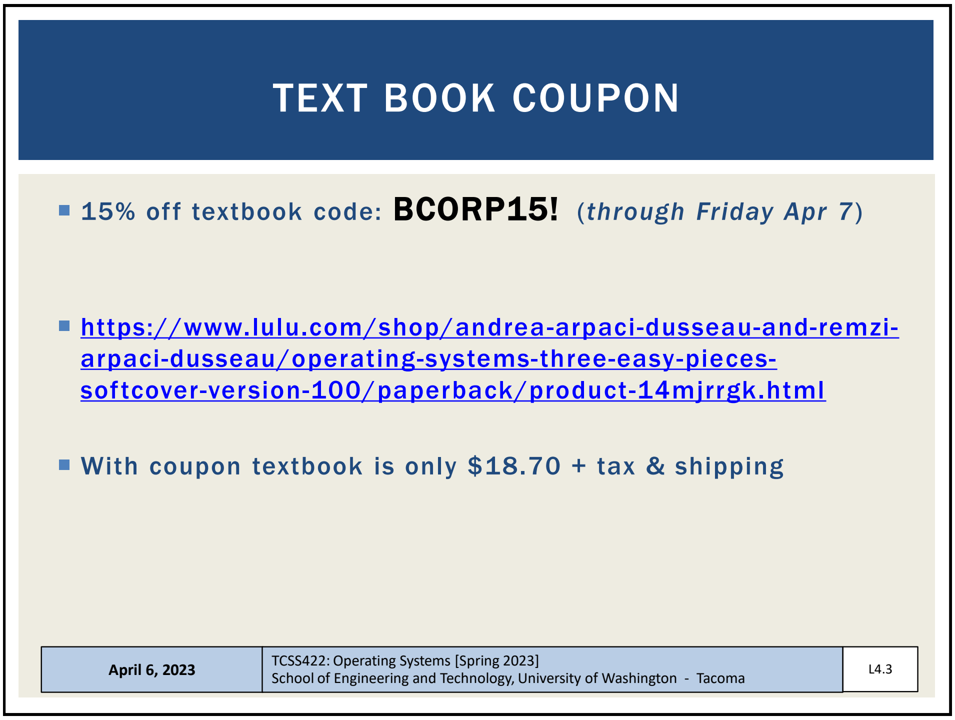
TCSS 422: OPERATING SYSTEMS

The Process API & Limited Direct Execution

Wes J. Lloyd
School of Engineering and Technology
University of Washington - Tacoma

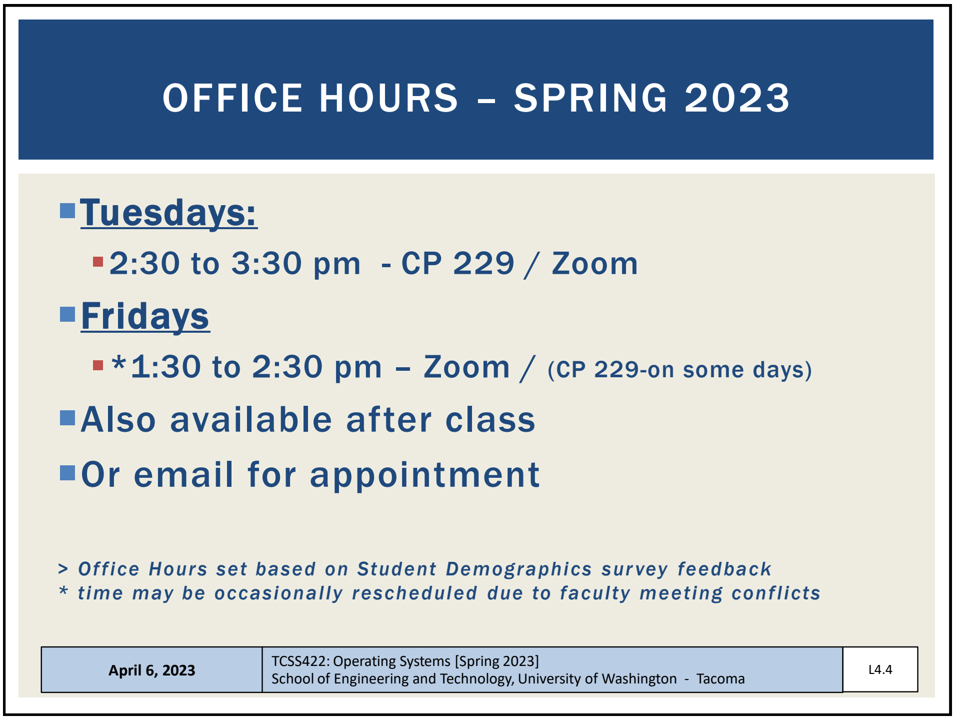
OBJECTIVES – 4/6

- Questions from 4/4
- C Review Survey – Closes Friday April 7
- Assignment 0
- Chapter 4: Linux process data structure - task_struct
- Chapter 5: Process API
  - fork(), wait(), exec()
- Chapter 6: Limited Direct Execution
  - Direct execution
  - Limited direct execution
  - CPU modes
  - System calls and traps
  - Cooperative multi-tasking
  - Context switching and preemptive multi-tasking



TEXT BOOK COUPON

- 15% off textbook code: **BCORP15!** (*through Friday Apr 7*)
- https://www.lulu.com/shop/andrea-arpaci-dusseau-and-remzi-arpaci-dusseau/operating-systems-three-easy-pieces-softcover-version-100/paperback/product-14mjrrgk.html
- With coupon textbook is only $18.70 + tax & shipping



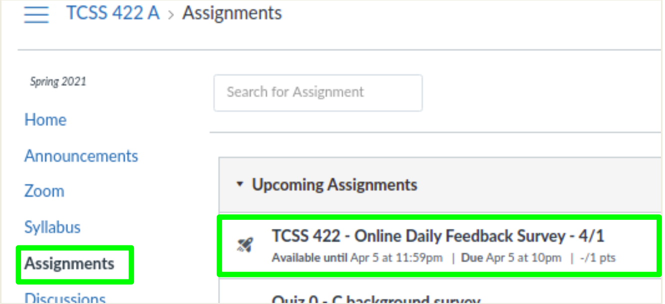
OFFICE HOURS – SPRING 2023

- **Tuesdays:**
  - 2:30 to 3:30 pm - CP 229 / Zoom
- **Fridays**
  - *1:30 to 2:30 pm – Zoom / (CP 229-on some days)
- Also available after class
- Or email for appointment

> Office Hours set based on Student Demographics survey feedback
** time may be occasionally rescheduled due to faculty meeting conflicts*

ONLINE DAILY FEEDBACK SURVEY

- Daily Feedback Quiz in Canvas – Available After Each Class
- Extra credit available for completing surveys ***ON TIME***
- Tuesday surveys: due by ~ Wed @ 11:59p
- Thursday surveys: due ~ Mon @ 11:59p



TCSS 422 - Online Daily Feedback Survey - 4/1
Available until Apr 5 at 11:59pm | Due Apr 5 at 10pm | -/1 pts

Quiz 0 - C background survey

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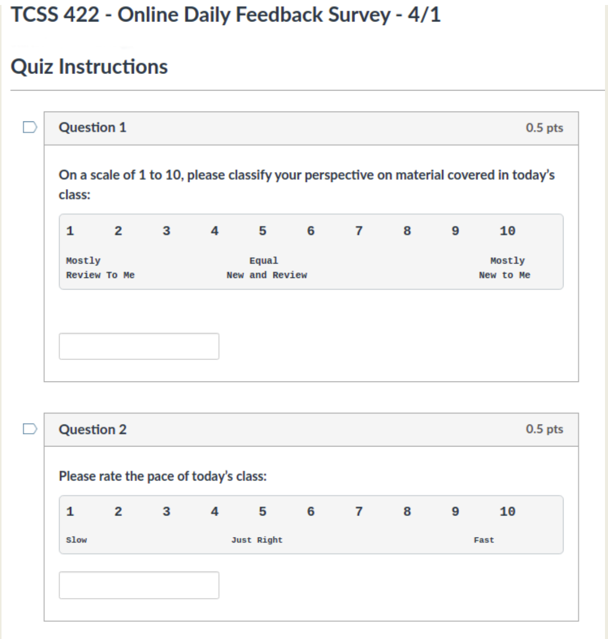

TCSS 422 - Online Daily Feedback Survey - 4/1

Quiz Instructions

Question 1 — 0.5 pts

On a scale of 1 to 10, please classify your perspective on material covered in today's class:

1	2	3	4	5	6	7	8	9	10
Mostly Review To Me				Equal New and Review					Mostly New to Me

Question 2 — 0.5 pts

Please rate the pace of today's class:

1	2	3	4	5	6	7	8	9	10
Slow				Just Right					Fast

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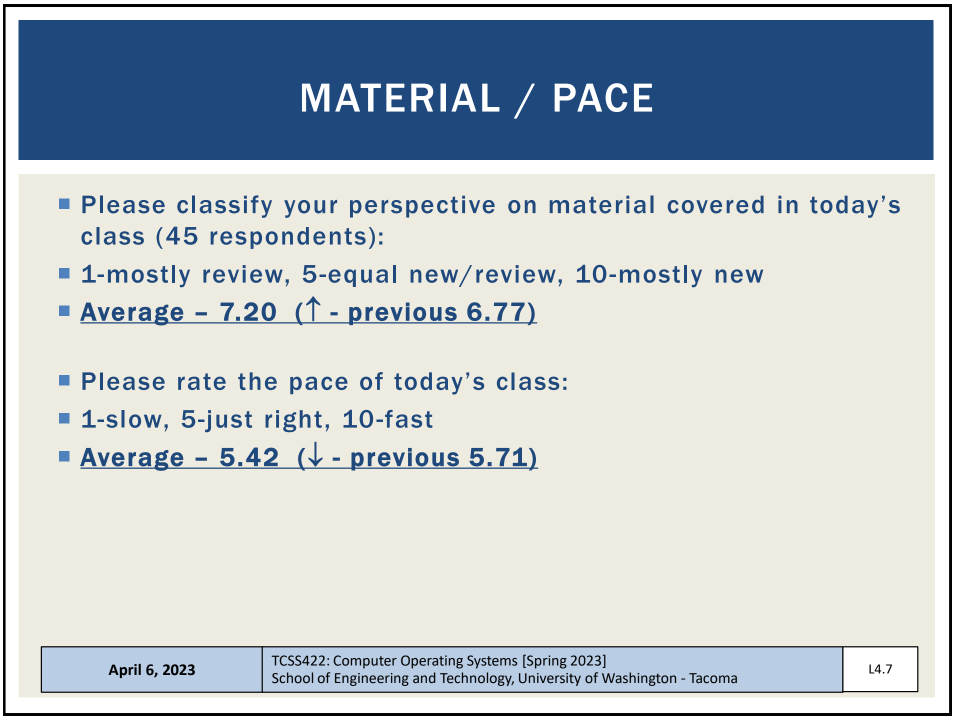

MATERIAL / PACE

- Please classify your perspective on material covered in today's class (45 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 7.20 (↑ - previous 6.77)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.42 (↓ - previous 5.71)**

