CIS 415: Operating Systems

Processes

Prof. Kevin Butler
Spring 2014
• Last class:
  ‣ Operating system structure

• Today:
  ‣ More basics, system calls, Process Management
• Lab sections: everyone should know where you’re going
  ‣ this week: debugging

• Assignment 1: due April 22

• Project 1: out today, due April 24

• Manage your time wisely!
Process Address Space

- All locations addressable by the process
- Can restrict use of addresses (RW)
- Restrictions enforced by OS
- Every running program can have its own private address space
  - How?
System Call Handling

Procedure call in user process
Initial work in user mode (libc)
Trap instruction to invoke kernel (int 0x80)
Preparation (e.g., sys_read, mmap2)
I/O command (read from disk)
Wait (disk is slow)
Completion (interrupt handling)
Return-from-interrupt instruction
Final work in user mode (libc)
Ordinary return instruction
Details on x86 / Linux

• A more accurate picture:
  ‣ consider a typical Linux process
  ‣ its thread of execution can be several places
    • in your program’s code
    • in glibc, a shared library containing the C standard library, POSIX support, and more
    • in the Linux architecture-independent code
    • in Linux x86-32/x86-64 code
Details on x86 / Linux

• Some routines your program invokes may be entirely handled by glibc
  ‣ without involving the kernel
    • e.g., `strcmp()` from `stdio.h`
  ‣ some initial overhead when invoking functions in dynamically linked libraries
  ‣ but, after symbols are resolved, invoking glibc routines is nearly as fast as a function call within your program itself
Details on x86 / Linux

- Some routines may be handled by glibc, but they in turn invoke Linux system calls
  - e.g., POSIX wrappers around Linux syscalls
    - POSIX `readdir()` invokes the underlying Linux `readdir()`
  - e.g., C stdio functions that read and write from files
    - `fopen()`, `fclose()`, `fprintf()` invoke underlying Linux `open()`, `read()`, `write()`, `close()`, etc.
Details on x86 / Linux

• Your program can choose to directly invoke Linux system calls as well
  ‣ nothing forces you to link with glibc and use it
  ‣ but, relying on directly invoked Linux system calls may make your program less portable across UNIX varieties
File Interface

- **Goal:** Provide a uniform abstraction for accessing the OS and its resources
- **Abstraction:** File
  - Use file system calls to access OS services
  - Devices, sockets, pipes, etc.
  - And OS in general
I/O with System Calls

• Much I/O is based on a streaming model
  ‣ sequence of bytes
• `write()` sends a stream of bytes somewhere
• `read()` blocks until a stream of input is ready
• Annoying details:
  ‣ might fail, can block for a while
  ‣ file descriptors...
  ‣ arguments are pointers to character buffers
  ‣ see the `read()` and `write()` man pages
File Descriptors

• A process might have several different I/O streams in use at any given time

• These are specified by a kernel data structure called a file descriptor
  ▸ each process has its own table of file descriptors

• open() associates a file descriptor with a file

• close() destroys a file descriptor

• Standard input and standard output are usually associated with a terminal
  ▸ more on that later
Regular File

• File has a pathname: /tmp/foo
• Can open the file
  ‣ int fd = open("/tmp/foo", O_RDWR )
  ‣ For reading and writing
• Can read from and write to the file
  ‣ bytes = read( fd, buf, max ); /* buf get output */
  ‣ bytes = write( fd, buf, len ); /* buf has input */
Socket File

• File has a pathname: /tmp/bar
  ‣ Files provide a persistence for a communication channel
  ‣ Usually used for local communication (UNIX domain sockets)

• Open, read, and write via socket operations
  ‣ sockfd = socket(AF_UNIX, TCP_STREAM, 0);
  ‣ local.path is set to /tmp/bar
  ‣ bind ( sockfd, &local, len )
  ‣ Use sock operations to read and write
Device File

- Files for interacting with physical devices
  - /dev/null (do nothing)
  - /dev/cdrom (CD-drive)

- Use file system operations, but are handled in device-specific ways
  - open, read, write correspond to device-specific functions
    - Function pointers!
  - Also, use ioctl (I/O control) to interact (later)
Sysfs File and `/proc` Files

- These files enable reading from and writing to kernel
- `/proc` files
  - enable reading of kernel state for a process
- Sysfs files
  - Provide functions that update kernel data
    - File’s `write` function updates kernel based on input data
Other System Calls

• It’s possible to hook the output of one program into the input of another: `pipe()`

• It’s possible to block until one of several file descriptor streams is ready: `select()`

• Special calls for dealing with network
  ‣ `AF_INET` sockets, etc.

