CSE 451: Operating Systems

Section 2

Interrupts, Syscalls, Virtual Machines, and Project 1

Interrupts

- Interrupt
  - Hardware or software
  - Hardware interrupts caused by devices signaling CPU
  - Software interrupts caused by code
- Exception
  - Unintentional software interrupt
  - E.g. errors, divide-by-zero, general protection fault
- Trap
  - Intentional software interrupt
  - Controlled method of entering kernel mode
  - System calls

Interrupts (continued)

- Execution halted
- CPU switched from user mode to kernel mode
- State saved
  - Registers, stack pointer, PC
- Look up interrupt handler in table
- Run handler
  - Handler is (mostly) just a function pointer
- Restore state
- CPU switched from kernel mode to user mode
- Resume execution

Interrupts (continued)

- What happens if there is another interrupt during the handler?
  - The kernel disables interrupts before entering a handler routine
- What happens if an interrupt fires while they 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

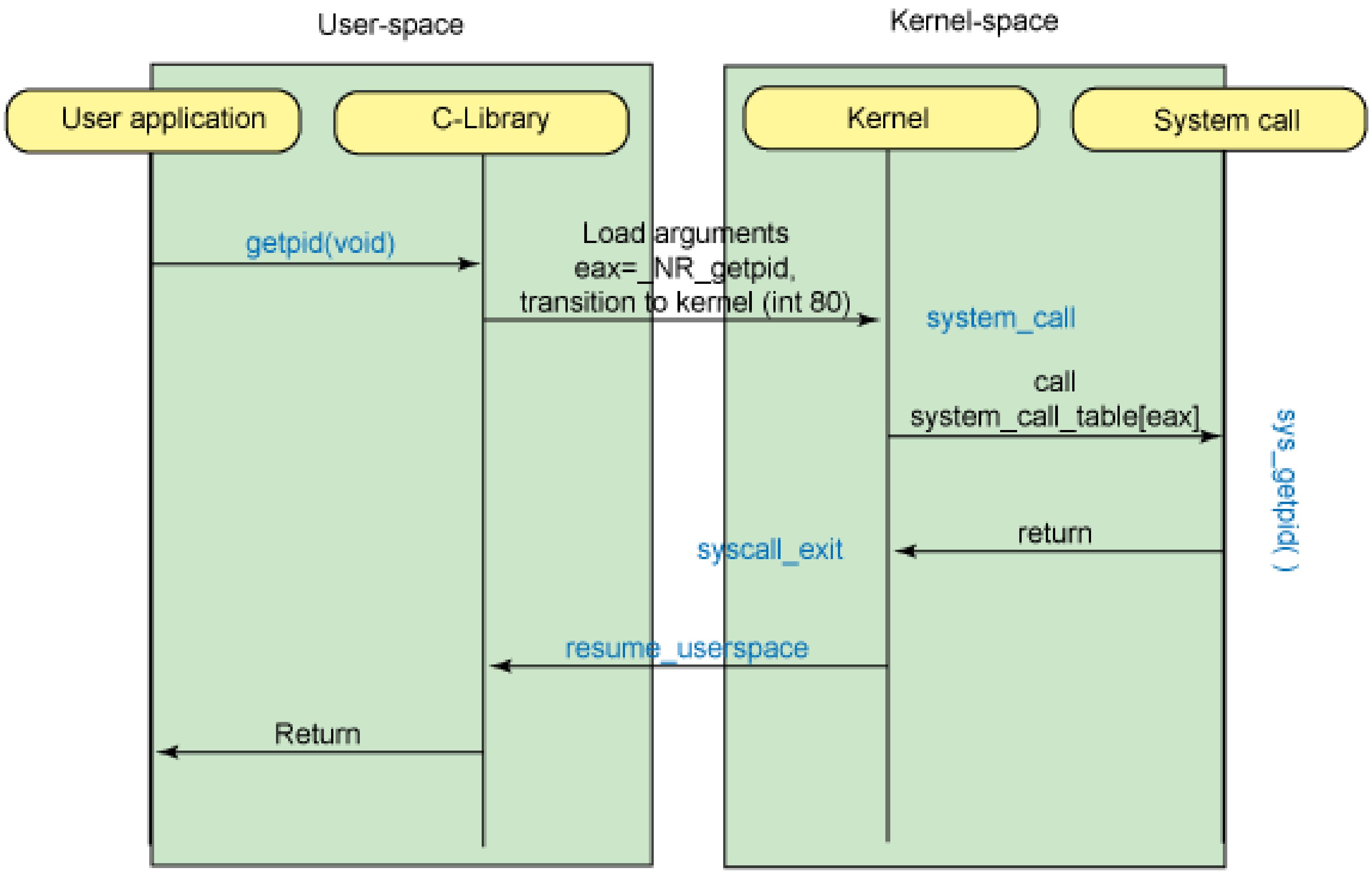
System call control flow

- 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 (continued)



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

How Linux does system calls

- The syscall handler is generally defined in `arch/x86/kernel/entry_[32|64].S`
- In the Ubuntu kernel I am running (2.6.38), `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- There used to be "`int`" and "`iret`" instructions, but those have been replaced by "`sysenter`" and "`sysexit`", which provide similar functionality.

Syscalls in a virtual machine

- For software VMMs (e.g. VMWare Player, VirtualBox, Microsoft Virtual PC), there are a couple options:
  - Install hardware interrupt handler for each VM (requires CPU support, such as with Core 2 Duo and up)
  - Use dynamic rewriting to avoid hardware trap entirely
- For paravirtualized VMMs (e.g. Xen) parts of the OS are actually rewritten to avoid hardware traps
- For hardware VMMs a.k.a embedded hypervisors (e.g. VMWare ESX), sandboxing requirements are smaller, as the only user-mode entities are VMs
- Is one approach “best”?

Project 1

- 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
- Due: April 18 at 11:59 PM.
  - Turn in code plus a writeup 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
Sat Mar 31 21:58:55 PDT 2012
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*
  - Error report: *perror*
  - Environment variables: *getenv*