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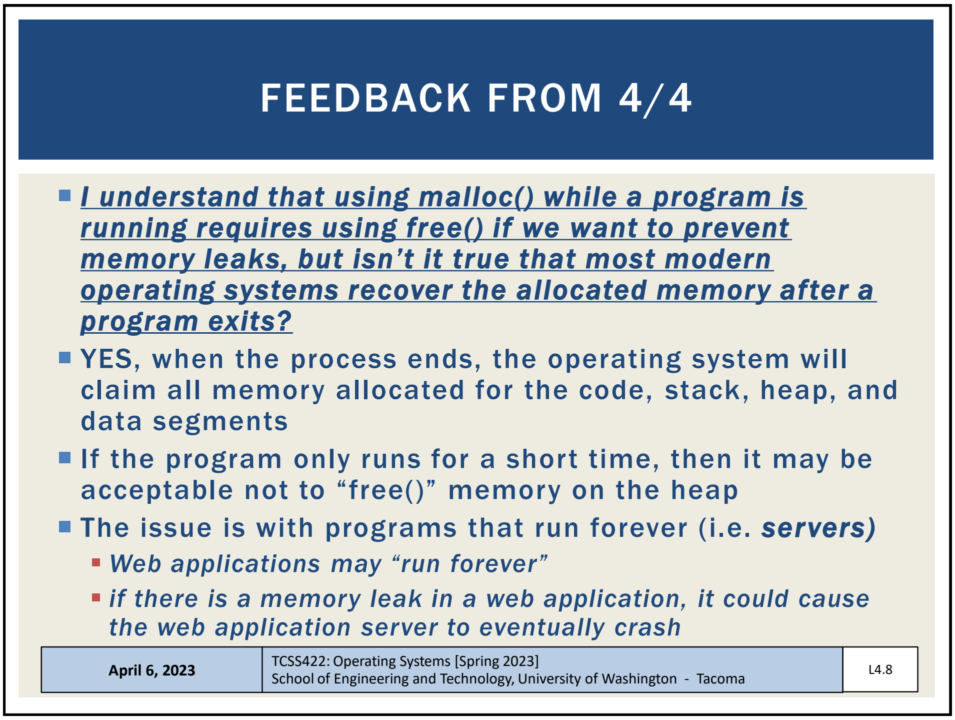

FEEDBACK FROM 4/4

- ***I understand that using malloc() while a program is running requires using free() if we want to prevent memory leaks, but isn't it true that most modern operating systems recover the allocated memory after a program exits?***
- YES, when the process ends, the operating system will claim all memory allocated for the code, stack, heap, and data segments
- If the program only runs for a short time, then it may be acceptable not to "free()" memory on the heap
- The issue is with programs that run forever (i.e. ***servers)***
  - *Web applications may "run forever"*
  - *if there is a memory leak in a web application, it could cause the web application server to eventually crash*

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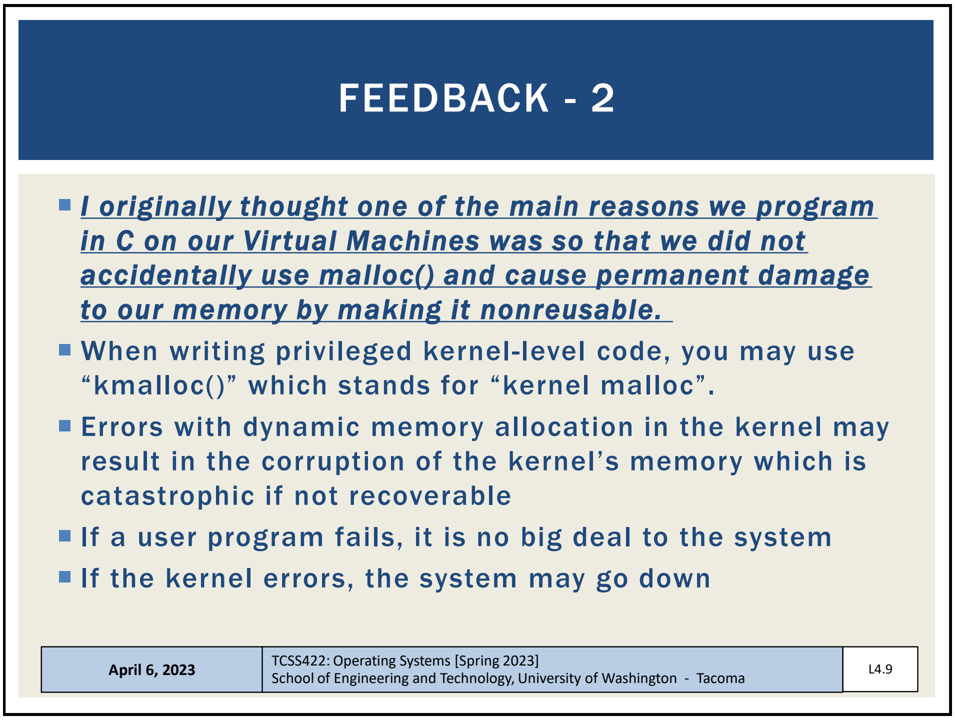

FEEDBACK - 2

- ***I originally thought one of the main reasons we program in C on our Virtual Machines was so that we did not accidentally use malloc() and cause permanent damage to our memory by making it nonreusable.***
- When writing privileged kernel-level code, you may use “kmalloc()” which stands for “kernel malloc”.
- Errors with dynamic memory allocation in the kernel may result in the corruption of the kernel’s memory which is catastrophic if not recoverable
- If a user program fails, it is no big deal to the system
- If the kernel errors, the system may go down

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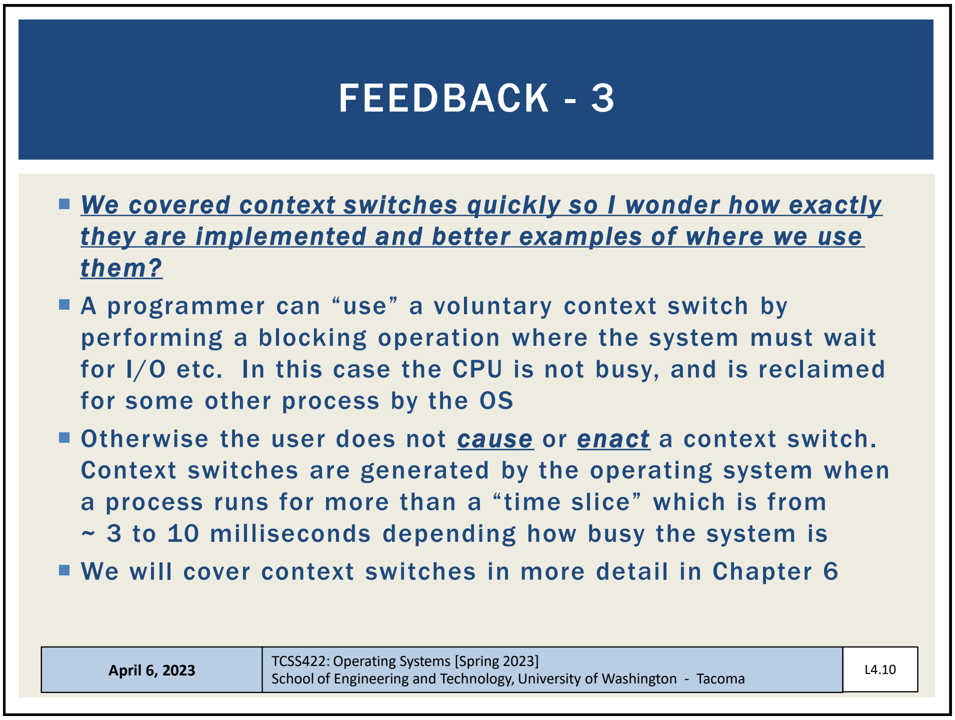

FEEDBACK - 3

- ***We covered context switches quickly so I wonder how exactly they are implemented and better examples of where we use them?***
- A programmer can “use” a voluntary context switch by performing a blocking operation where the system must wait for I/O etc. In this case the CPU is not busy, and is reclaimed for some other process by the OS
- Otherwise the user does not ***cause*** or ***enact*** a context switch. Context switches are generated by the operating system when a process runs for more than a “time slice” which is from ~ 3 to 10 milliseconds depending how busy the system is
- We will cover context switches in more detail in Chapter 6

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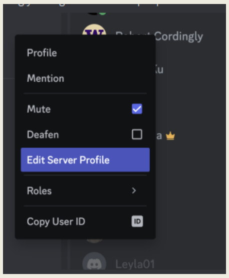
TCSS 422 DISCORD SERVER

- Please join the TCSS 422 A – Spring 2023 Discord Server
- https://discord.gg/hqNanxEQ
- Under Edit Server Profile:
  Please update your 'Server Nickname'
  to your real name or UW NET ID
  THANK YOU



OBJECTIVES – 4/6

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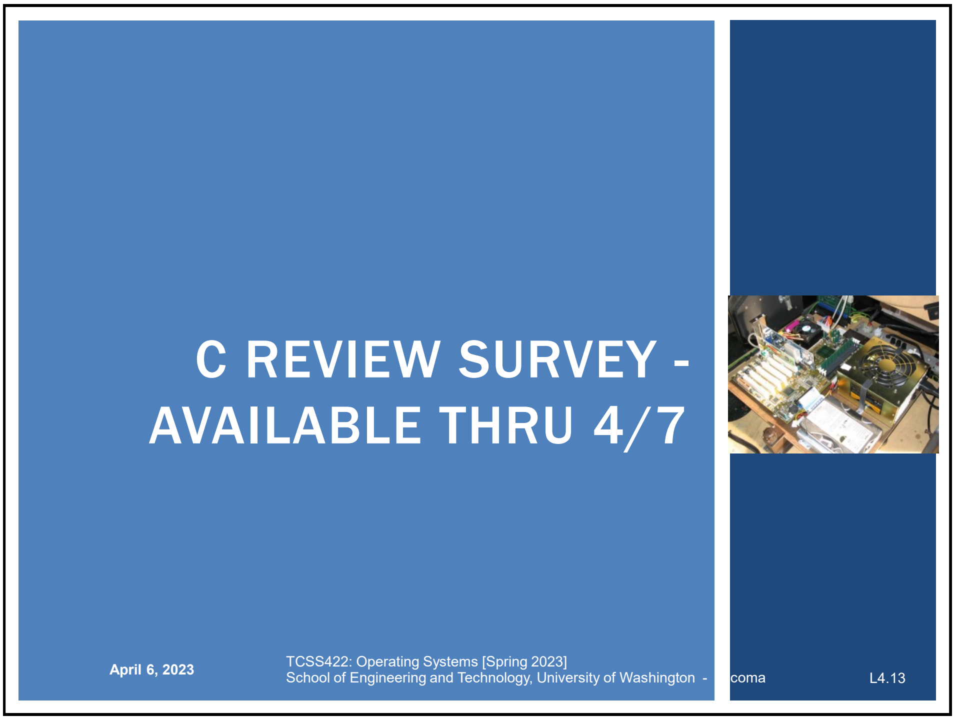

