

# Lecture 20: Process Control

Philipp Koehn

October 24, 2022

601.229 Computer Systems Fundamentals



# Control Flow

- ▶ The CPU executes one instruction after another
- ▶ Typically, they are next to each other in memory (unless jumps, branches, and returns from subroutine)
- ▶ Exceptional Control Flow, triggered by
  - ▶ hardware exception
  - ▶ software exception

# Exceptions

- ▶ Interrupts
  - ▶ signal from I/O device
  - ▶ also: timer interrupts for multi-tasking

# Exceptions

- ▶ Interrupts
  - ▶ signal from I/O device
  - ▶ also: timer interrupts for multi-tasking
- ▶ Traps and system calls
  - ▶ intentional
  - ▶ triggered by instruction ("syscall")

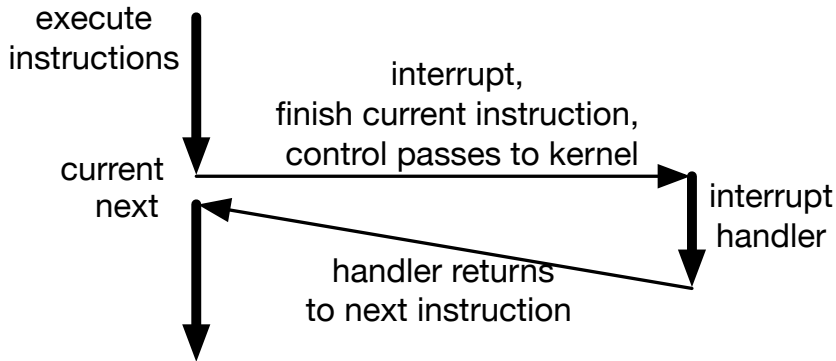
# Exceptions

- ▶ Interrupts
  - ▶ signal from I/O device
  - ▶ also: timer interrupts for multi-tasking
- ▶ Traps and system calls
  - ▶ intentional
  - ▶ triggered by instruction ("syscall")
- ▶ Faults
  - ▶ maybe recoverable, e.g., swapped out memory ("page fault")
  - ▶ if recovered, return to regular control flow

# Exceptions

- ▶ Interrupts
  - ▶ signal from I/O device
  - ▶ also: timer interrupts for multi-tasking
- ▶ Traps and system calls
  - ▶ intentional
  - ▶ triggered by instruction ("syscall")
- ▶ Faults
  - ▶ maybe recoverable, e.g., swapped out memory ("page fault")
  - ▶ if recovered, return to regular control flow
- ▶ Aborts
  - ▶ unrecoverable fatal error, e.g., memory corrupted
  - ▶ application process is terminated

# Abrupt Change in Control Flow



# Processes



# Process

- ▶ Exceptions are the basic building block for processes
- ▶ Modern computers seem to run several things at once
  - ▶ retrieve and display web pages
  - ▶ play music in the background
  - ▶ accept emails and alert you to them

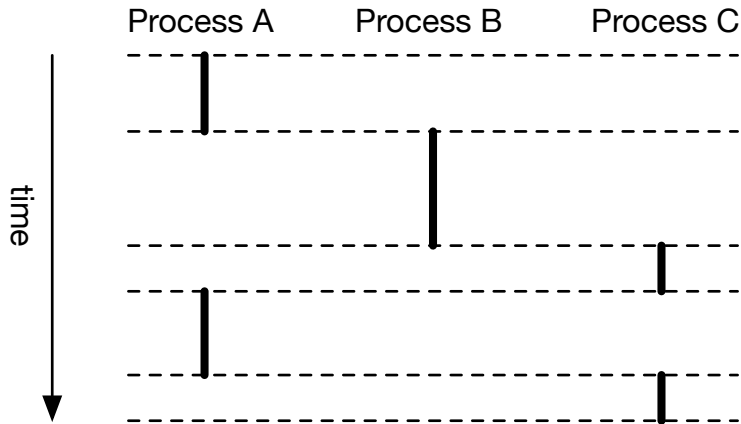
# Process

- ▶ Exceptions are the basic building block for processes
- ▶ Modern computers seem to run several things at once
  - ▶ retrieve and display web pages
  - ▶ play music in the background
  - ▶ accept emails and alert you to them
- ▶ Process = a running program
  - ▶ appears to have full access to memory
  - ▶ appears to run without interruptions

