Processes and Wrap-up

CSCI 237: Computer Organization
35th Lecture, Friday, December 6, 2024

Kelly Shaw

Administrative Details

- Lab #6 due today at 5pm
- "Sample" final on Glow (from S18, not all questions are relevant)
- Extra practice problems added to webpage (solns on Glow)
- Review session on Tues 4-5:30pm in TCL 202
  - Bring questions!
- Final exam
  - Wednesday, December 11, 9:30am – 11:30am (2 hours)
  - Clark Hall 105
- Colloquium talk on Friday at 2:35pm in Wege
  - "Systems research to address societal problems"
  - Aruna Balasubramanian, Stony Brook University
- WICS + Allies Hot Cocoa
  - Monday at 3pm CS Common Area

Last Time

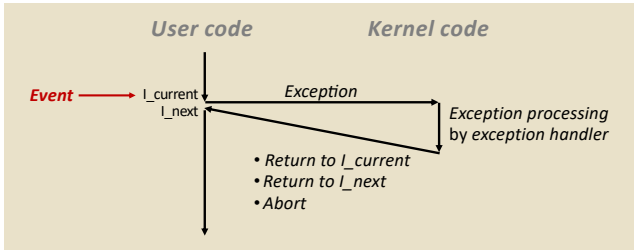
- Dynamic Memory Allocation (Ch 9.9)
  - Tracking Free Blocks
    - Implicit Lists
    - Explicit Lists
    - Segregated Lists
- Exceptional Control Flow
- Exceptions

Today: Processes and Wrap-up

- Exceptions
- Processes
- Current Computer Architecture
- Wrap up

Exceptions

- An *exception* is a transfer of control to the OS *kernel* in response to some *event* (i.e., change in processor state)
  - Kernel is the memory-resident part of the OS
  - Examples of events: Divide by 0, arithmetic overflow, page fault, I/O request completes, typing Ctrl-C



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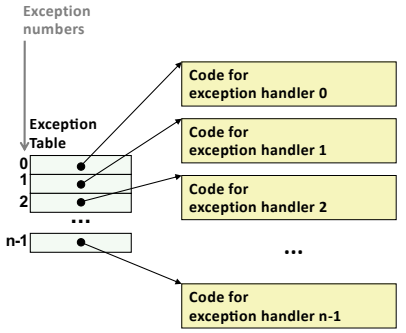
Exception Tables



- Each type of event has a unique exception number k
- k = index into exception table (a.k.a. interrupt vector)
- Handler k is called each time exception k occurs

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Asynchronous Exceptions (Interrupts)

- Caused by events external to the processor
  - Indicated by setting the processor's *interrupt pin*
  - Handler returns to "next" instruction
- Examples:
  - Timer interrupt
    - Every few ms, an external timer chip triggers an interrupt
    - Used by the kernel to take back control from user programs
  - I/O interrupt from external device
    - Hitting Ctrl-C at the keyboard
    - Arrival of a packet from a network
    - Arrival of data from a disk

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Synchronous Exceptions

- Caused by events that occur as a result of executing an instruction:
  - ***Traps***
    - Intentional
    - Examples: ***system calls***, breakpoint traps, special instructions
    - Returns control to "next" instruction
  - ***Faults***
    - Unintentional but possibly recoverable
    - Examples: page faults (recoverable), protection faults (unrecoverable), floating point exceptions
    - Either re-executes faulting ("current") instruction or aborts
  - ***Aborts***
    - Unintentional and unrecoverable
    - Examples: illegal instruction, parity error, machine check
    - Aborts current program

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System Calls

- **Each x86-64 system call has a unique ID number**
- **Examples:**

Number	*Name*	*Description*
0	`read`	Read file
1	`write`	Write file
2	`open`	Open file
3	`close`	Close file
4	`stat`	Get info about file
57	`fork`	Create process
59	`execve`	Execute a program
60	`_exit`	Terminate process
62	`kill`	Send signal to process

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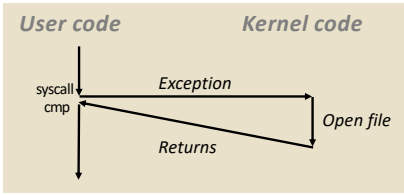
System Call Example: Opening File