C REVIEW SURVEY - AVAILABLE THRU 4/7

April 6, 2023

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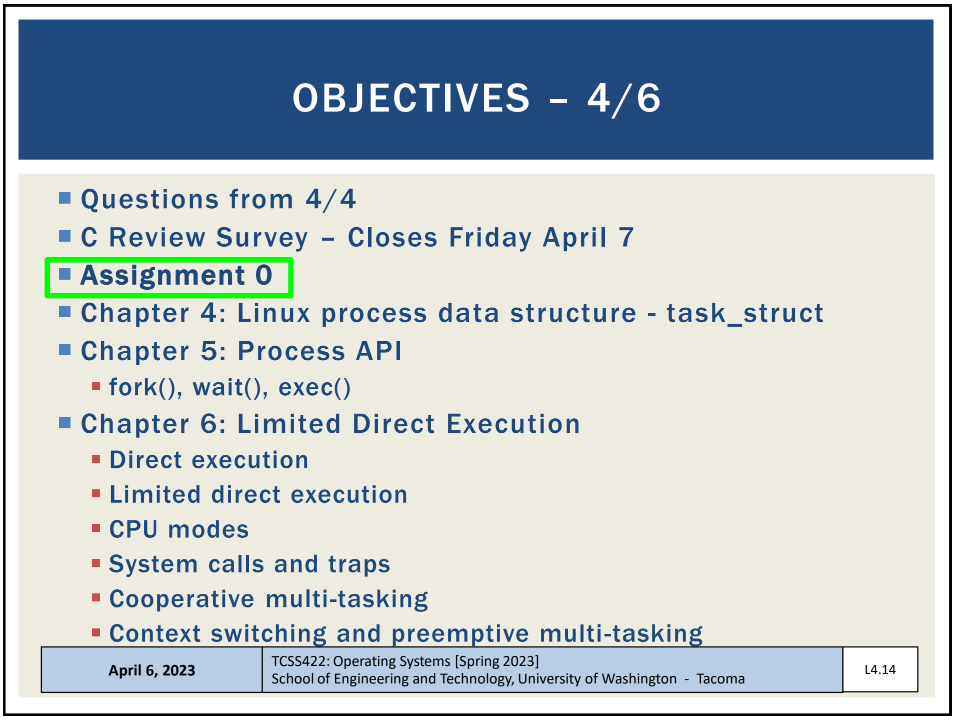

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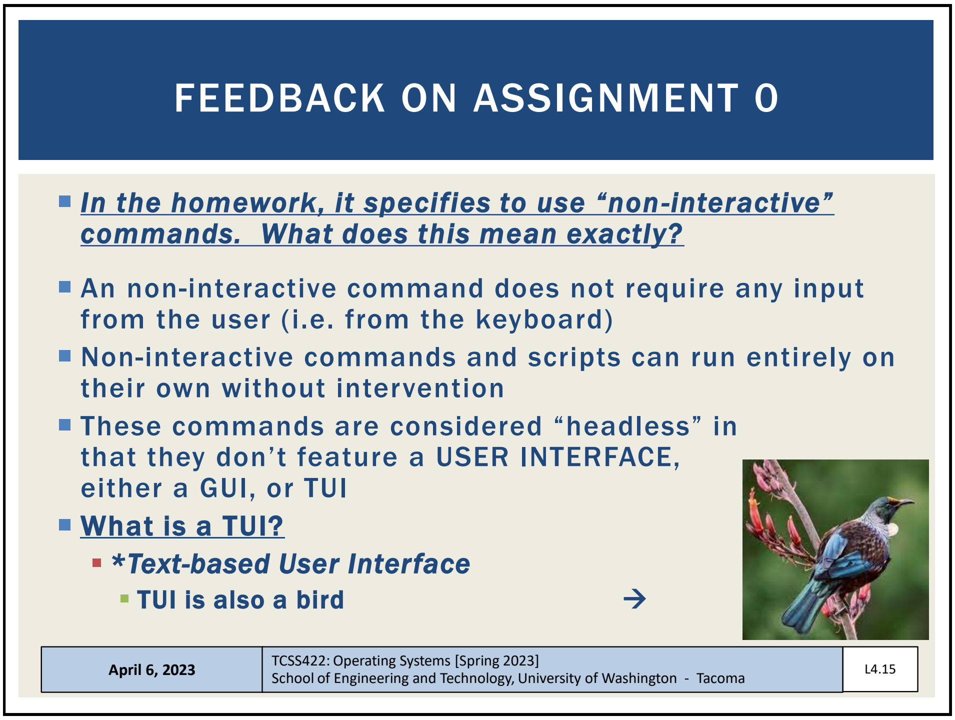

FEEDBACK ON ASSIGNMENT 0

- ***In the homework, it specifies to use "non-interactive" commands. What does this mean exactly?***
- An non-interactive command does not require any input from the user (i.e. from the keyboard)
- Non-interactive commands and scripts can run entirely on their own without intervention
- These commands are considered "headless" in that they don't feature a USER INTERFACE, either a GUI, or TUI
- **What is a TUI?**
  - ****Text-based User Interface***
    - **TUI is also a bird** →

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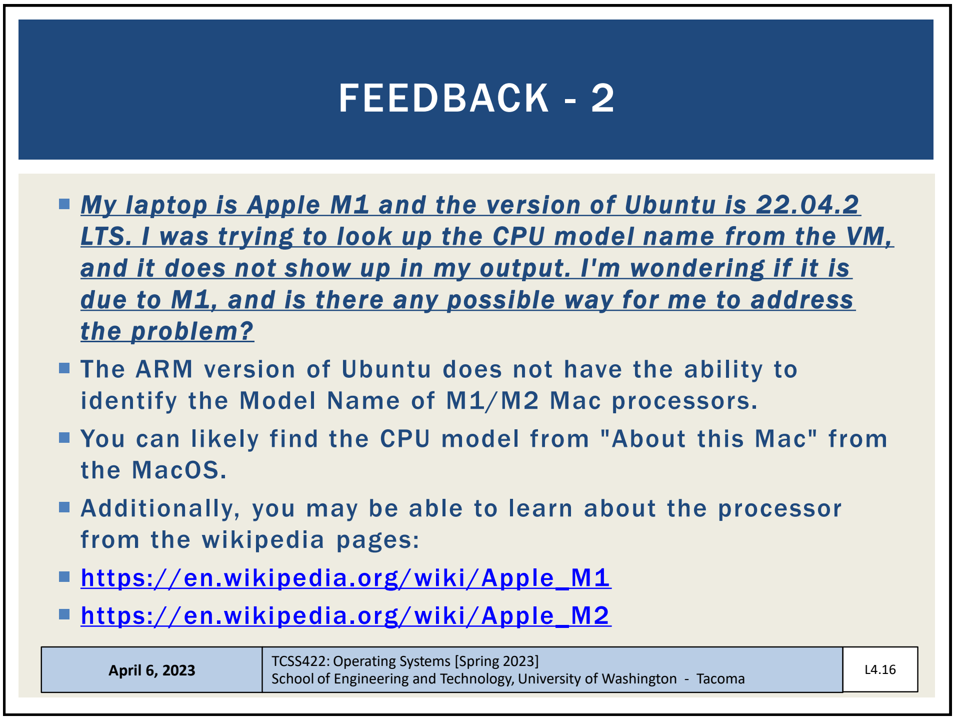

FEEDBACK - 2

- ***My laptop is Apple M1 and the version of Ubuntu is 22.04.2 LTS. I was trying to look up the CPU model name from the VM, and it does not show up in my output. I'm wondering if it is due to M1, and is there any possible way for me to address the problem?***
- The ARM version of Ubuntu does not have the ability to identify the Model Name of M1/M2 Mac processors.
- You can likely find the CPU model from "About this Mac" from the MacOS.
- Additionally, you may be able to learn about the processor from the wikipedia pages:
- https://en.wikipedia.org/wiki/Apple_M1
- https://en.wikipedia.org/wiki/Apple_M2

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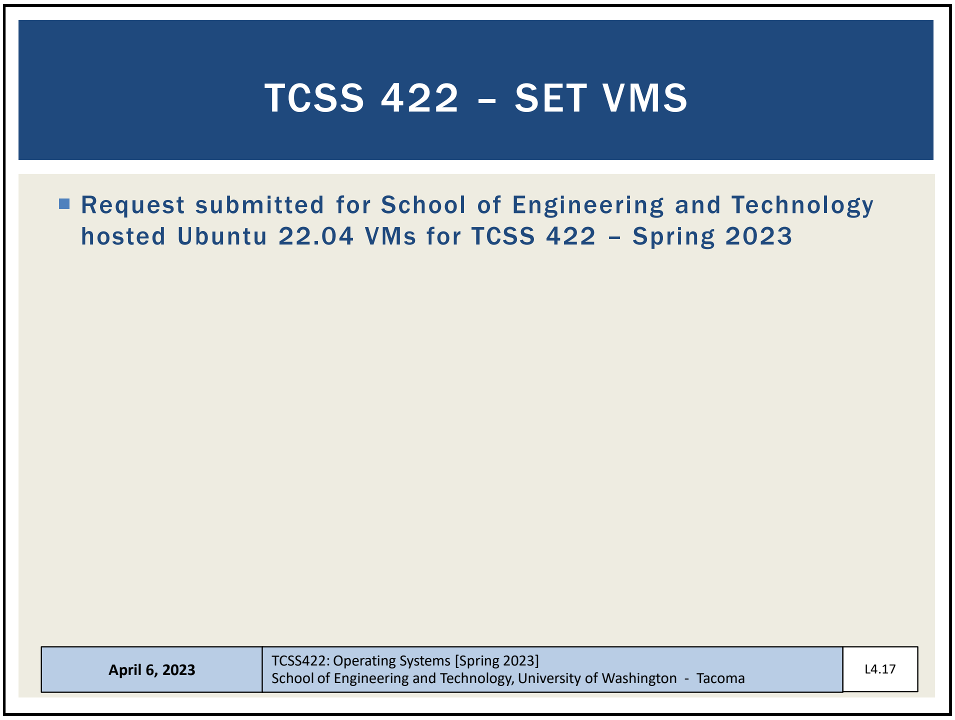

TCSS 422 – SET VMS

- Request submitted for School of Engineering and Technology hosted Ubuntu 22.04 VMs for TCSS 422 – Spring 2023

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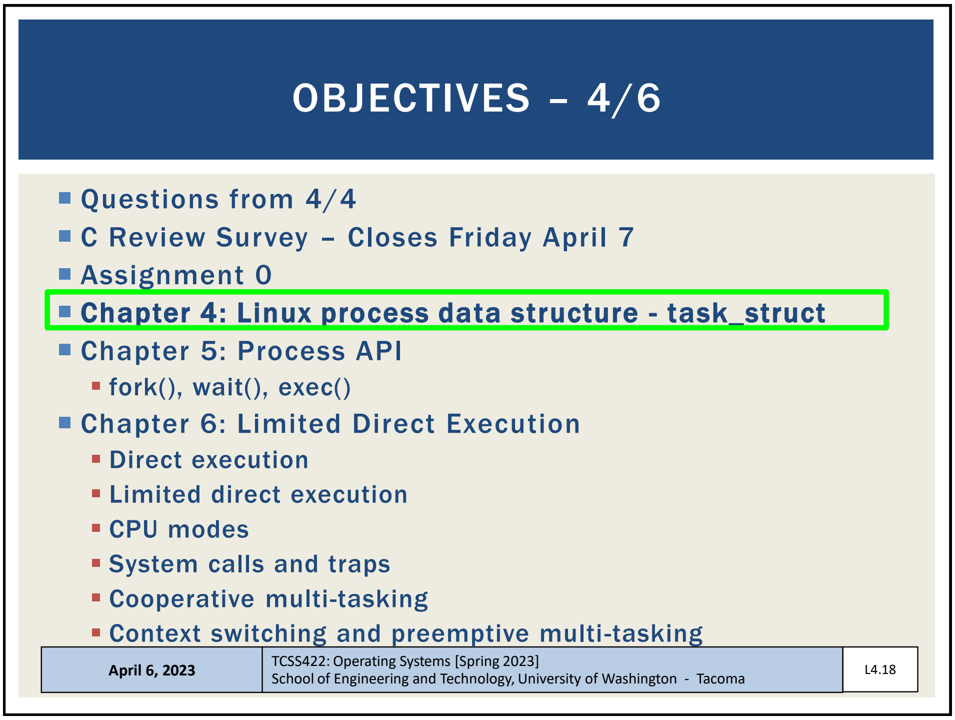

