

Background: Operating Systems

Brad Karp
UCL Computer Science



CS 0133
2nd October 2019

Outline

- Goals of an operating system
- Sketch of UNIX
 - User processes, kernel
 - Process-kernel communication
 - Waiting for I/O
- Simple web server design

Why Discuss OS Now?

- Real distributed systems run on an OS
- OS details affect design, robustness, performance
 - Sometimes because of OS idiosyncrasies
 - More often because OS already solves some hard problems
- **Ask questions if something isn't clear!**
- Further reading:
 - General overview:
Tanenbaum, *Modern Operating Systems*, 4th Edition
 - Details of a modern UNIX:
McKusick et al., *The Design and Implementation of the 4.4 BSD Operating System*

Goals of OS Designers

- Share hardware resources
 - e.g., one CPU, many applications running
- Protection (app-to-app, app-to-OS)
 - Bug in one app shouldn't crash whole box or bring down other app
- Communication (app-to-app, app-to-OS)
- Hardware independence
 - Don't want to rewrite apps for each new CPU, each new I/O device
- How? Using abstractions and well-defined interfaces

UNIX Abstractions

- Process
 - Address space
 - Thread of control
 - User ID
- Filesystem
- File Descriptor
 - File on disk
 - Pipe between processes
 - Network connection
 - Hardware device

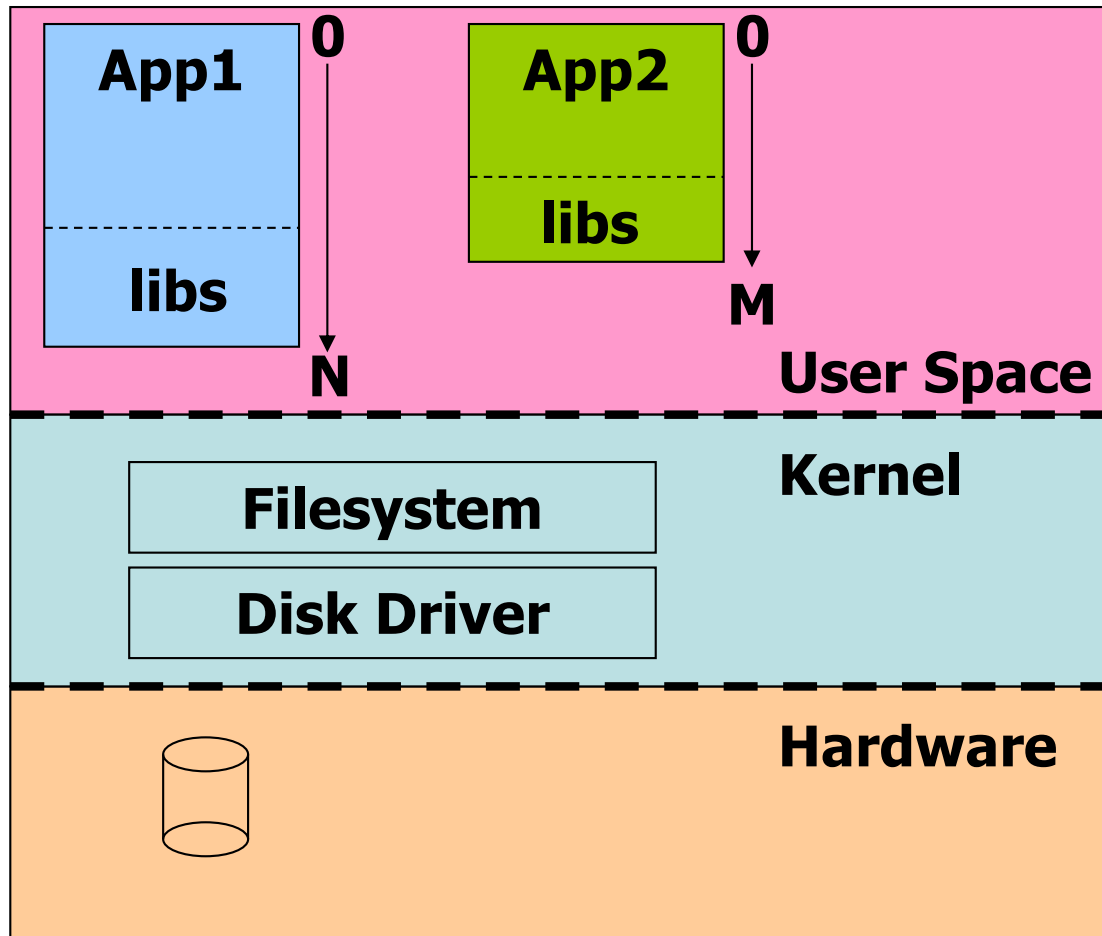
OS Virtualizes Hardware

- Kernel implements abstractions, executes with privilege to directly touch hardware
- OS multiplexes CPU, memory, disk, network among multiple processes (apps)
- Apps can **share resources**
- Apps can **control resources**
- Apps see **simple interface**

