Operating Systems Concepts

System Calls and Context Switches

CS 4375, Fall 2025

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Summery

- More xv6 system calls
- Inter process communication
  - Pipes
- In class activity
  - Implement IPC through pipes

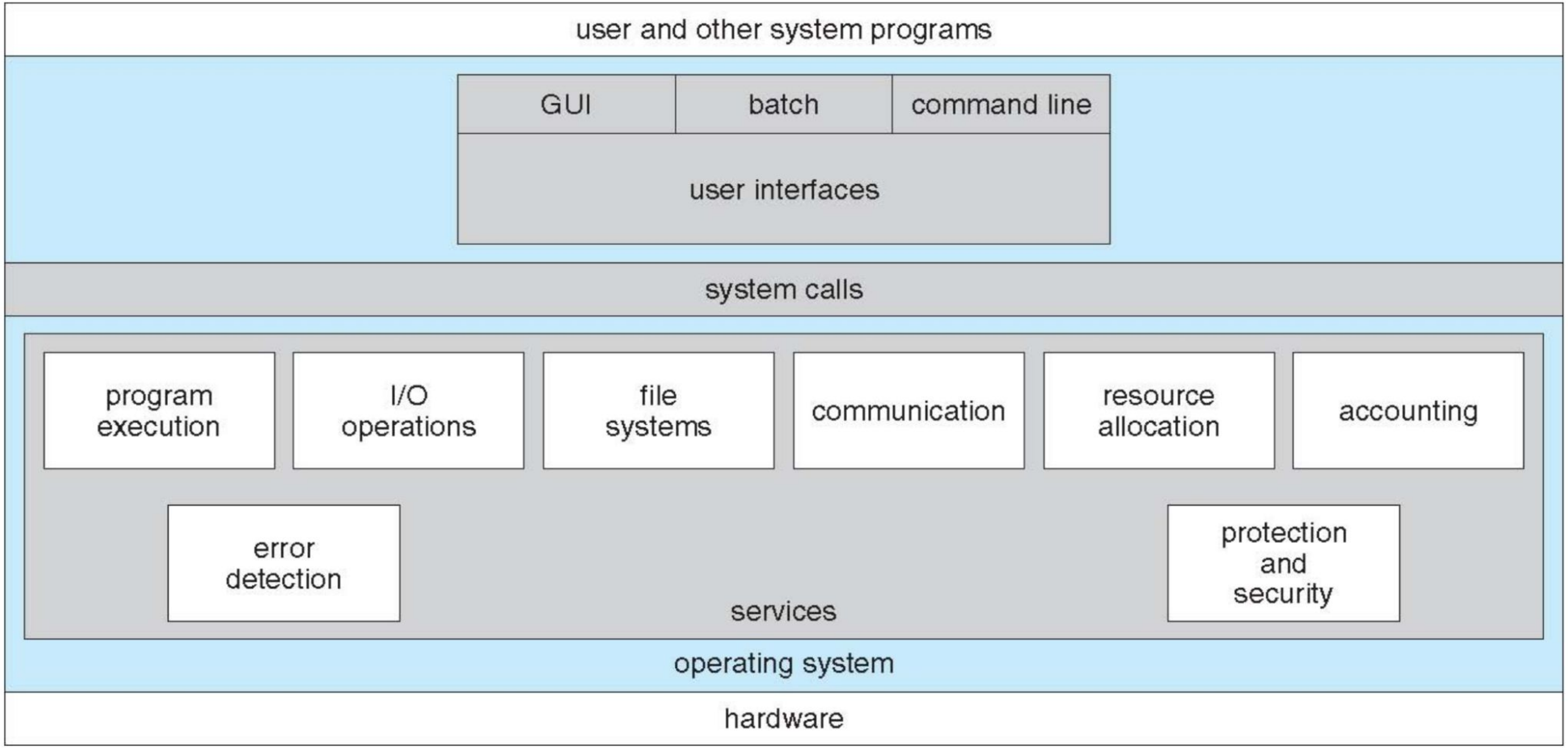
Agenda

- Operating system Services
- Operating system design choices
  - Direct execution protocol
  - Limited direct execution
- System calls
  - Implementation of system calls
- Context switch between processes

Operating System Services

- OS provides an environment to execute programs and provide services to programs and users
    - User interfaces: command line (CLI), graphical (GUI), batch
    - Program execution: loading program into memory, run program, end execution (normally or abnormally)
    - I/O operations: handle filesystem, networking, interprocess communication
    - Error detection: handle hardware failures, debugging
    - Resource allocation, accounting, protection, security

Operating System Services



Operating System Services

- Virtualize the CPU
    - **Performance**
        - Avoid overhead
        - Maximize CPU usage
    - **Control**
        - Provide performance while retaining control
        - CPU time, I/O resources, etc.

