CSE 506: Operating Systems

What Software Expects of the OS
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• Memory
• System Calls
• System Services
• Launching “Program” Executables
• Shell
Memory Abstraction

• OS provides memory space to application
  – Application observes a contiguous “private” memory space
  – OS prevents “illegal” actions (e.g., no-exec, read-only)

• Memory typically includes several “sections”
  .text – program area
  .rodata – read-only variables
  .data – variables that have an initial value
  .bss – variables that are initially zero
  heap
  stack
Traditional Memory View

- Don’t use addrs. close to 0
  - Allows to detect bad accesses
- Heap grows upward
  - Increases when app asks for mem.
- Stack grows **downward**
  - Function calls push return addr.
  - Local variables go on stack
    - Main source of stack smash attacks
  - Must reserve stack space
    - Ensure that heap doesn’t hit stack

```
#FFFF,FFFF

stack ↓

↑
heap
bss
data
rodata
program
#0000,0000
```
Modern Memory View

- Heap no longer allocated up \#FFFF,FFFF
  - Although it still can be
- Shared libraries appear
- [vdso] adds magic memory
  - e.g., always contains current time
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System Calls

• Mechanism for app to interact with the OS
  – Similar to function calls
  – Code securely implemented in the OS
  – Follows predefined interface
    • Called “ABI” – Application Binary Interface
    • Functions referenced by predefined number

• Example syscall triggers
  – “trap” instruction
  – Special “syscall” instruction
  – Forced memory exception
Example System Calls

• getpid()
  – Return process’s ID
  – Function 39 in 64-bit Linux, 20 in FreeBSD

• brk()
  – Return current “top” of heap
  – Function 12 in 64-bit Linux, 69 in FreeBSD

Linux has ~650, FreeBSD ~400 syscalls
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Services Provided by OS

• Usually through syscalls
  – Variants: vdso provides time of day, stack grows on faults

• Typical “important” services
  – Scheduler
  – Memory management
  – Threads
  – Terminal
  – File system
  – Network
  – Limits

Numerous services exist; we’ll stick to these above.
• Create and control processes and threads
  – Same syscall for both in Linux: \textit{clone()}
  – FreeBSD uses \textit{fork()} for procs and \textit{thr_create()} for threads

• Difference between processes and threads?
  – Fundamentally similar, separate “threads” of control
  – Threads share same memory space
    • But have their own stack pointers
  – All threads should share one PID, but have own TIDs

• Exert control over processes
  – \textit{kill()}/\textit{signal()} to KILL, TERMinate, STOP, CONTinue
Process Control and Threads (2/2)

- Create and control processes and threads
  - `clone()` in Linux, `fork()` in FreeBSD

- Creates an identical copy of the process:

```c
int pid = fork();
if (pid == 0) {
    // child code
} else if (pid > 0) {
    // parent code
} else {
    // error (pid == -1)
}
```
Scheduler

• If there are multiple processes
  – Something has to decide what should run

• Takes into account many parameters
  – Readiness to run, priority, history

• Can be invoked by various triggers
  – On syscall – called cooperative multi-tasking
    • Low overhead
    • What happens when there are no system calls?
  – On timer – called preemptive multi-tasking
    • Processes can get de-scheduled at any time
    • Can still be slightly cooperative by calling yield() syscall
Memory Management

• Each process sees its own memory space
  – Called *virtual* memory

• Computer has DRAM chips plugged into it
  – Called *physical* memory

• OS manages physical memory
  – Operates on contiguous *pages* of memory (typically 4KB)
  – Maintains a virtual-to-physical mapping
    • Physical pages are allocated on demand
  – Supports *paging* (saving physical page contents to disk)
    • Sometimes used interchangeably with *swapping* (entire apps)
Memory Management

• Process starts with some memory
  – text, data, stack, heap

• Stack grows automatically
  – On an access below the stack
  – Allocate up to and including the demanded page

• Heap grows on request
  – Traditionally, \texttt{brk(new\_value)}
  – Modern systems use \texttt{mmap()}
  – \texttt{malloc()} uses one or the other
    • Implementations rarely release \texttt{brk()} memory back to the OS
Terminal (1/3)