OS Abstraction Design

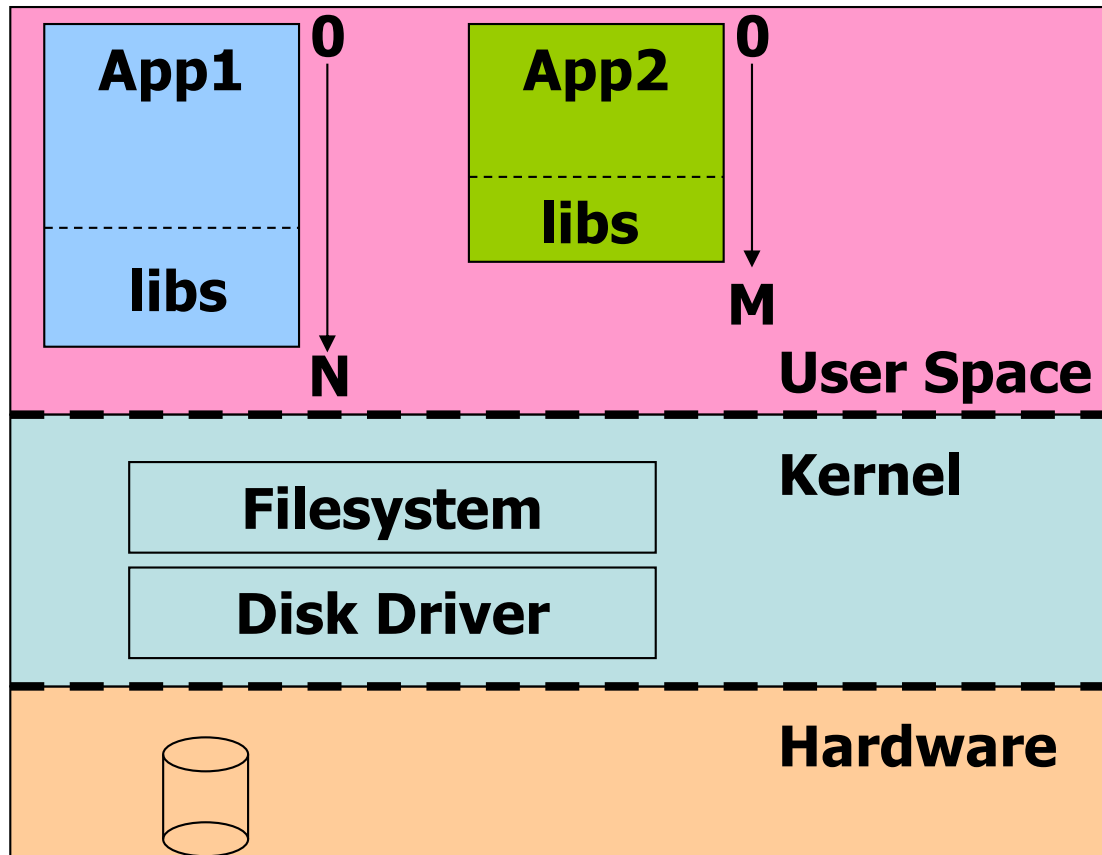
- OS abstractions interact
 - If can start program, must be able to read executable file
- Processes see **system call** interface to kernel abstractions
 - Looks like function call, but special
 - e.g., `fork()`, `exec()`
 - e.g., `open()`, `read()`, `creat()`

Typical UNIX System



- App1 and App2 in separate address spaces; protected from one another
- Hardware runs kernel with elevated privilege

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How do processes and kernel communicate?
How do processes and kernel wait for events (e.g., disk and network I/O)?