Basic direct execution protocol

OS	Program
Create entry for process list	
Allocate memory for program	
Load program into memory	
Set up stack with argc/argv	
Clear registers	
Execute **call** main()	
	Run main()
	Execute **return** from main
Free memory of process	
Remove from process list	

Analysis

- Pros
  - Fast: runs natively on the hardware CPU
- Cons
  - What about restricted operations?
    - I/O request to a disk, or gaining access to more system resources such as CPU or memory
  - Giving full access to a user process
    - A process can do whatever it wants

Analysis

- Pros
  - Fast: runs natively on the hardware CPU
- Cons
  - Giving full access to a user process
    - A process can do whatever it wants

OS and the hardware work together to provide limited direct execution

Solution

- Hardware
  - Different modes of execution
  - **User mode**
    - Does not have full access to resource
  - **Kernel mode**
    - OS have full access to the hardware resources
  - Provides special instructions to **trap** into the kernel and **return-from-trap** back to user-mode programs, and instructions for the OS to tell the hardware where the **trap table** resides in memory.

Solution

- OS
    - **System calls**
        - Allows the user program to request privileged operation
    - **Flow of system calls**
        - Trap into the kernel (special instruction)
            - Raises privilege level
        - Kernel execution the privilege operation
        - Return-from-trap to the user program (special instruction)
            - Reduced privilege

Solution

- OS
  - **System calls**
    - Allows the user program to request privileged operation
  - **Accurate return to the caller**
    - Needs to store important register
    - In x86 (architecture specific)
      - Per-process **kernel stack**
      - The hardware does the store or restore

Solution

- OS
    - **System calls**
        - Allows the user program to request privileged operation
    - **Trap table**
        - Kernel boots first (privileged)
        - Sets up the **trap table**
        - Informs the hardware about trap handlers (Privileged instructions)
        - Hardware remembers until next reboot

Limited Direct Execution Protocol

Phase 1

OS @ boot (kernel mode)	**Hardware**
initialize trap table	
	remember address of... syscall handler

Phase 2

OS @ run (kernel mode)	**Hardware**	**Program (user mode)**
Create entry for process list Allocate memory for program Load program into memory Setup user stack with argv Fill kernel stack with reg/PC **return-from-trap**		
	restore regs from kernel stack move to user mode jump to main	
		Run main() ... Call system call **trap** into OS
	save regs to kernel stack move to kernel mode jump to trap handler	
Handle trap Do work of syscall **return-from-trap**		
	restore regs from kernel stack move to user mode jump to PC after trap	
		... return from main **trap** (via `exit()`)
Free memory of process Remove from process list		

System Calls

- On modern operating systems, processes do not talk to hardware directly, but must go through OS
- **System Call:** request from a process for OS to do some kind of work on its behalf
- **Application Programming Interface (API):** interface provided by OS, usually in a high-level language (C or C++), that is easier to work with than raw system calls
    - POSIX for macOS, Linux, and other Unix-like, accessible through libc.so