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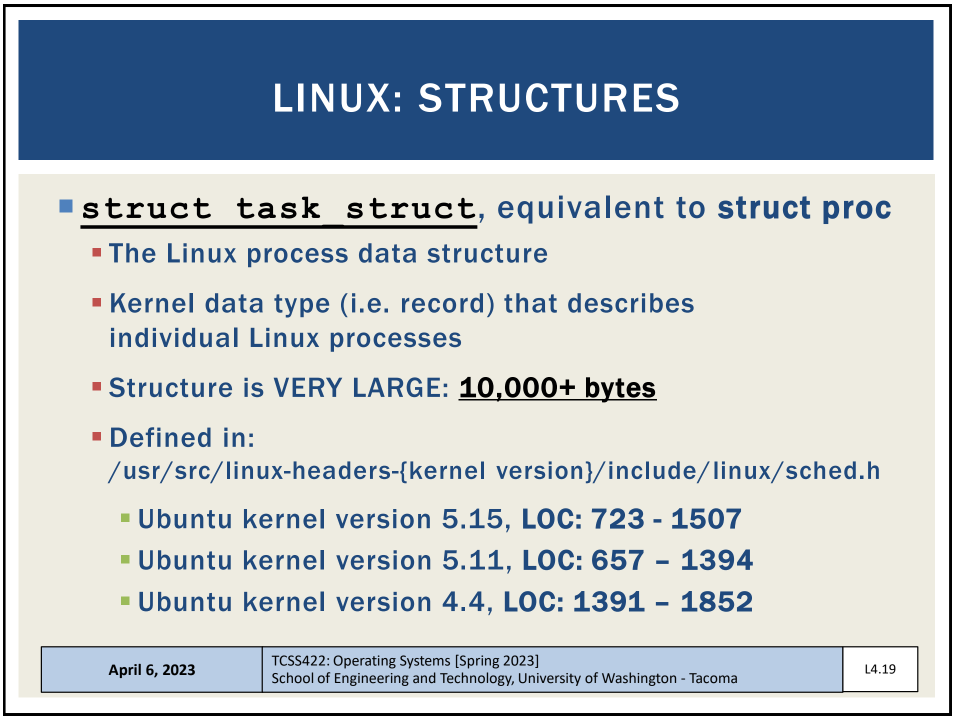

LINUX: STRUCTURES

- **struct task_struct**, equivalent to **struct proc**
  - The Linux process data structure
  - Kernel data type (i.e. record) that describes individual Linux processes
  - Structure is VERY LARGE: **10,000+ bytes**
  - Defined in: /usr/src/linux-headers-{kernel version}/include/linux/sched.h
    - Ubuntu kernel version 5.15, **LOC: 723 - 1507**
    - Ubuntu kernel version 5.11, **LOC: 657 – 1394**
    - Ubuntu kernel version 4.4, **LOC: 1391 – 1852**

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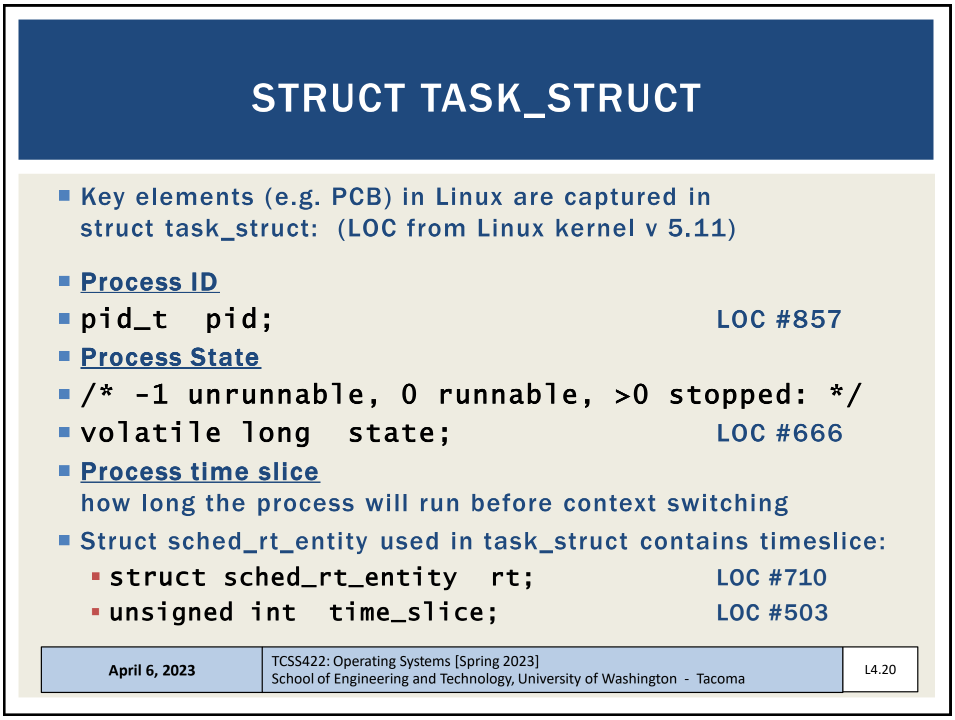

STRUCT TASK_STRUCT

- Key elements (e.g. PCB) in Linux are captured in struct task_struct: (LOC from Linux kernel v 5.11)
- **Process ID**
- `pid_t  pid;` LOC #857
- **Process State**
- `/* -1 unrunnable, 0 runnable, >0 stopped: */`
- `volatile long  state;` LOC #666
- **Process time slice**
  how long the process will run before context switching
- Struct sched_rt_entity used in task_struct contains timeslice:
  - `struct sched_rt_entity  rt;` LOC #710
  - `unsigned int  time_slice;` LOC #503

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STRUCT TASK_STRUCT - 2

- **Address space of the process:**
- "mm" is short for "memory map"
- struct mm_struct *mm; LOC #779

- **Parent process**, that launched this one
- struct task_struct __rcu *parent; LOC #874

- **Child processes** (as a list)
- struct list_head children; LOC #879

- **Open files**
- struct files_struct *files; LOC #981

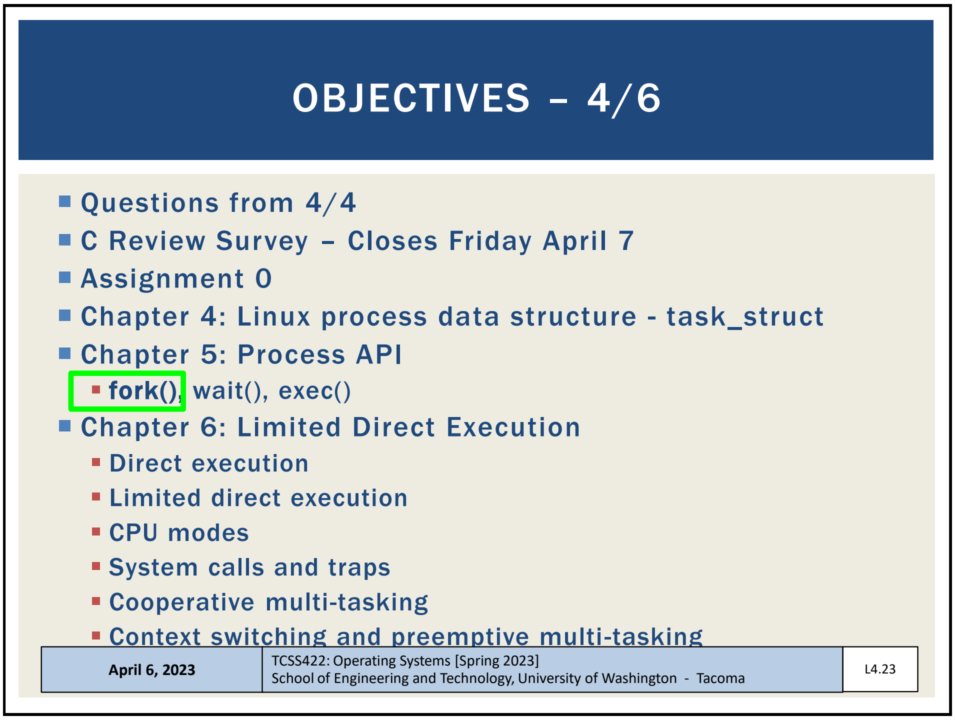
LINUX STRUCTURES - 2

- List of Linux data structures:
  http://www.tldp.org/LDP/tlk/ds/ds.html

- Description of process data structures:
  https://learning.oreilly.com/library/view/linux-kernel-development/9780768696974/cover.html

  3rd edition is online (dated from 2010):
  See chapter 3 on Process Management

  Safari online – accessible using UW ID SSO login
  Linux Kernel Development, 3rd edition
  Robert Love
  Addison-Wesley



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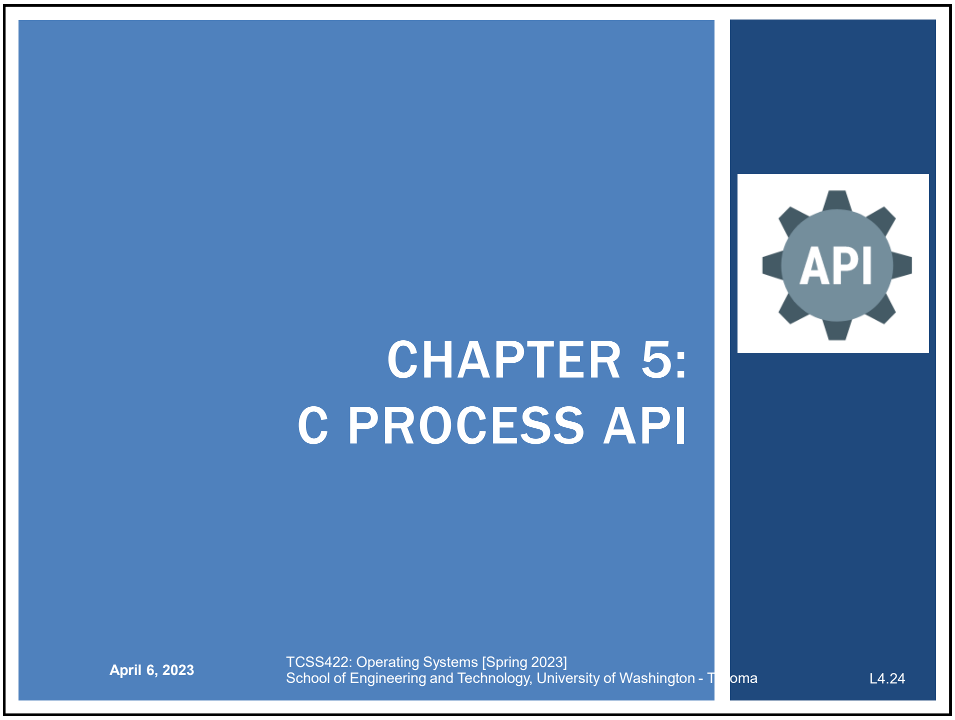

CHAPTER 5: C PROCESS API

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fork()