• Not the same as *console*
  – Although *console* is usually connected to a *terminal*

• Terminals have two ends
  – One connects to an input/output device
    • Teletype, more recently serial port, today screen and keyboard
  – Other end attached to software (e.g., bash)
  – Anything written into one end comes out the other
    • Extremely convenient for such a simple interface

• Provide input discipline
  – Buffers input until newline

• Handles necessities like *local echo*
Terminal (2/3)

• Formatting done via escape sequences
  – Sequences of characters control output behavior
  – E.g., vt100 family sets red color with: ESC[31m

• Input also has a level of processing
  – Printable characters pass as-is
  – Modifiers (e.g., Control) used for additional control
    • “H” is ASCII 40, “Ctrl+H” is ASCII 8
      – Backspace key is typically just ASCII 8
    • “C” is ASCII 35, “Ctrl+C” is ASCII 3
      – Terminal sends SIGINT to foreground process when receiving char 3
  – Implements type-ahead, buffers chars until they are read
Terminal (3/3)

• Most systems today use *pseudo terminals*
  – No physical hardware attached for I/O
    • Simulated with network (e.g., ssh) or graphical widow (e.g., xterm)
  – Arranged as pair of devices in OS
    • Traditional software end is *slave*
    • Traditional teletype is *master*
    • Things written to slave end come out of master and vice versa

• Terminals are a fundamental part of the OS
  – Sadly, many people consider them archaic and legacy
  – In truth, a necessary and major modern component
File System

• Provides access to data
  – open, read, write, seek, close, chdir, getcwd
  – opendir, readdir, closedir, unlink
  – mmap (interface combines memory and files)
• Organized as mount points
  – Each mount point is a directory in the parent system
  – “root” mount point always at the top
• OS maintains a descriptor table for each open file
  – Returned by open()
  – Used by all subsequent operations

Everyone here must already be familiar with this
Network

- Enables communication between processes
  - Can be even on same machine (e.g., “localhost”)
- Dominated by IPv4 today
- Common operations
  - Assign address to an interface
  - Manipulate routing table
  - Make outgoing connections, receive incoming connections
  - Send data, receive data
- Uses same descriptor table as files
  - Called *socket descriptors* for network

Everyone here *must* already be familiar with this
Limits

- OS protects processes from each other
  - And processes from themselves
- Parent process limits are inherited by child process
- Process can set its own limits
  - Can set **hard** limits lower or equal to existing ones
    - Can only reduce, can never increase
  - Can set **soft** limits lower or equal to hard ones
    - These are the actual limits enforced by the OS
- Examples:
  - Max memory, max stack size, max open files
  - Some limits are **per user** – e.g., number of processes
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Launching Program Executables (1/2)

• Roughly a 3-step process
  – Load initial contents into memory
  – Find starting point (usually function called \_start())
  – Set initial registers (stack pointer, program counter)

• How to load program into memory?
  – Dictated by *binary format*
    • Most systems today use ELF or PE
  – Defines parts of the file to load and where to load them
    • Broken up into sections
      – Offset (in the file), length, destination address, and size
      – Length can be smaller than size – indicates zero pad
Launching Program Executables (2/2)

• Programs are launched using `execve` syscall

• First bytes determine binary format
  – 0x7F E L F : ELF binary
  – #!command : (shebang) interpret with (command)

• An “interpreter” is run instead of the program
  – Program becomes first argument to interpreter
  – Interpreter path also supported in ELF binaries
    • Useful for shared libraries
    • Interpreter is set to /lib/ld.so for instance
      – Running “/bin/ls /” is equivalent to “/libexec/ld-elf.so /bin/ls /”
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Shell

- Gives user ability to interact with machine
  - Can be text or graphical
- Traditionally text-based
  - Two families – sh (bash, zsh, ksh) and csh (tcsh)
- Interprets commands, one by one
  - Commands are either shell built-ins or executables
  - Shells include many user-friendly features
    - PATH env variable, tab completion, ...

- System starts by running /etc/rc ("run commands")
  - Starts with #!/bin/sh