• Send a message to other (or all) processes: `signal()`

• Most of these in section 2 of manual
  ‣ e.g., `man 2 select`
Syscall Functionality

• System calls are the main interface between processes and the OS
  ‣ like an extended “instruction set” for user programs that hide many details
  ‣ first Unix system had a couple dozen system calls
  ‣ current systems have many more (>300 in Linux, >500 in FreeBSD)
  ‣ Understanding the system call interface of a given OS lets you write useful programs under it

• Natural questions to ask:
  ‣ is this the right interface? how to evaluate?
  ‣ how can these system calls be implemented?
Why Processes?

• We have programs, so why do we need processes?
Overview

• Questions that we explore
  ‣ How are processes created?
    • From binary program to process
  ‣ How is a process represented and managed?
    • Process creation, process control block
  ‣ How does the OS manage multiple processes?
    • Process state, ownership, scheduling
  ‣ How can processes communicate?
    • Interprocess communication, concurrency, deadlock
Supervisor and User Modes

• OS runs in supervisor mode
  ‣ Has access to protected instructions only available in that mode (ring 0)
  ‣ Can manage the entire system

• OS loads processes into user mode
  ‣ Many processes can run in user mode

• How does OS get programs loaded into processes in user mode and keep them straight?
Process

• Address space + threads + resources
• Address space contains code and data of a process
• Threads are individual execution contexts
• Resources are physical support necessary to run the process (memory, disk, …)
Process Address Space

- Program (Text)
- Global Data (Data)
- Dynamic Data (Heap)
- Thread-local Data (Stack)
- Each thread has its own stack
int value = 5;  

int main()
{
    int *p;

    p = (int *)malloc(sizeof(int));

    if (p == 0) {
        printf("ERROR: Out of memory\n");
        return 1;
    }

    *p = value;
    printf("%d\n", *p);
    free(p);
    return 0;
}
Heap + stack

#include <stdlib.h>

int *copy(int a[], int size) {
    int i, *a2;

    a2 = malloc(
        size * sizeof(int));
    if (a2 == NULL)
        return NULL;

    for (i = 0; i < size; i++)
        a2[i] = a[i];
    return a2;
}

int main(...) {
    int nums[4] = {2, 4, 6, 8};
    int *ncopy = copy(nums, 4);
    // ... do stuff ...
    free(ncopy);
    return 0;
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Heap + stack

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```
Process Creation

• Parent process create children processes,
  ‣ which, in turn create other processes, forming a tree of processes

• Resource sharing options
  ‣ Parent and children share all resources
  ‣ Children share subset of parent’s resources
  ‣ Parent and child share no resources

• Execution options
  ‣ Parent and children execute concurrently
  ‣ Parent waits until children terminate
Process Creation

• Address space
  ‣ Child duplicate of parent
  ‣ Child has a program loaded into it

• UNIX examples
  ‣ fork system call creates new process
  ‣ exec system call used after a fork to replace the process’s memory space with a new program
Process Creation

• What happens?
  ‣ New process object in kernel
    • Build process data structures
  ‣ Allocate address space (abstract resource)
    • Later, allocate memory (physical resource)
  ‣ Add to execution queue
    • Runnable?
Process Creation

- fork()
  - child
    - exec()
      - exit()
    - wait
      - resumes
- parent
Process Layout

1. PCB with new id created
2. Memory allocated for child
   - Initialized by copying over from the parent
3. If parent had called wait, it is moved to a waiting queue
4. If child had called exec, its memory overwritten with new code & data
5. Child added to ready queue, all set to go now!

OS

Process calls fork

Processes

RAM

Parent’s PCB

Child’s PCB

Parent’s memory

Child’s memory

Id=2000
State=ready

Id=2001
State=ready
1. PCB with new Id created
2. Memory allocated for child

Initialized by copying over from the parent
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int main( )
{
    pid_t pid;
    /* fork another process */
    pid = fork( );
    if (pid < 0) { /* error occurred */
        fprintf(stderr, "Fork Failed");
        exit(-1);
    }
    else if (pid == 0) { /* child process */
        execvp("/bin/ls", "ls", NULL);
    }
    else { /* parent process */
        /* parent will wait for the child to complete */
        wait (NULL);
        printf("Child Complete");
        exit(0);
    }
}
Graphically
Graphically

client

connect

server
Graphically

client

fork() child

server

server
Graphically

client

server

child exit( )’s / parent wait( )’s
Graphically

client – server

server

parent closes its client connection
Graphically

client --> server

server --> server
Graphically

client ────→ server

fork( ) child

client ────→ server

server

server
Graphically
Graphically
Program Creation

• Design Choices
  ‣ Resource Sharing
    • What resources of parent should the child share?
    • What about after exec?
  ‣ Execution
    • Should parent wait for child?
  ‣ What is the relationship between parent and child?
    • Hierarchical or grouped or …?
Program Creation