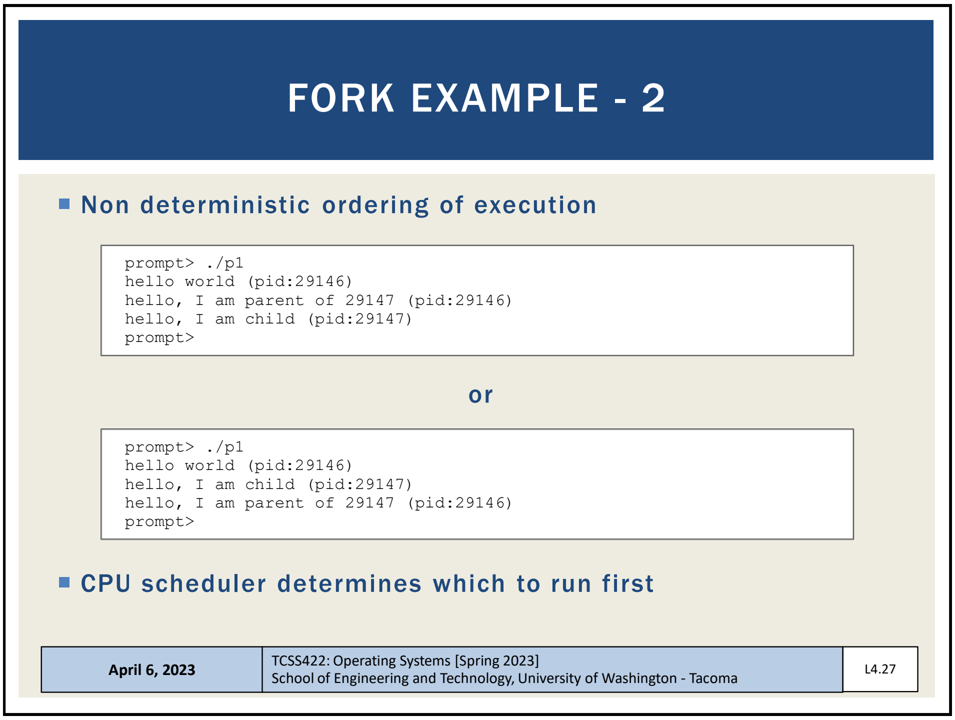
- Creates a new process - think of "a fork in the road"
- "Parent" process is the original
- Creates "child" process of the program from the **current execution point**
- Book says "pretty odd"
- Creates a **duplicate** program instance (these are **processes!**)
- **Copy** of
  - Address space (memory)
  - Register
  - Program Counter (PC)
- Fork returns
  - child PID to parent
  - 0 to child

FORK EXAMPLE

- p1.c

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>

int main(int argc, char *argv[]){
    printf("hello world (pid:%d)\n", (int) getpid());
    int rc = fork();
    if (rc < 0) {          // fork failed; exit
        fprintf(stderr, "fork failed\n");
        exit(1);
    } else if (rc == 0) { // child (new process)
        printf("hello, I am child (pid:%d)\n", (int) getpid());
    } else {               // parent goes down this path (main)
        printf("hello, I am parent of %d (pid:%d)\n",
        rc, (int) getpid());
    }
    return 0;
}
```



FORK EXAMPLE - 2

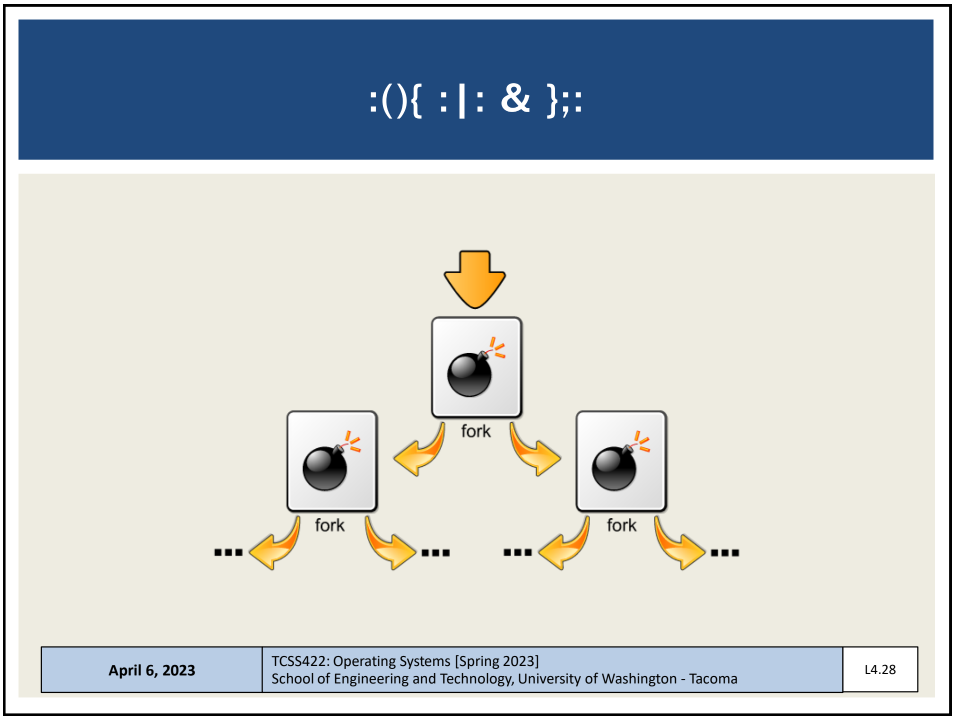
- Non deterministic ordering of execution

```
prompt> ./p1
hello world (pid:29146)
hello, I am parent of 29147 (pid:29146)
hello, I am child (pid:29147)
prompt>
```

or

```
prompt> ./p1
hello world (pid:29146)
hello, I am child (pid:29147)
hello, I am parent of 29147 (pid:29146)
prompt>
```

- CPU scheduler determines which to run first



:(){ :|: & };:

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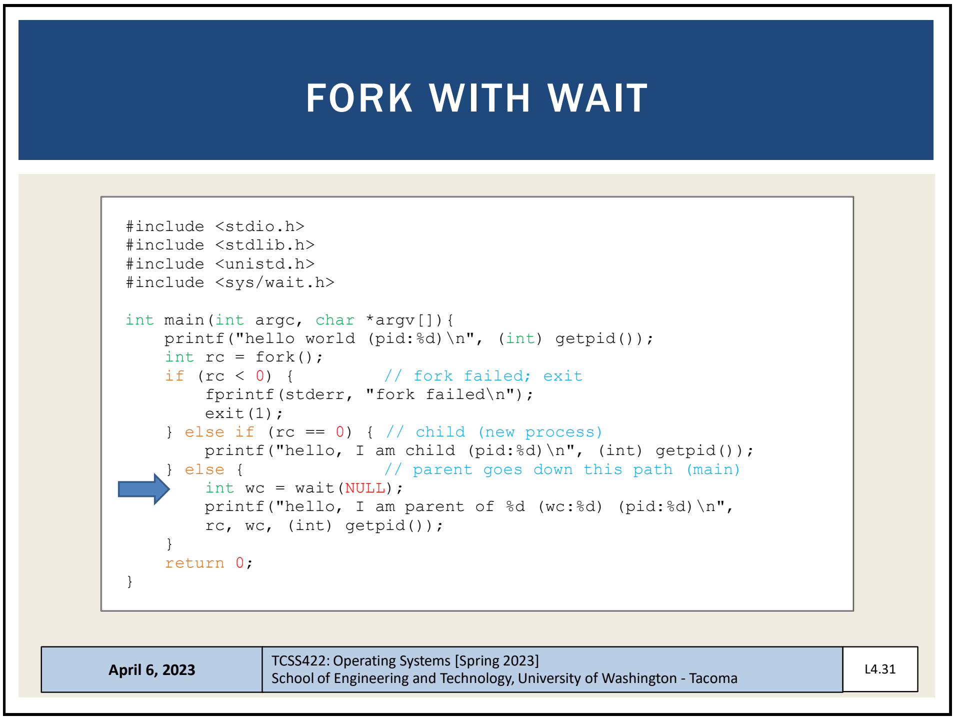
wait()

- wait(), waitpid()
- Called by parent process
- Waits for a child process to finish executing
- Not a sleep() function
- Provides some ordering to multi-process execution



FORK WITH WAIT

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <sys/wait.h>

int main(int argc, char *argv[]){
    printf("hello world (pid:%d)\n", (int) getpid());
    int rc = fork();
    if (rc < 0) {           // fork failed; exit
        fprintf(stderr, "fork failed\n");
        exit(1);
    } else if (rc == 0) { // child (new process)
        printf("hello, I am child (pid:%d)\n", (int) getpid());
    } else {                // parent goes down this path (main)
        int wc = wait(NULL);
        printf("hello, I am parent of %d (wc:%d) (pid:%d)\n",
        rc, wc, (int) getpid());
    }
    return 0;
}
```

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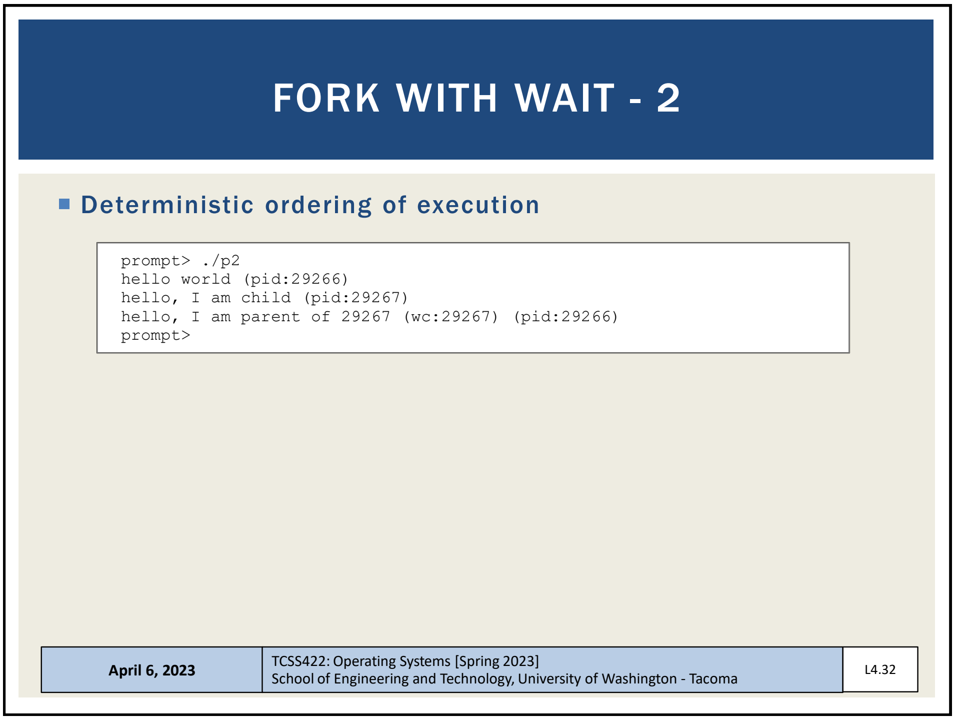

FORK WITH WAIT - 2

- Deterministic ordering of execution

```
prompt> ./p2
hello world (pid:29266)
hello, I am child (pid:29267)
hello, I am parent of 29267 (wc:29267) (pid:29266)
prompt>
```