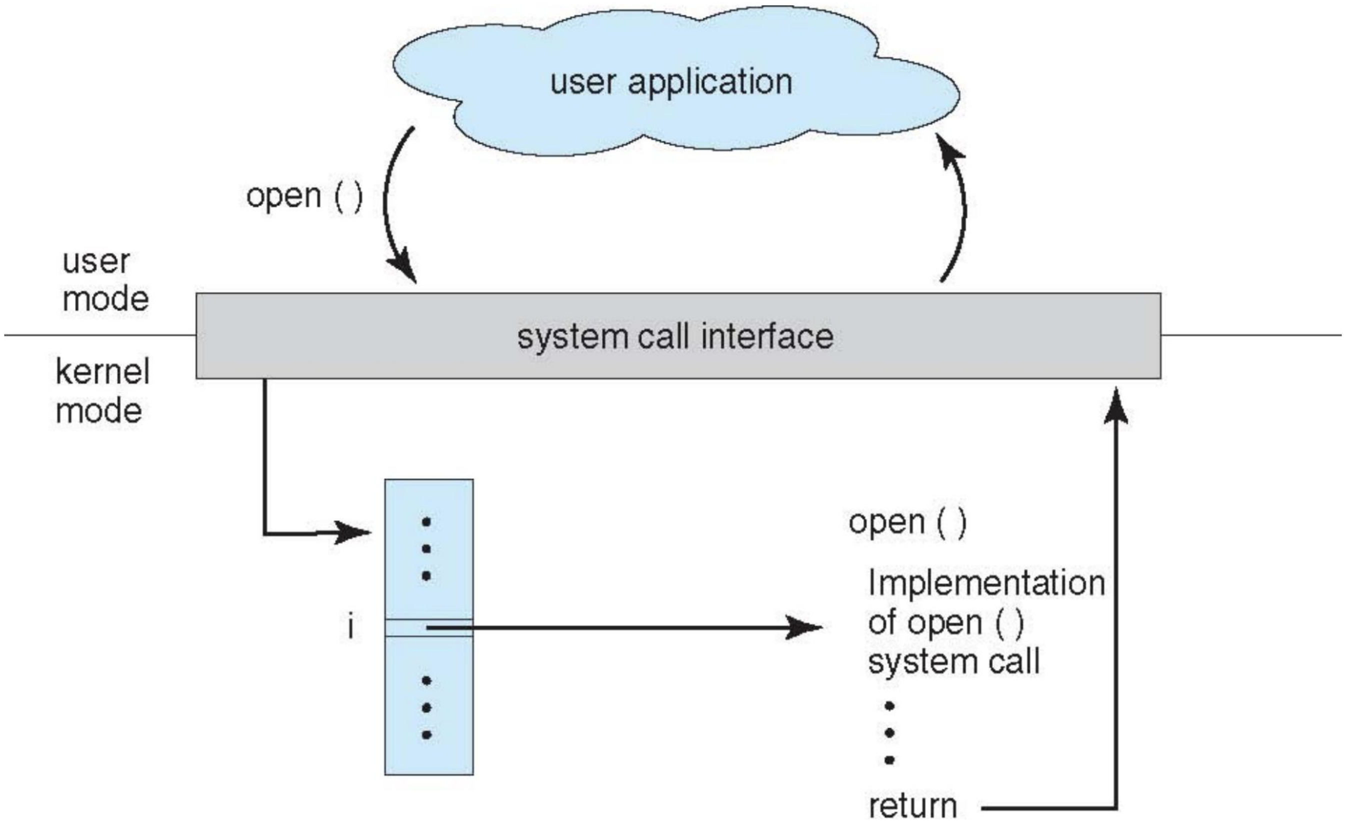
Typical System Call Implementation

- Each system call has a unique numeric identifier
    - OS has a **system call table** that maps numbers to functionality requested
- When invoking a system call, user places system call number and associated parameters in an “agreed upon” location, then executes the **trap** instruction
- OS retrieves system call number and parameters, then performs action
- OS writes output data and return value to an “agreed upon” location, then resumes user process

Why system calls look like function calls?

- Syntax
  - fork(), exit (), open() or read()
- Because it’s a function call
  - Calls systems calls internally
  - Uses special **trap** instruction
  - Sets up values in specific registers

System Call Interface



Examples of System Calls

- **Process control:** create process, terminate, load program, get process attributes, wait for time, wait for event, allocate memory, obtain locks, debugging support
- **I/O:** create file, open file, read file, get file attributes
- **Device management:** request device, release device, read data
- **Information maintenance:** get system time, set system time
- **Communications:** send message, receive message, share data with another process

Parameter Passing

- OS writer and user programs rely upon convention when choosing where to store parameters and return values:
  - Simplest: put all values in **registers** (hopefully there are enough!)
  - **Memory region:** write to memory, then store starting memory address in a register
  - Push values onto **stack**; OS will pop values off the stack (based upon stack register)
- Usually, hardware constraints dictate which **system call convention** used

Linux x86-64 System Call Convention

1. User-level applications use as integer registers for passing the sequence %rdi, %rsi, %rdx, %rcx, %r8 and %r9. The kernel interface uses %rdi, %rsi, %rdx, %r10, %r8 and %r9.