# Process

- ▶ Exceptions are the basic building block for processes
- ▶ Modern computers seem to run several things at once
  - ▶ retrieve and display web pages
  - ▶ play music in the background
  - ▶ accept emails and alert you to them
- ▶ Process = a running program
  - ▶ appears to have full access to memory
  - ▶ appears to run without interruptions
- ▶ Multi-tasking: modern OS that allow multiple processes at once

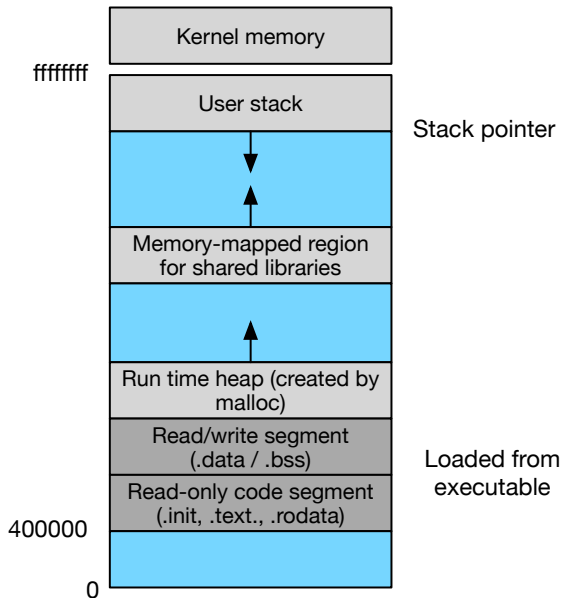
# Logical Control Flow



# User and Kernel Mode

- ▶ Mode bit in control register
- ▶ Kernel mode: may execute any instruction, access any memory
- ▶ User mode: limited to private memory
- ▶ Switch from user to kernel mode
  - ▶ voluntary (sleep)
  - ▶ triggered by interrupt
  - ▶ system call

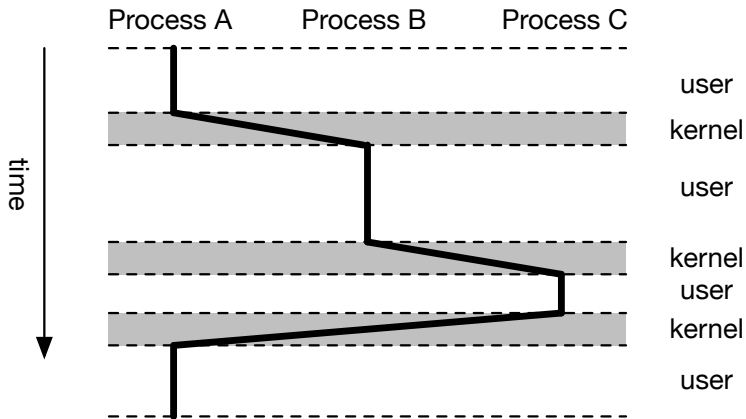
# Private Address Space



# Process Context

- ▶ Kernel maintains context for each process
- ▶ Context
  - ▶ program counter
  - ▶ register values
  - ▶ address table (more on that soon)
  - ▶ opened files
  - ▶ various meta information (e.g., process name)
- ▶ In Linux, each process context viewable in `/proc` "file" system

# Context Switches





# System calls

# Examples

Number	Name	Description
0	read	read from file
1	write	write to file
2	open	open file
3	close	close file
33	pause	suspend process until signal arrives
39	getpid	get process id
57	fork	create new process
60	exit	end process
61	wait4	wait for a process to terminate
62	kill	kill another process