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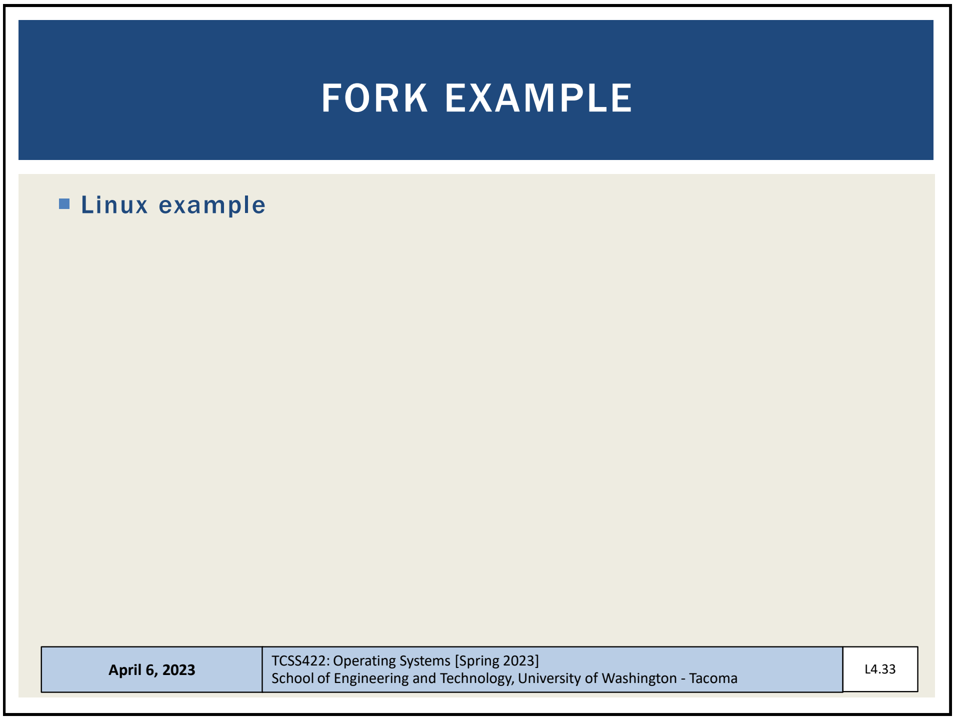

FORK EXAMPLE

- Linux example

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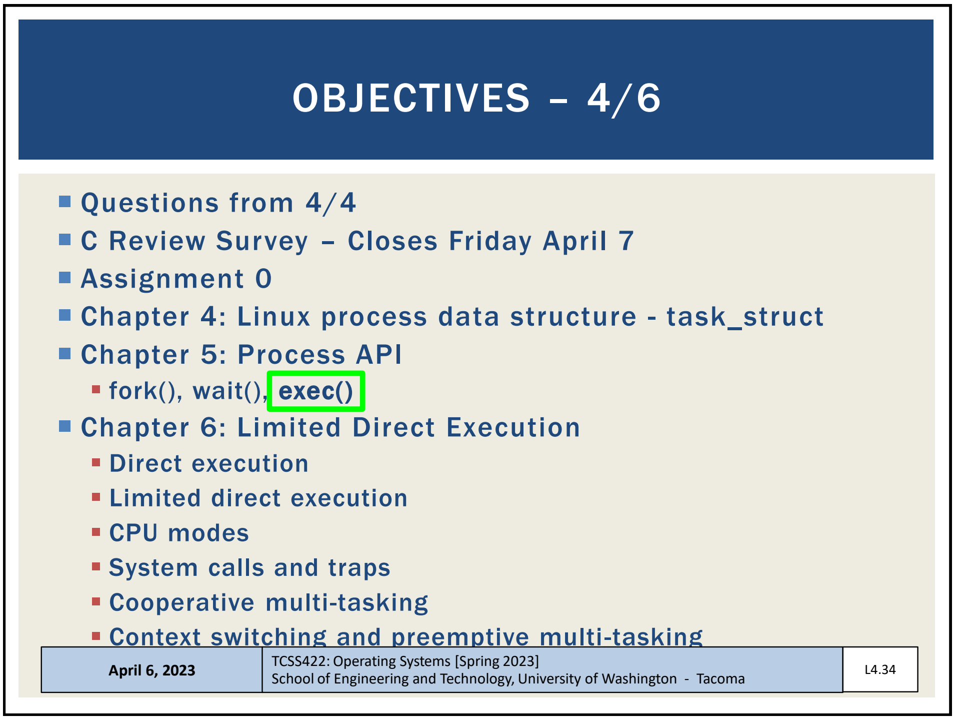

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exec()

- Supports running an external program **by "transferring control"**
- 6 types: execl(), execlp(), execle(), execv(), execvp(), execvpe()

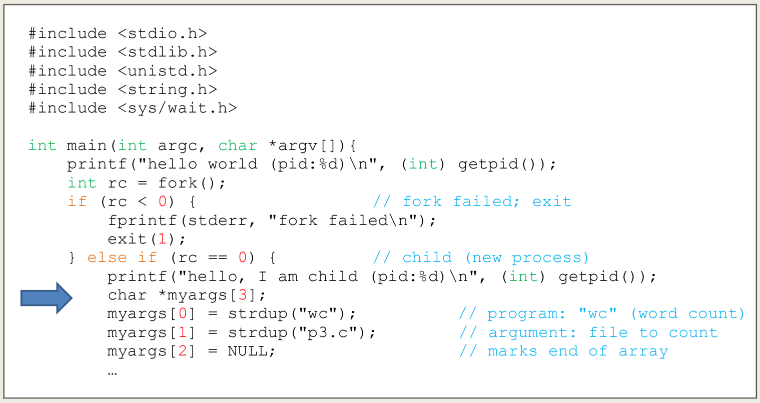
- execl(), execlp(), execle(): const char *arg ***(example: execl.c)***

  Provide cmd and args as individual params to the function
  Each arg is a pointer to a null-terminated string
  ODD: pass a variable number of args: (arg0, arg1, .. argn)

- Execv(), execvp(), execvpe() ***(example: exec.c)***
  Provide cmd and args as an Array of pointers to strings

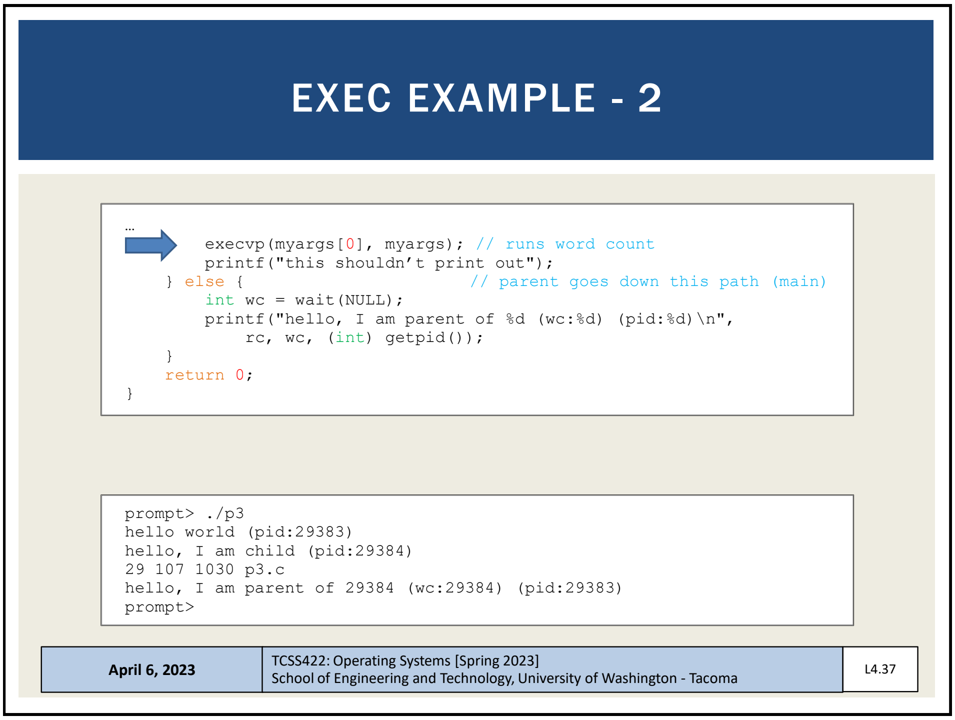
  Strings are null-terminated
  First argument is name of command being executed
  Fixed number of args passed in

EXEC EXAMPLE



```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <string.h>
#include <sys/wait.h>

int main(int argc, char *argv[]){
    printf("hello world (pid:%d)\n", (int) getpid());
    int rc = fork();
    if (rc < 0) {                  // fork failed; exit
        fprintf(stderr, "fork failed\n");
        exit(1);
    } else if (rc == 0) {          // child (new process)
        printf("hello, I am child (pid:%d)\n", (int) getpid());
        char *myargs[3];
        myargs[0] = strdup("wc");          // program: "wc" (word count)
        myargs[1] = strdup("p3.c");        // argument: file to count
        myargs[2] = NULL;                  // marks end of array
        …
```



EXEC EXAMPLE - 2

```
…
        execvp(myargs[0], myargs); // runs word count
        printf("this shouldn’t print out");
    } else {                    // parent goes down this path (main)
        int wc = wait(NULL);
        printf("hello, I am parent of %d (wc:%d) (pid:%d)\n",
            rc, wc, (int) getpid());
    }
    return 0;
}
```

```
prompt> ./p3
hello world (pid:29383)
hello, I am child (pid:29384)
29 107 1030 p3.c
hello, I am parent of 29384 (wc:29384) (pid:29383)
prompt>
```

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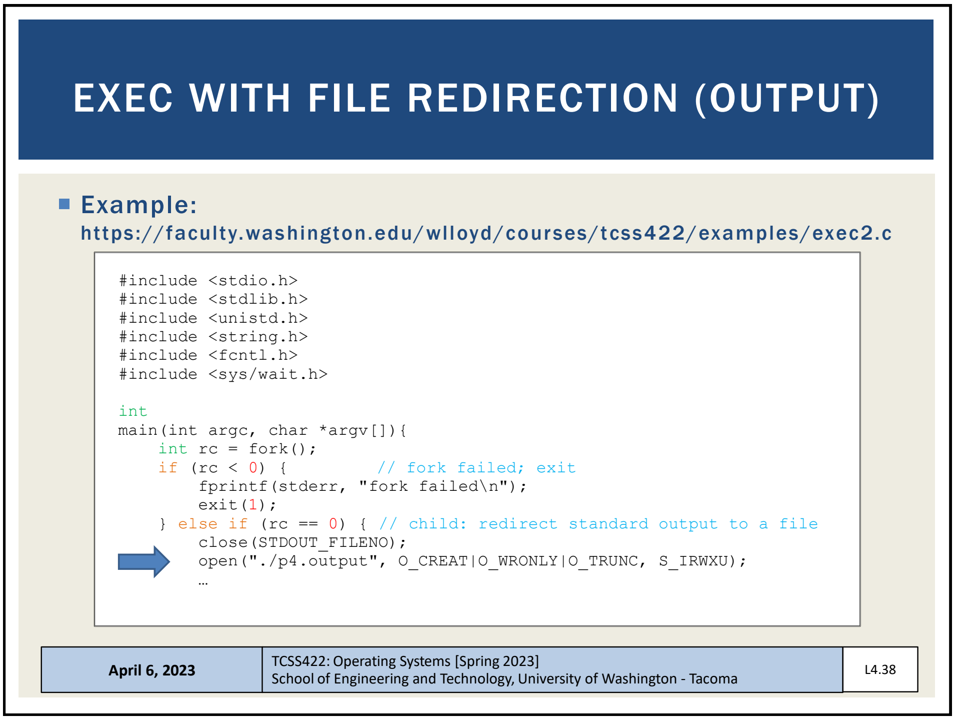

EXEC WITH FILE REDIRECTION (OUTPUT)

- Example:
https://faculty.washington.edu/wlloyd/courses/tcss422/examples/exec2.c

```
#include <stdio.h>
#include <stdlib.h>
#include <unistd.h>
#include <string.h>
#include <fcntl.h>
#include <sys/wait.h>

int
main(int argc, char *argv[]){
    int rc = fork();
    if (rc < 0) {          // fork failed; exit
        fprintf(stderr, "fork failed\n");
        exit(1);
    } else if (rc == 0) { // child: redirect standard output to a file
        close(STDOUT_FILENO);
        open("./p4.output", O_CREAT|O_WRONLY|O_TRUNC, S_IRWXU);
        …
```