- **fork** -- copy address space and all threads
- **forkl** -- copy address space and only calling thread
- **vfork** -- do not copy address space; shared between parent and child
- **exec** -- load new program; replace address space
  - Some resources may be transferred (open file descriptors)
  - Specified by arguments
A tree of processes on a typical system
Process Termination

• Process executes last statement and asks the operating system to delete it (exit)
  ‣ Output data from child to parent (via wait)
  ‣ Process’ resources are deallocated by operating system

• Parent may terminate execution of children processes (abort)
  ‣ Child has exceeded allocated resources
  ‣ Task assigned to child is no longer required
  ‣ If parent is exiting
    • Some operating system do not allow child to continue if parent terminates
    • All children terminated - cascading termination
Executing a Process

• What to execute?
  ‣ Register that stores the program counter
    • Next instruction to be executed

• Registers store state of execution in CPU
  ‣ Stack pointer
  ‣ Data registers

• Thread of execution
  ‣ Has its own stack
Executing a Process

• Thread executes over the process’s address space
  ‣ Usually the text segment

• Until a trap or interrupt…
  ‣ Time slice expires (timer interrupt)
  ‣ Another event (e.g., interrupt from other device)
  ‣ Exception (oops)
  ‣ **System call** (switch to kernel mode)
Relocatable Memory

• Mechanism that enables the OS to place a program in an arbitrary location in memory
  ‣ Gives the programmer the impression that they own the processor

• Program is loaded into memory at program-specific locations
  ‣ Need virtual memory to do this

• Also, may need to share program code across processes
Process State

• What do we need to track about a process?
  ‣ how many processes?
  ‣ what’s the state of each of them?

• Process table: kernel data structure tracking processes on system

• Process control block: structure for tracking process context
Scheduling Processes

- Processes transition among *execution states*
Process States

- **Running**
  - Running == in processor and in memory with all resources
- **Ready**
  - Ready == in memory with all resources, waiting for dispatch
- **Waiting**
  - Waiting == waiting for some event to occur
State Transitions

- New Process $\Rightarrow$ Ready
  - Allocate resources
  - End of process queue
- Ready $\Rightarrow$ Running
  - Head of process queue
  - Scheduled
- Running $\Rightarrow$ Ready
  - Interrupt (Timer)
  - Back to end of process queue
State Transitions: Page Fault Handling

• Running ==> Waiting
  ‣ Page fault exception (similar for syscall or I/O interrupt)
  ‣ Wait for event

• Waiting ==> Ready
  ‣ Event has occurred (page fault serviced)
  ‣ End of process queue (or head?)

• Ready ==> Running
  ‣ As before…
State Transitions: Other Issues

• Priorities
  ‣ Can provide policy indicating which process should run next
    • More when we discuss scheduling…

• Yield
  ‣ System call to give up processor
  ‣ For a specific amount of time (sleep)

• Exit
  ‣ Terminating signal (Ctrl-C)
Process Control Block

- State of running process
- Linked list of process control information
Per Process Control Info

• Process state
  ‣ Ready, running, waiting (momentarily)

• Links to other processes
  ‣ Children

• Memory Management
  ‣ Segments and page tables

• Resources
  ‣ Open files

• And Much More…
/proc File System

• Linux and Solaris
  ‣ `ls /proc`
  ‣ A directory for each process

• Various process information
  ‣ `/proc/<pid>/io` -- I/O statistics
  ‣ `/proc/<pid>/environ` -- Environment variables (in binary)
  ‣ `/proc/<pid>/stat` -- process status and info
Context Switch

• OS switches from one execution context to another
  ‣ One process to another process
  ‣ Interrupt handling
  ‣ Process to kernel (*mode transition*, not context switch)

• Current Process to New Process
  ‣ Save the state of the current process
    • *Process control block*: describes the state of the process in the CPU
  ‣ Load the saved context for the new process
    • Load the new process’s process control block into OS and registers
  ‣ Start the new process

• Does this differ if we are running an interrupt handler?
Context Switch

process $P_0$  operating system  process $P_1$

- executing
  - interrupt or system call
    - save state into PCB$_0$
    - ... ...
    - reload state from PCB$_1$
  - idle
- executing
  - interrupt or system call
    - save state into PCB$_1$
    - ... ...
    - reload state from PCB$_0$
  - idle
Context Switch

• No useful work is being done during a context switch
  ‣ Speed it up and limit system calls to things that can’t be done in user mode

• Hardware support
  ‣ Multiple register sets (Sun UltraSPARC)

• However, hardware optimization may conflict
  ‣ TLB flush is necessary
  ‣ Different virtual to physical mappings on different processes
Next class

• IPC