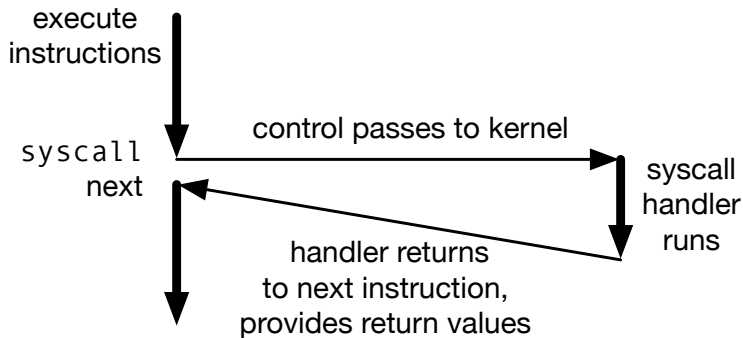
# Assembly Example

```
.section .data
string:
    .ascii "hello, world!\n"
string_end:
    .equ len, string_end - string

.section .text
.globl main
main:
    movq $1, %rax        ; write is system call 1
    movq $1, %rdi        ; arg1: stdout is "file" 1
    movq string, %rsi    ; arg2: hello world string
    movq len, %rdx       ; arg3: length of string
    syscall

    movq $60, %rax       ; exit is system call 60
    movq $0, %rdi        ; exit status
    syscall
```

# System Call Control



# Zoom poll!

Which of these C library functions, when called, might result in a system call?  
(Note: there could be multiple correct answers.)

- A. `printf`
- B. `malloc`
- C. `strcpy`
- D. All of A–C
- E. None of A–C

# Process control

# Creating New Processes

- ▶ C code that spawns a child process

```
int main() {  
    int x = 1;  
    pid_t  pid = fork();  
  
    if (pid == 0) {  
        printf("child x=%d", ++x);  
        exit(0);  
    }  
    printf("parent x=%d", --x);  
    exit(0);  
}
```

- ▶ When run, it returns

parent x=0

child x=2

# Syscall 57: Fork

- ▶ `fork()` creates a child process
- ▶ Call once, return twice
  - ▶ in child process: return value 0
  - ▶ in parent process: return value is process id of child



# Syscall 57: Fork

- ▶ `fork()` creates a child process
- ▶ Call once, return twice
  - ▶ in child process: return value 0
  - ▶ in parent process: return value is process id of child
- ▶ Concurrent execution
  - ▶ parent and child processes run concurrently
  - ▶ no guarantee which proceeds first (and for how long)

# Syscall 57: Fork

- ▶ `fork()` creates a child process
- ▶ Call once, return twice
  - ▶ in child process: return value 0
  - ▶ in parent process: return value is process id of child
- ▶ Concurrent execution
  - ▶ parent and child processes run concurrently
  - ▶ no guarantee which proceeds first (and for how long)
- ▶ Duplicate by separate address space
  - ▶ initially memory is identical
  - ▶ each process makes changes to its private copy

# Another Example

## ► Multiple forks

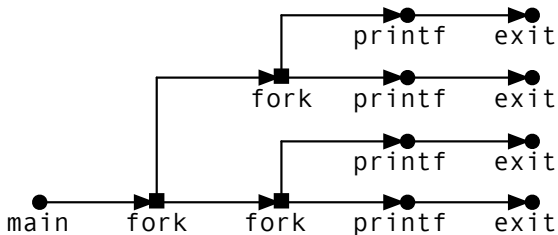
```
int main() {  
    fork();  
    fork();  
    printf("hello\n");  
    exit(0);  
}
```

# Another Example

- Multiple forks

```
int main() {  
    fork();  
    fork();  
    printf("hello\n");  
    exit(0);  
}
```

- Outputs "hello" 4 times



# Death in the Family

- ▶ What happens when what dies when?
- ▶ Child process dies
  - ▶ process still in kernel's process table
  - ▶ waiting for parent to read exit status
  - ▶ "zombie": dead, but still active
- ▶ Parent process dies
  - ▶ children processes become orphaned
  - ▶ orphan killing: terminate all orphaned processes
  - ▶ re-parenting: make init process (pid: 1) parent  
(→ a "daemon" process)

# Waiting for Child to Die

1. Parent spawns child process
2. Both processes running
3. Parent waits for child to complete
  - ▶ C: `waitpid()`
  - ▶ Assembly: `syscall 61`
4. Parent stalls
5. Child dies (zombie)
6. Parent receives exit status of child
7. Child dies completely

- ▶ Parent process may execute another program
  - ▶ C: `execve(filename, argv, envp)`
  - ▶ Assembly: `syscall 59`
- ▶ Passes environment variables (`envp`)
- ▶ Executed command takes over
- ▶ If both should run: `fork` first