CSE451 shell hints (continued)

- 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 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
  - Don't split the project along the three parts among group members. Each one should contribute some work to each part 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 you call 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.
  - Simple, right? ;)

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.

Userspace vs. kernel mode conventions

- Can’t use application libraries (e.g. libc)
  - E.g. can’t use printf
- Use only functions defined by the kernel
  - E.g. use printk instead
- Include files are different in the kernel
- Don’t forget you’re in kernel space
  - *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 grep as a starting point to find code
  - For example:
  - `find . -name *.c | xargs grep -n gettimeofday`
  - This will search all c files below your current directory for gettimeofday and print out the line numbers where it occurs
- Pete has an awesome tutorial on the website about using ctags and cscope to cross-reference variable, struct, and function definitions:
  - http://www.cs.washington.edu/education/courses/cse451/12sp/tutorials/tutorial_ctags.html

Kernel development hints (continued)

- Use git to collaborate with your project partners
  - Pete has a guide to getting git set up for use with project 1 on the website:
  - http://www.cs.washington.edu/education/courses/cse451/12sp/tutorials/tutorial_git.html
  - Overview of use:
    - Create a shared repository in /projects/instr/12sp/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

Project 1 development

- Option 1: Use VMWare on a Windows lab machine
  - Can use forkbomb for kernel compilation (fast)
  - …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 your work to attu, your shared repository, or some other "safe" place
- Option 2: Use your own machine
  - Can use VMWare, VirtualBox, or your VMM of choice
  - See the "VM information" page on the website for getting this set up
  - http://www.cs.washington.edu/education/courses/cse451/12sp/vminfo.html

Project 1 development (continued)

- If you build the kernel on forkbomb, copy the resulting bzImage file to your VM and overwrite `/boot/vmlinuz-2.6.38.2-CSE451`
- If you build the kernel inside the VM, run `sudo make install` from inside the kernel directory to install it
- Reboot with `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)