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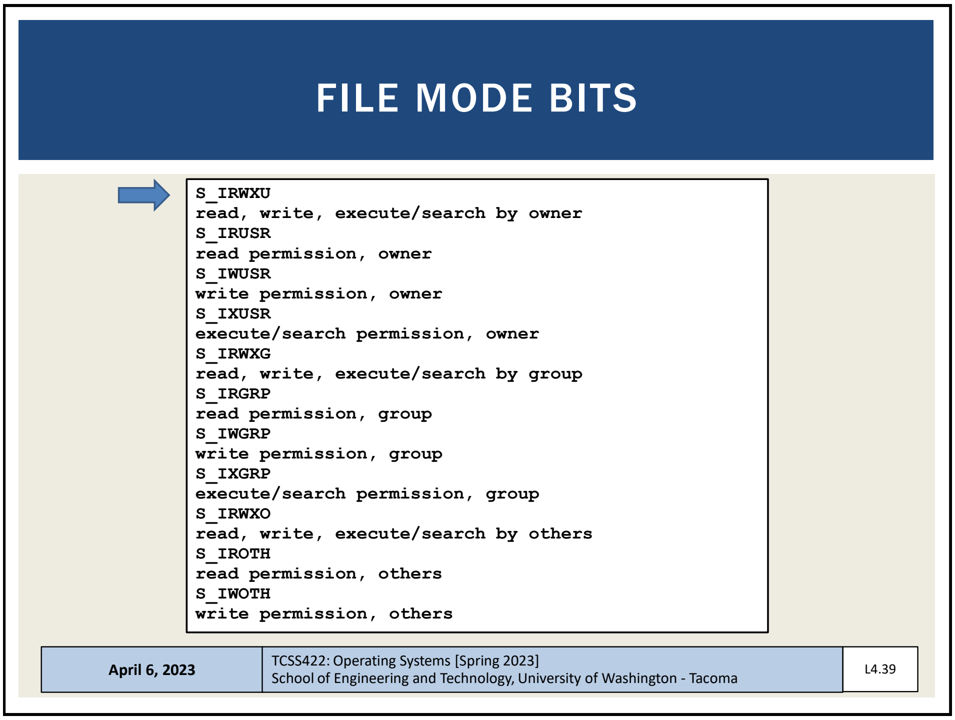
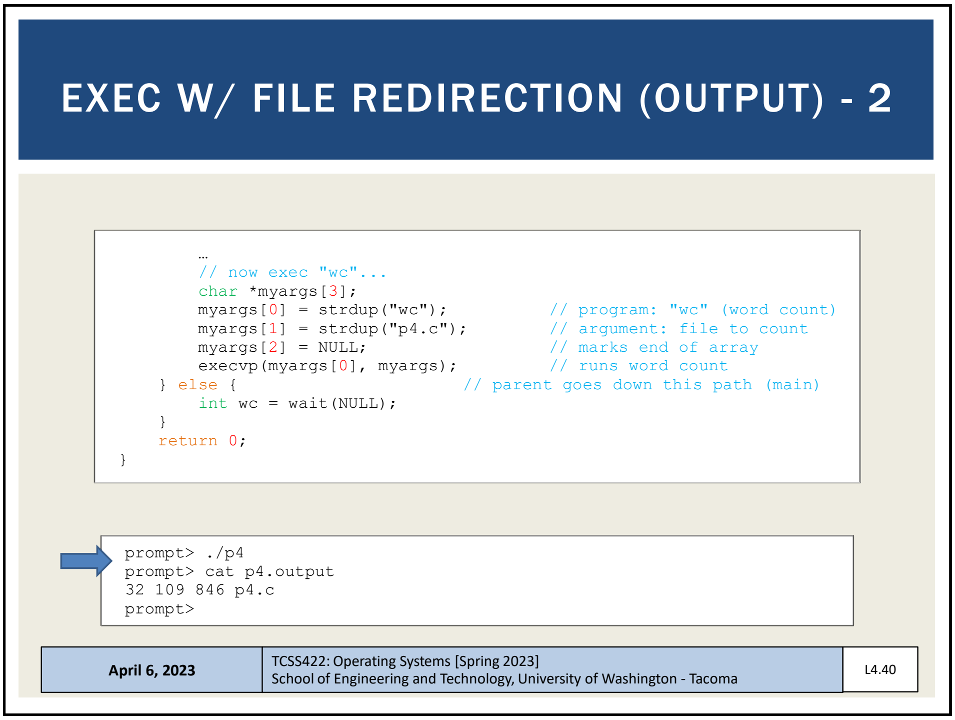


FILE MODE BITS

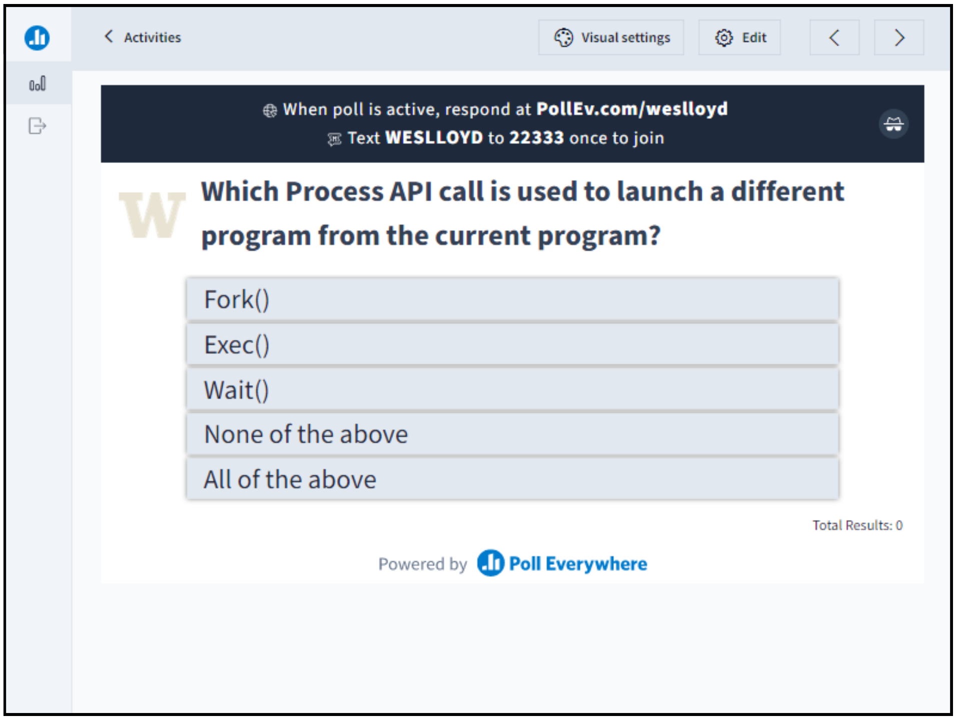
```
S_IRWXU
read, write, execute/search by owner
S_IRUSR
read permission, owner
S_IWUSR
write permission, owner
S_IXUSR
execute/search permission, owner
S_IRWXG
read, write, execute/search by group
S_IRGRP
read permission, group
S_IWGRP
write permission, group
S_IXGRP
execute/search permission, group
S_IRWXO
read, write, execute/search by others
S_IROTH
read permission, others
S_IWOTH
write permission, others
```



EXEC W/ FILE REDIRECTION (OUTPUT) - 2

```
        …
        // now exec "wc"...
        char *myargs[3];
        myargs[0] = strdup("wc");          // program: "wc" (word count)
        myargs[1] = strdup("p4.c");        // argument: file to count
        myargs[2] = NULL;                  // marks end of array
        execvp(myargs[0], myargs);         // runs word count
    } else {                         // parent goes down this path (main)
        int wc = wait(NULL);
    }
    return 0;
}
```

```
prompt> ./p4
prompt> cat p4.output
32 109 846 p4.c
prompt>
```



When poll is active, respond at **PollEv.com/weslloyd**
Text **WESLLOYD** to **22333** once to join

Which Process API call is used to launch a different program from the current program?

- Fork()
- Exec()
- Wait()
- None of the above
- All of the above

Total Results: 0

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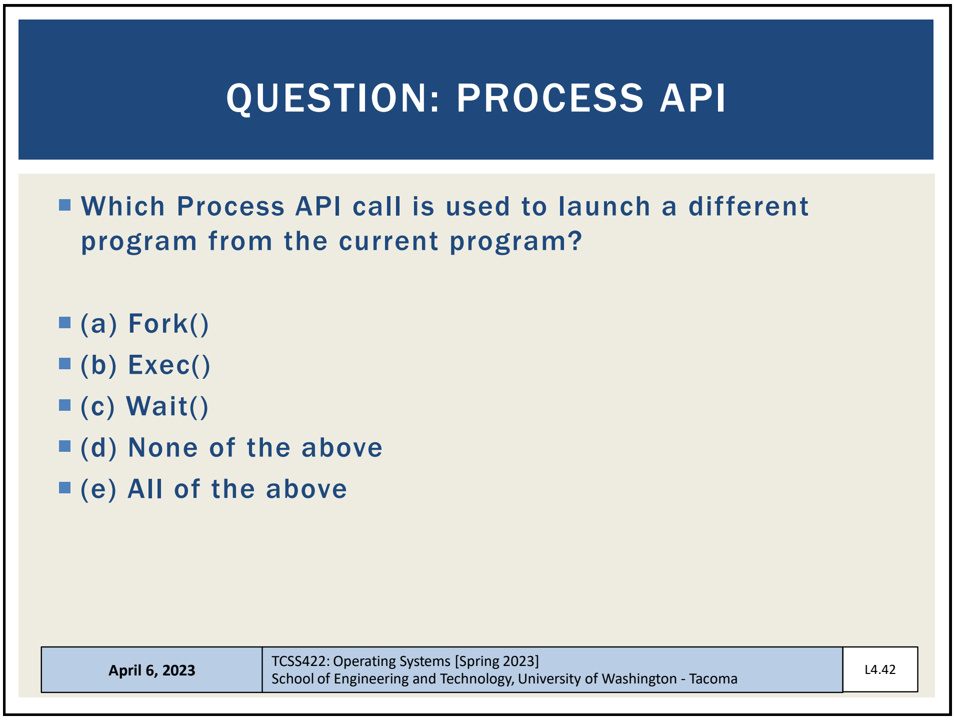

QUESTION: PROCESS API

- Which Process API call is used to launch a different program from the current program?
- (a) Fork()
- (b) Exec()
- (c) Wait()
- (d) None of the above
- (e) All of the above