System Calls: Process-Kernel Communication

- Application closes a file:

```
close(3);
```

- C library:

```
close(x) {  
    R0 <- 73  
    R1 <- x  
    TRAP  
    RET  
}
```

System Calls: Traps

- TRAP instruction:
 - XP <- PC
 - switch to kernel address space
 - set privileged flag
 - PC <- address of kernel trap handler
- Kernel trap handler:
 - save regs to this process' "process control block" (PCB)
 - set SP to kernel stack
 - call `sys_close()`, ordinary C function
 - ...now executing in "kernel half" of process...
 - restore registers from PCB
 - TRAPRET

System Calls: TRAPRET

- TRAPRET instruction:
 - PC \leftarrow XP
 - clear privileged flag
 - switch to process address space
 - continue execution

System Call Properties

- Protected transfer
 - Process granted kernel privilege level by hardware
 - But jump **must be to known kernel entry point**
- Process suspended until system call finishes
- **What if system call must wait (e.g., read() from disk)?**

Blocking I/O

- On a busy server, system calls often must wait for I/O; e.g.,
- `sys_open(path)`
 - for each pathname component
 - start read of directory from disk
 - sleep waiting for disk read
 - process directory contents
- `sleep()`
 - save kernel regs to PCB1 (including SP)
 - find runnable PCB2
 - restore PCB2 kernel registers (SP, &c.)
 - return

Blocking I/O

- On a busy server, system calls often must wait for I/O; e.g.,
- `sys_open(path)`
for each `pathname` component

Each user process has kernel stack
contains state of pending system call
System call "blocks" while awaiting I/O

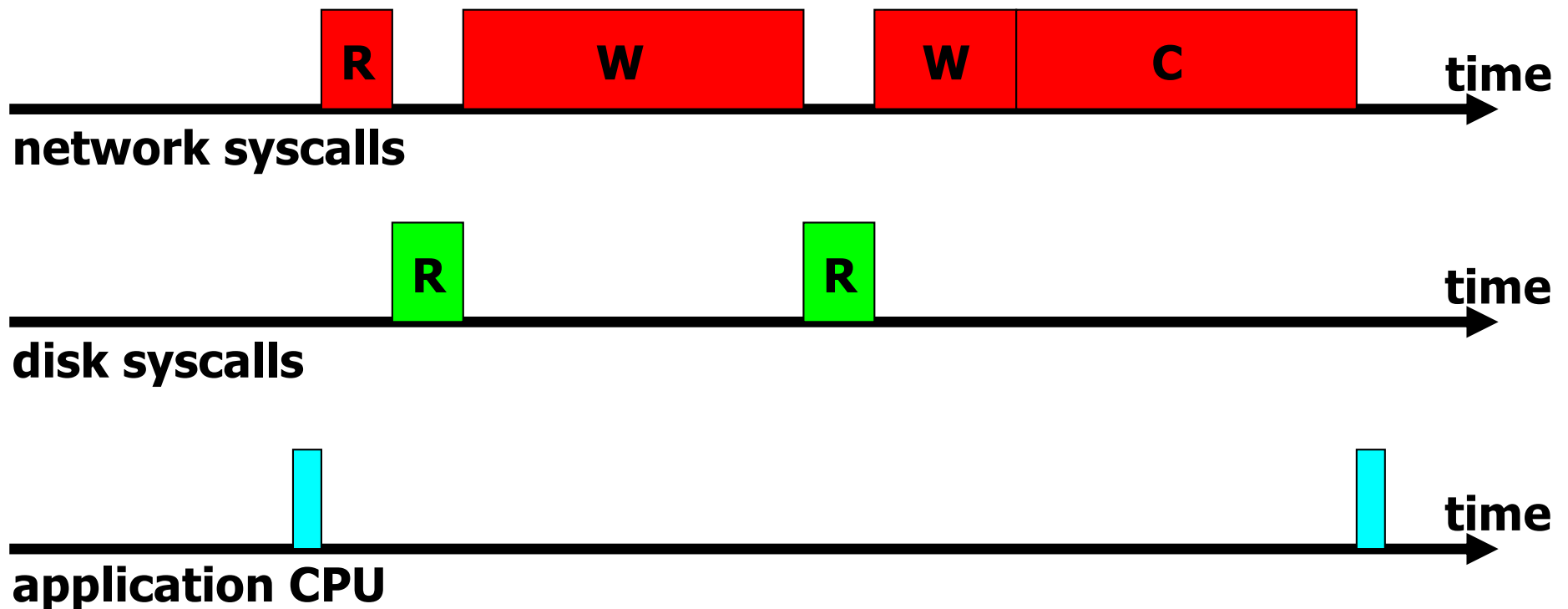
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Disk I/O Completion

- How does process continue after disk I/O completes?
- Disk controller generates **interrupt**
- Device interrupt routine in kernel finds process blocked on that I/O
- Marks process as **runnable**
- Returns from interrupt
- Process scheduler will **reschedule waiting process**

How Do Servers Use Syscalls?