- User calls: `open(filename, options)`
- Calls `__open` function, which invokes system call instruction `syscall`

```
0000000000e5d70 <__open>:
...
e5d79:   b8 02 00 00 00      mov  $0x2,%eax  # open is syscall #2
e5d7e:   0f 05               syscall         # Return value in
%rax
e5d80:   48 3d 01 f0 ff ff   cmp  $0xfffffffffffff001,%rax
...
e5dfa:   c3                  retq
```



- `%rax` contains syscall number
- Other arguments in `%rdi`, `%rsi`, `%rdx`, `%r10`, `%r8`, `%r9`
- Return value in `%rax`
- Negative value is an error corresponding to negative `errno`

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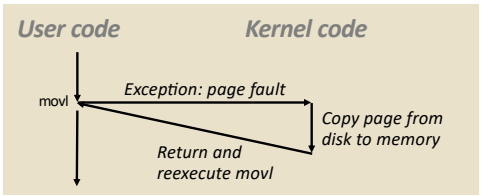
Fault Example: Page Fault

- User writes to memory location
- That portion (page) of user's memory is currently on disk

```
int a[1000];
main ()
{
    a[500] = 13;
}
```

```
80483b7:    c7 05 10 9d 04 08 0d   movl   $0xd,0x8049d10
```



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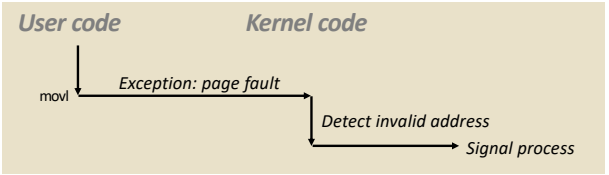
Fault Example: Invalid Memory Reference

```
int a[1000];
main ()
{
    a[5000] = 13;
}
```

```
80483b7:    c7 05 60 e3 04 08 0d   movl   $0xd,0x804e360
```



- Sends `SIGSEGV` signal to user process
- User process exits with "segmentation fault"

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Today: Processes and Wrap-up

- Exceptions
- Processes
- Current Computer Architecture
- Wrap up

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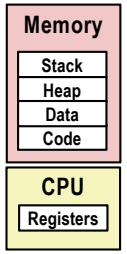
Processes

- Definition: A *process* is an instance of a running program.
  - One of the most profound ideas in computer science
  - Not the same as "program" or "processor"

- Process provides each program with two key abstractions:
  - ***Logical control flow***
    - Each program seems to have exclusive use of the CPU
    - Provided by kernel mechanism called *context switching*
  - ***Private address space***
    - Each program seems to have exclusive use of main memory.
    - Provided by kernel mechanism called *virtual memory*



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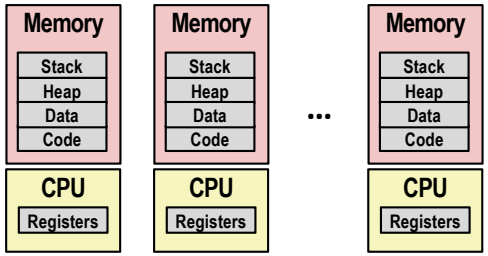
Multiprocessing: The Illusion



- Computer runs many processes simultaneously
  - Applications for one or more users
    - Web browsers, email clients, editors, …
  - Background tasks
    - Monitoring network & I/O devices

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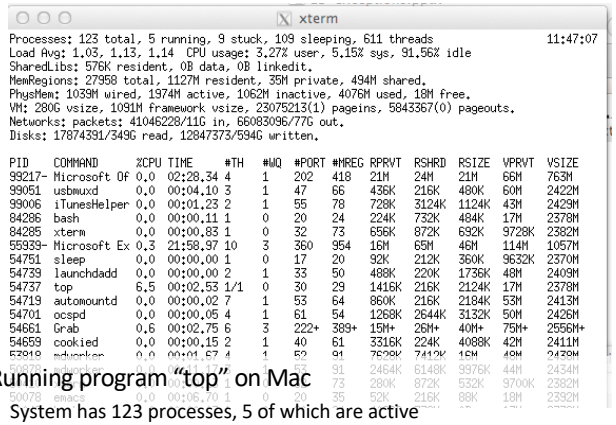
Multiprocessing Example