2. A system-call is done via the syscall instruction. The kernel destroys registers %rcx and %r11.

3. The number of the syscall has to be passed in register %rax.

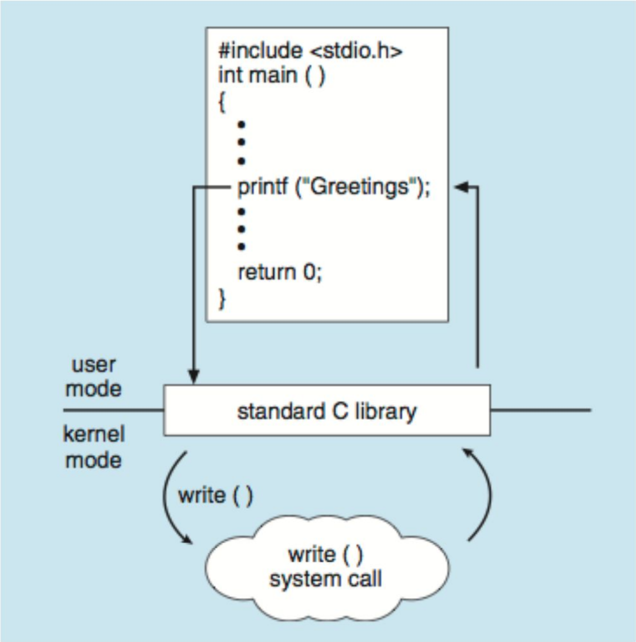
4. System-calls are limited to six arguments, no argument is passed directly on the stack.

5. Returning from the syscall, register %rax contains the result of the system-call. A value in the range between -4095 and -1 indicates an error, it is -errno.

6. Only values of class INTEGER or class MEMORY are passed to the kernel.

Standard C Library Example

- Many standard C functions invoke underlying system calls
- Example: on Linux x86-64, **printf**() internally invokes write() (syscall number 1)



Switch between processes

- **One wants to use a OS that can run one application at a time**
- How can the operating system regain control of the CPU so that it can switch between processes?
- Cooperative Approach: Wait For System Calls
    - Common for most procedures
    - When kernel gains control serve a different process
    - What is a process never makes a system call?
        - Malicious or by mistake

Switch between processes

- **One wants to use a OS that can run one application at a time**
- How can the operating system regain control of the CPU so that it can switch between processes?
- Non-Cooperative Approach: The OS Takes Control
  - Timer interrupt
    - Raise an interrupt every so many milliseconds
    - Pre-configured interrupt handler in the OS runs

LDE Protocol (Timer Interrupt)

OS @ boot (kernel mode)	**Hardware**
initialize trap table	
	remember addresses of... syscall handler timer handler
start interrupt timer	
	start timer interrupt CPU in X ms

OS @ run (kernel mode)	**Hardware**	**Program (user mode)**
		Process A ...
	timer interrupt save regs(A) to k-stack(A) move to kernel mode jump to trap handler	
Handle the trap Call `switch()` routine save regs(A) to proc-struct(A) restore regs(B) from proc-struct(B) switch to k-stack(B) **return-from-trap (into B)**		
	restore regs(B) from k-stack(B) move to user mode jump to B's PC	
		Process B ...

Context Switch in xv6 (swtch.S)

```
#   void swtch(struct context *old, struct context *new);
#
# Save current registers in old. Load from new.


.globl swtch
swtch:
        sd ra, 0(a0)
        sd sp, 8(a0)
        sd s0, 16(a0)
        sd s1, 24(a0)
        sd s2, 32(a0)
        sd s3, 40(a0)
        sd s4, 48(a0)
        sd s5, 56(a0)
        sd s6, 64(a0)
        sd s7, 72(a0)
        sd s8, 80(a0)
        sd s9, 88(a0)
        sd s10, 96(a0)
        sd s11, 104(a0)

        ld ra, 0(a1)
        ld sp, 8(a1)
        ld s0, 16(a1)
        ld s1, 24(a1)
        ld s2, 32(a1)
        ld s3, 40(a1)
        ld s4, 48(a1)
        ld s5, 56(a1)
        ld s6, 64(a1)
        ld s7, 72(a1)
        ld s8, 80(a1)
        ld s9, 88(a1)
        ld s10, 96(a1)
        ld s11, 104(a1)

        ret
```

Announcement

- Homework 1
  - Due Monday September 22nd
  - DON'T FORGET TO GIVE GITHUB REPO ACCESS PERMISSION TO THE TA
    - danielmarin350@gmail.com
- THERE WILL BE CHECKS ON HOMEWORK SUBMISSION
  - **Randomly** picked 20 student per assignment