- Consider `server_1()` web server (in handout)

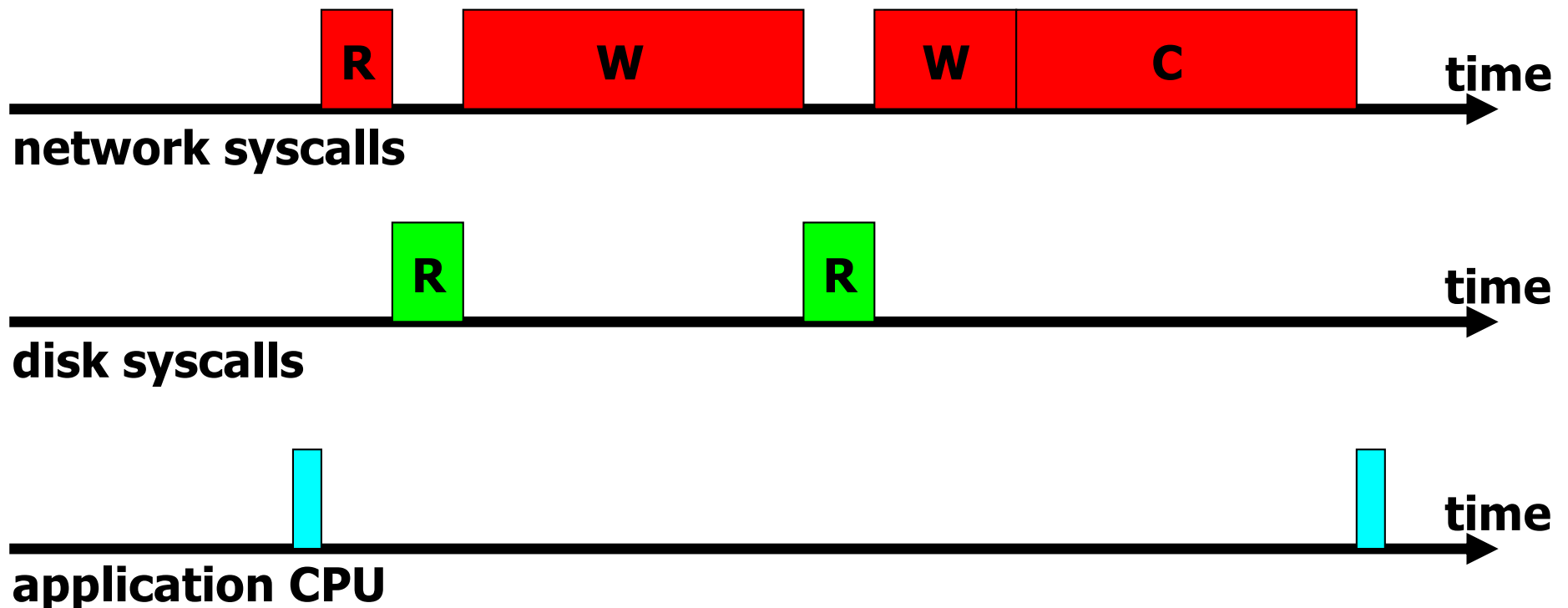


How Do Servers Use Syscalls?

Server waits for each resource in turn

Each resource largely idle

What if there are many clients?



Performance and Concurrency

- Under heavy load, server_1():
 - Leaves resources idle
 - ...and has a lot of work to do!
- Why?
 - Software poorly structured!
 - What would a better structure look like?

Solution: I/O Concurrency

- Can we overlap I/O with other useful work? Yes:
 - Web server: if files in disk cache, I/O wait spent mostly **blocked on write to network**
 - Networked file system client: could **compile first part of file while fetching second part**
- Performance benefits potentially huge
 - Say one client causes disk I/O, **10 ms**
 - **If other clients' requests in cache, could serve 100 other clients during that time!**

Solution: I/O Concurrency

- Can we overlap I/O with other useful work? Yes:
 - Web server: if files in disk cache, I/O wait spent mostly **blocked on write to network**

Next: how to achieve I/O concurrency!

- Performance benefits potentially huge
 - Say one client causes disk I/O, **10 ms**
 - **If other clients' requests in cache, could serve 100 other clients during that time!**