- Running program "top" on Mac
  - System has 123 processes, 5 of which are active
  - Identified by Process ID (PID)

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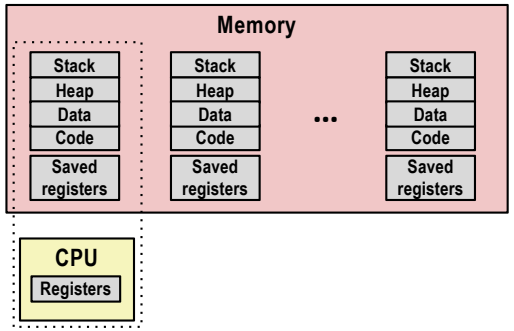
Multiprocessing: The (Traditional) Reality



- Single processor executes multiple processes concurrently
  - Process executions interleaved (multitasking)
  - Address spaces managed by virtual memory system
  - Register values for non-executing processes saved in memory

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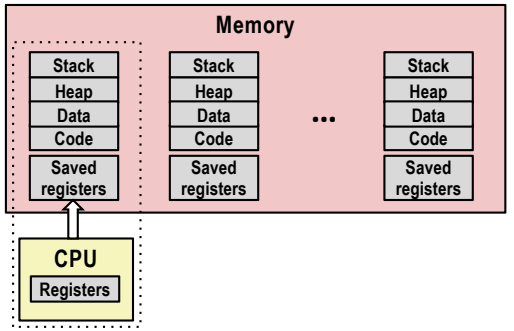
Multiprocessing: The (Traditional) Reality



- Save current registers in memory

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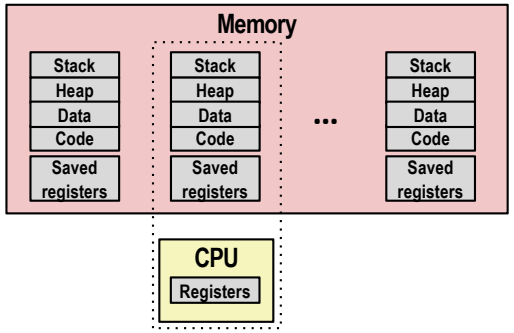
Multiprocessing: The (Traditional) Reality



- Schedule next process for execution

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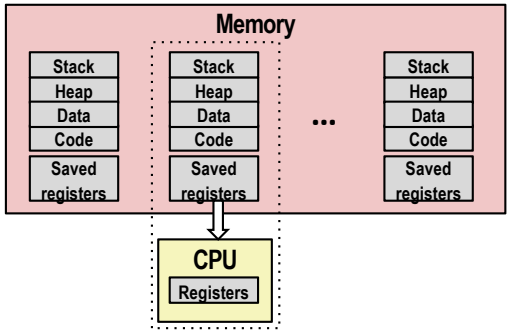
Multiprocessing: The (Traditional) Reality



- Load saved registers and switch address space (context switch)

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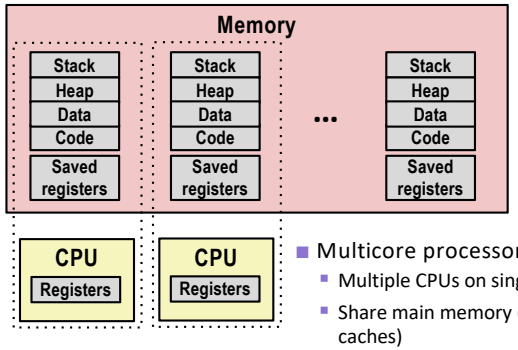
Multiprocessing: The (Modern) Reality



- Multicore processors
  - Multiple CPUs on single chip
  - Share main memory (and some of the caches)
  - Each can execute a separate process
    - Scheduling of processors onto cores done by kernel (OS)

