I am running, `entry_64.S` contains `ENTRY(system_call)`, which is where the syscall logic starts
- There used to be “`int`” and “`iret`” instructions, but those have been replaced by “`sysenter`” and “`sysexit`”, which provide similar functionality.

Project 1

- Due: **Oct 18th** at 11:59 PM.
- Three parts of varying difficulty:
  - Write a simple shell in C
  - Add a new system call and track state in kernel structures to make it work
  - Write a library through which the system call can be invoked
- Turn in code plus a write-up related to what you learned/should have learned

The CSE451 shell

- Print out prompt
- Accept input
- Parse input
- If built-in command
  - Do it directly
- Else spawn new process
  - Launch specified program
  - Wait for it to finish
- Repeat

```
CSE451Shell% /bin/date
Wed Apr 31 21:58:55 PDT 2013
CSE451Shell% pwd
/root
CSE451Shell% cd /
CSE451Shell% pwd
/
CSE451Shell% exit
```

CSE451 shell hints

- In your shell:
  - Use `fork` to create a child process
  - Use `execvp` to execute a specified program
  - Use `wait` to wait until child process terminates
- Useful library functions (see man pages):
  - Strings: `strcmp`, `strncpy`, `strtok`, `atoi`
  - I/O: `fgets` or (preferrably) `readline`
  - Error reporting: `perror`
  - Environment variables: `getenv`

CSE451 shell hints

- Advice from a previous TA:
  - Try running a few commands in your completed shell and then type exit. If it doesn't exit the first time, you're doing something wrong
  - `echo $?` prints the last exit code, so you can check your exit code against what is expected.
  - Check the return values of all library/system calls. They might not be working as you expect
  - Each partner in your group should contribute some work to each piece or you won't end up understanding the big picture

Adding a system call

- Add `execcounts` system call to Linux:
  - Purpose: collect statistics
  - Count number of times a process *and all of its descendents* call the `fork`, `vfork`, `clone`, and `exec` system calls
- Steps:
  - Modify kernel to keep track of this information
  - Add `execcounts` to return the counts to the user
  - Use `execcounts` in your shell to get this data from kernel and print it out

Programming in kernel mode

- Your shell will operate in user mode
- Your system call code will be in the Linux kernel, which operates in kernel mode
- Be careful - different programming rules, conventions, etc.

Kernel programming

- Can't use application libraries (e.g. libc)
  - No printf—use prink instead
- Use only headers/functions exposed by the kernel
- You cannot trust user space
- For example, you should validate user buffers (look in kernel source for what other syscalls, e.g. `gettimeofday` do)

Kernel development hints

- Use find + grep as a starting point to find interesting code

```
find . -type f -name "*.h" -exec grep -n \
  gettimeofday {} +
```

- Pete Hornyack (a previous TA) put together a tutorial on using ctags and cscope to cross-reference type definitions: http://www.cs.washington.edu/education/courses/cse451/13sp/tutorials/tutorial_ctags.html

Kernel development hints

- Use Git to collaborate with your project partners
  - There is a guide to getting Git set up for use with project 1 on the website:
    - http://www.cs.washington.edu/education/courses/cse451/13sp/tutorials/tutorial_git.html
  - Overview of use:
    - Create a shared repository in /projects/instr/13sp/cse451/X, where X is your group's letter
  - Check the project's kernel source into the repository
  - Have each group member check out the kernel source, make modifications to it as necessary, and check in their changes
  - See the web page for more information
- Git makes it easy to find any files you've changed.

Project 1 development

- Use forkbomb for kernel compilation
  - You have /cse451/netid directories with lots of space
- Option 1: Use VMWare on a Windows lab machine
  - …or use the VM itself for kernel compilation (slow?)
  - The VM files are not preserved once you log out of the Windows machine, so copy/git push your work to attu, your shared repository, or some other "safe" place
- Option 2: Use Qemu on your box/lab linux machine
  - See the Project 1 page (live now!) http://www.cs.washington.edu/education/courses/cse451/13au/projects/project1.html

Option 1: VMWare Player

- Once you have built the kernel, copy the resulting bzImage file to your VM and overwrite `/boot/vmlinuz-3.8.3-201.cse451custom`
- Reboot with `sudo shutdown -r now`
- If your kernel fails to boot, pick a different kernel from the menu to get back into the VM
- While inside the running VM, use the `dmesg` command to print out the kernel log (your `printk`s will show up here—use `grep` to find the ones you care about)

Option 2: QEmu

- Instructions are up on the course website
  - Much more convenient than Vmware
  - It will run in a terminal window
  - You can debug the kernel from your host machine using GDB
  - It's a bit trickier to set up … but good stuff to know if you plan to get into backend dev
  - Forkbomb is a Qemu virtual machine!

Adding a syscall: demo

- Files to modify:
  - include/linux/syscalls.h
  - arch/x86/syscalls/syscall_64.tbl
  - kernel/sys_ni.c
  - Makefile
- Write your syscall (kernel/my_sys_call.c)
- Compile the kernel!