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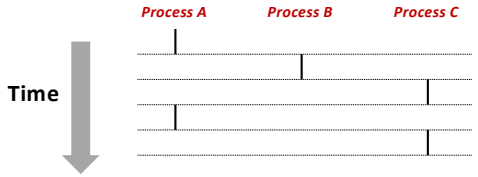
Concurrent Processes

- Each process is a logical control flow.
- Two processes *run concurrently* (*are concurrent)* if their flows overlap in time
- Otherwise, they are *sequential*
- Examples (running on single core):
  - Concurrent: A & B, A & C
  - Sequential: B & C



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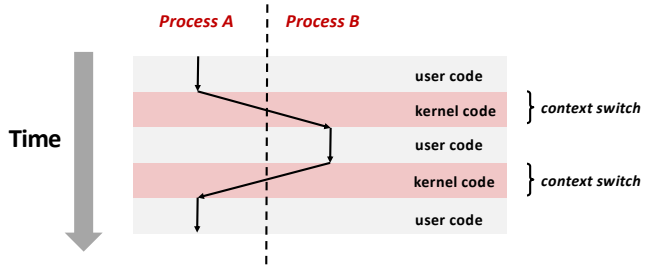
Context Switching

- Processes are managed by a shared chunk of memory-resident OS code called the *kernel*
  - Important: the kernel is not a separate process, but rather runs as part of some existing process.
- Control flow passes from one process to another via a *context switch*



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Today: Processes and Wrap-up

- Exceptions
- Processes
- Current Computer Architectures
- Wrap up

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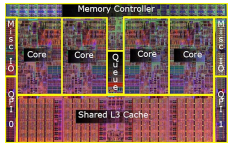
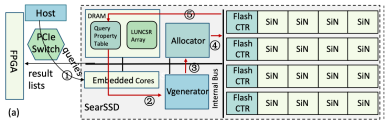
Current Computer Architecture Trends

- Chip multiprocessors
  - Small number of independent computation
  - Data sharing challenging
- GPUs
  - Thousands of almost identical calculations
- Accelerators
  - Specialized computation hardcoded into hardware



Intel multiprocessor


NVIDIA architecture



NDSearch: Accelerating Graph-Traversal-Based Approximate Nearest Neighbor Search through Near Data Processing

Start by Writing a Program in C

```
kshaw — ssh -l kshaw limia.cs.williams.edu — 80×24
File Edit Options Buffers Tools C Help
#include <stdio.h>

void printMessage(char **strings, int num)
{
  for(int i = 0; i < num; i++){
    printf("%s ", strings[i]);
  }
  printf("\n");
}

int main(int argc, char *argv[])
{
  char *array[] = {"Have", "a", "safe", "break!"};

  printMessage(array, 4);

  return 0;
}

-UUU:----F1  hello.c        All L9     (C/*l Abbrev) ----------
```

- Learned how to write and debug C code
  - Ah, pointers, we love you! ❤
- Learned how to use gcc, gdb, make, valgrind, address sanitizer

Compile it to an Executable

gcc! make!

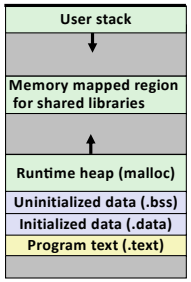
- Learned how to represent data
  - Twos complement
  - Floating point
- Learned how to manipulate data
  - Logical and bitwise manipulation
  - Arithmetic operations (including shifting for ÷ and ✖)
- How to convert C code to assembly code
  - Registers/memory
  - `if`/`else`, `for`/`while`/`do-while`, `switch`
  - Function calls
  - Layout of arrays and structs in memory
- How executables are created
  - Text segment holds instructions
    - Encoded in binary (Y86-64)
  - Data segments hold global data

A Process is Created to Run Our Executable

```
kshaw — ssh -l kshaw limia.cs.williams.edu — 80×24
-> ls
hello*  hello.c  hello.c~
-> ./hello
```

Linux commands!

- Each process has its instructions and data loaded from the executable into a virtual address space
- Each process thinks it has all of memory to itself
  - Enabled by virtual memory
- Each process thinks it has the CPU to itself
  - Exceptional control flow allows process context switching



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Process Starts Running (1)


```
kshaw — ssh -l kshaw limia.cs.williams.edu — 80×24
-> hello
Have a safe break!
->
```

- PC register is set with address of first instruction
- Register storing page table address is set
- Instructions executed on pipelined datapath
  - Stalling or data forwarding pipeline used depending on processor
  - Branch prediction used to reduce control hazards
  - Every virtual address (instructions and data) translated to physical address and sent to memory hierarchy
    - Access TLB, page table, potentially causes page fault
    - Physical addresses sent to L1/L2/DRAM

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Process Starts Running (2)

```
kshaw — ssh -l kshaw limia.cs.williams.edu — 80×24
-> hello
Have a safe break!
->
```

- Operating system invoked on traps/faults/syscalls/interrupts
  - Examples: grow heap, page fault, timer interrupt, divide by 0, read virtual address 0
  - If instruction causes exception, flag is set and carried down pipeline until instruction reaches WB stage
    - Process state (i.e. registers, condition codes) saved into memory
    - Exception table used to find starting address in kernel of exception handler
    - Handler code starts running on processor
- Calls to dynamic memory allocator just normal execution of instructions in library code until system calls to grow heap invoke OS

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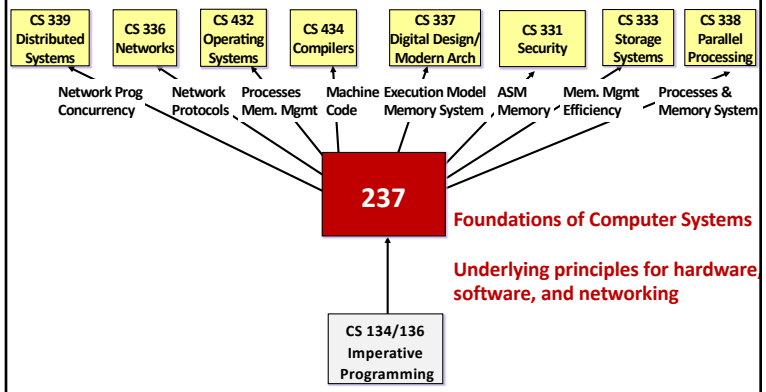
Role within CS Curriculum



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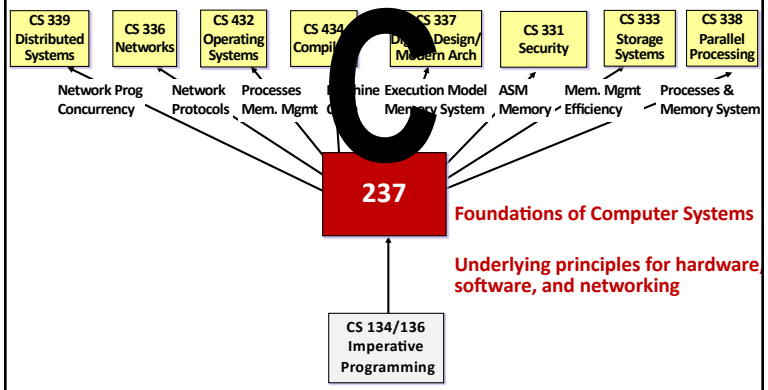
Role within CS Curriculum



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Final Exam

- Closed book, closed notes
- Cumulative with emphasis on material not tested on yet
- Will provide info w/ instructions and registers similar to midterm
- Things to think about
  - Midterm, quizzes, practice problems, in-lecture questions
  - Short answer conceptual questions

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Thank You!

- It's been a challenging semester with the ongoing pandemic.
- This is a tough course with a **lot** of material to learn.
- Be proud of all you accomplished! You learned lots of conceptual knowledge and lots of skills. Both will serve you well in future classes and beyond.
- Thanks for being so great throughout!
- It's been fun getting to know you! Please don't be strangers.

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Student Course Surveys

- Please complete them!

*To access the online evaluations, log into **Glow** (glow.williams.edu) using your regular Williams username and password (the same ones you use for your Williams email account). On your Glow dashboard you'll see a course called "**Course Evaluations**." Click on this and then follow the instructions you see on the screen. If you have trouble finding the evaluation, you can ask a neighbor for help or reach out to ir@williams.edu.*

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