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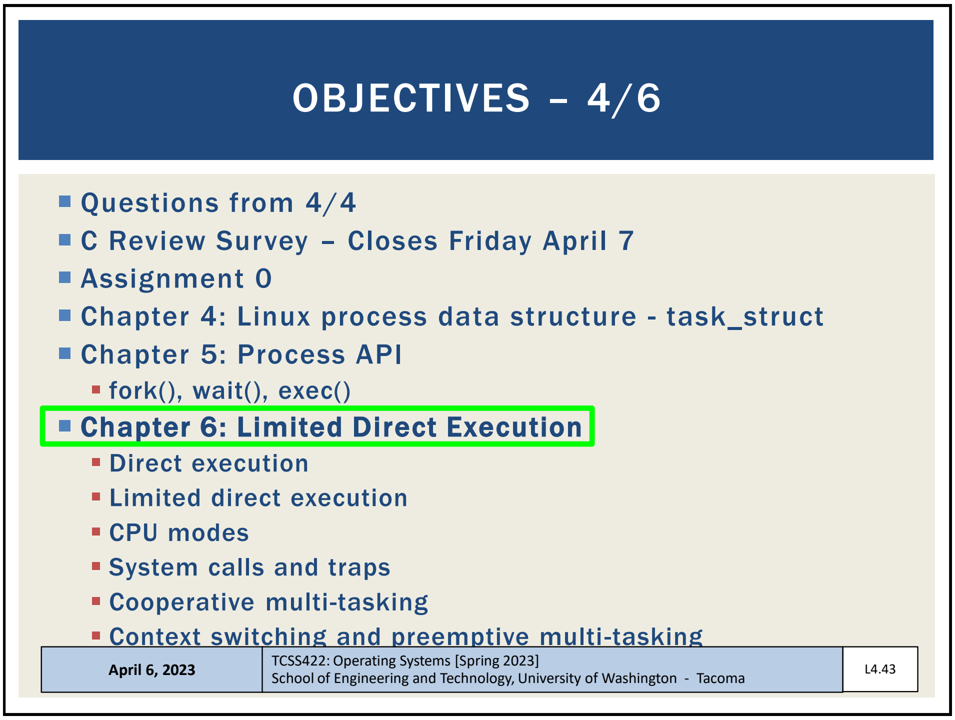

OBJECTIVES – 4/6

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  - fork(), wait(), exec()
- **Chapter 6: Limited Direct Execution**
  - Direct execution
  - Limited direct execution
  - CPU modes
  - System calls and traps
  - Cooperative multi-tasking
  - Context switching and preemptive multi-tasking

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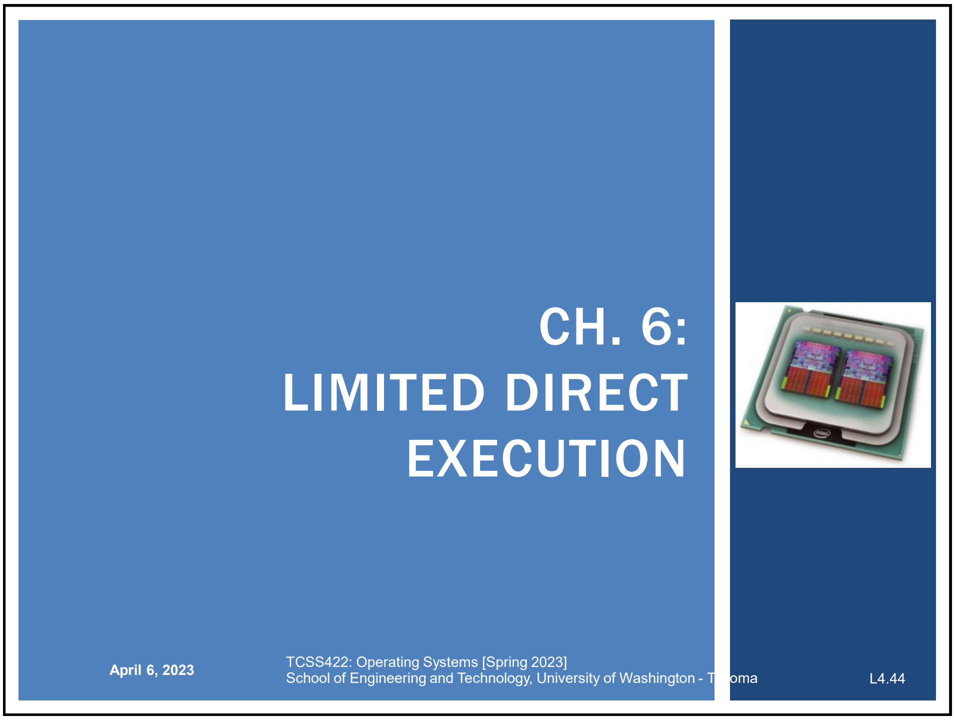

CH. 6: LIMITED DIRECT EXECUTION

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OBJECTIVES – 4/6

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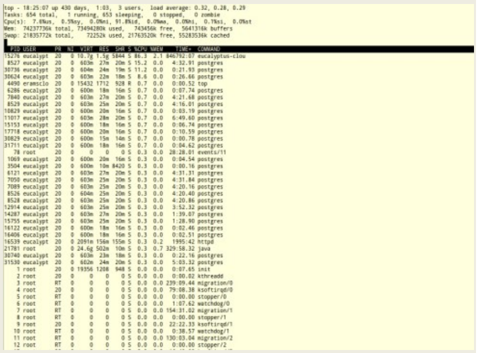
- Chapter 5: Process API
  - fork(), wait(), exec()
- Chapter 6: Limited Direct Execution
  - **Direct execution**
  - Limited direct execution
  - CPU modes
  - System calls and traps
  - Cooperative multi-tasking
  - Context switching and preemptive multi-tasking

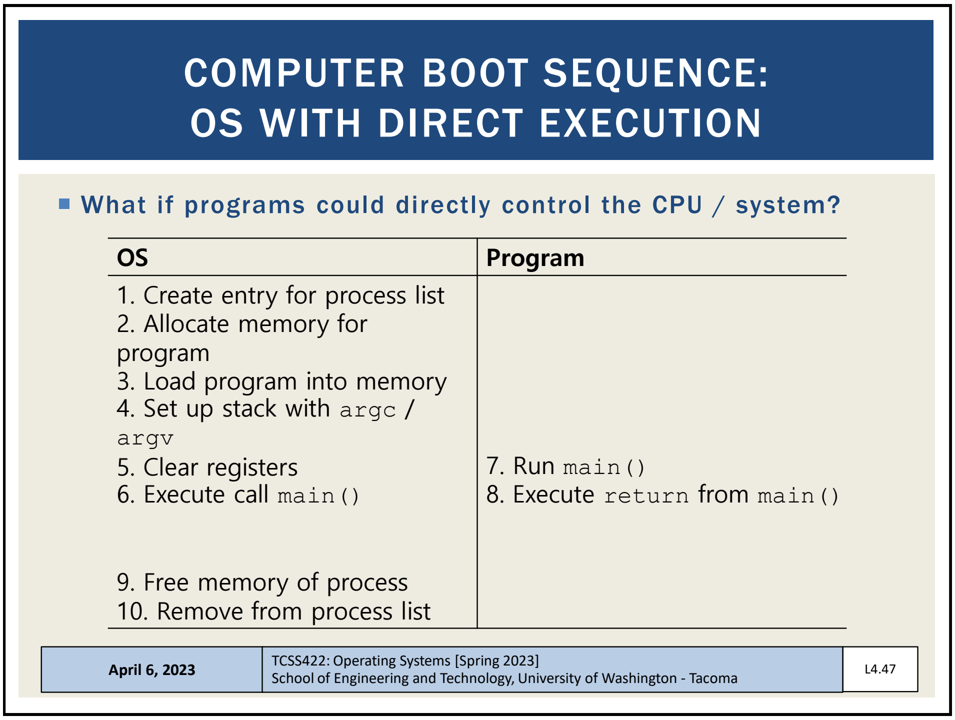
VIRTUALIZING THE CPU

- How does the CPU support running so many jobs simultaneously?
- **Time Sharing**
- Tradeoffs:
  - Performance
    - Excessive overhead
  - Control
    - Fairness
    - Security
- Both HW and OS support is used



```
top - 18:25:07 up 430 days,  1:03,  3 users,  load average: 0.32, 0.28, 0.29
Tasks: 654 total,   1 running, 653 sleeping,   0 stopped,   0 zombie
Cpu(s):  7.6%us,  0.5%sy,  0.0%ni, 91.8%id,  0.0%wa,  0.0%hi,  0.1%si,  0.0%st
Mem:  74237736k total, 73494280k used,   743456k free,  5641316k buffers
Swap: 21835772k total,    72252k used, 21763520k free, 55283536k cached

  PID USER      PR  NI  VIRT  RES  SHR S %CPU %MEM    TIME+  COMMAND
15276 eucalypt  20   0 10.7g 1.5g 5844 S 86.3  2.1 846792:07 eucalyptus-clou
 8527 eucalypt  20   0  603m  27m  20m S 15.2  0.0   4:32.91 postgres
30736 eucalypt  20   0  604m  24m  19m S 11.2  0.0   0:21.93 postgres
30624 eucalypt  20   0  603m  22m  18m S  8.6  0.0   0:26.66 postgres
 4490 eramsclo  20   0 15432 1712  928 R  0.7  0.0   0:00.52 top
 6286 eucalypt  20   0  600m  18m  16m S  0.7  0.0   0:07.74 postgres
 7840 eucalypt  20   0  603m  27m  20m S  0.7  0.0   4:21.68 postgres
 8529 eucalypt  20   0  603m  25m  20m S  0.7  0.0   4:16.01 postgres
10829 eucalypt  20   0  600m  20m  16m S  0.7  0.0   0:03.19 postgres
11017 eucalypt  20   0  603m  28m  20m S  0.7  0.0   6:49.60 postgres
15153 eucalypt  20   0  600m  18m  16m S  0.7  0.0   0:06.74 postgres
17718 eucalypt  20   0  600m  20m  16m S  0.7  0.0   0:10.59 postgres
30829 eucalypt  20   0  600m  15m  14m S  0.7  0.0   0:00.78 postgres
31711 eucalypt  20   0  600m  18m  16m S  0.7  0.0   0:04.62 postgres
   78 root      20   0     0    0    0 S  0.3  0.0  28:28.01 events/11
 1069 eucalypt  20   0  600m  20m  16m S  0.3  0.0   0:04.54 postgres
 3504 eucalypt  20   0  600m  10m 8420 S  0.3  0.0   0:00.16 postgres
 6121 eucalypt  20   0  603m  27m  20m S  0.3  0.0   4:31.31 postgres
 7050 eucalypt  20   0  603m  25m  20m S  0.3  0.0   4:31.84 postgres
 7089 eucalypt  20   0  603m  25m  20m S  0.3  0.0   4:20.16 postgres
 8526 eucalypt  20   0  604m  25m  20m S  0.3  0.0   4:20.40 postgres
 8528 eucalypt  20   0  603m  25m  20m S  0.3  0.0   4:20.86 postgres
12914 eucalypt  20   0  603m  25m  20m S  0.3  0.0   3:52.32 postgres
14287 eucalypt  20   0  603m  27m  20m S  0.3  0.0   1:39.07 postgres
15755 eucalypt  20   0  603m  25m  20m S  0.3  0.0   1:28.90 postgres
16122 eucalypt  20   0  600m  18m  16m S  0.3  0.0   0:02.46 postgres
16406 eucalypt  20   0  600m  18m  16m S  0.3  0.0   0:02.51 postgres
16539 eucalypt  20   0 2091m 156m 155m S  0.3  0.2   1995:42 httpd
21781 root      20   0 24.6g 502m  10m S  0.3  0.7 329:58.32 java
30740 eucalypt  20   0  603m  23m  18m S  0.3  0.0   0:22.16 postgres
31530 eucalypt  20   0  602m  24m  20m S  0.3  0.0   5:03.32 postgres
    1 root      20   0 19356 1208  948 S  0.0  0.0   0:07.65 init
    2 root      20   0     0    0    0 S  0.0  0.0   0:00.02 kthreadd
    3 root      RT   0     0    0    0 S  0.0  0.0 239:09.44 migration/0
    4 root      20   0     0    0    0 S  0.0  0.0  79:08.38 ksoftirqd/0
    5 root      RT   0     0    0    0 S  0.0  0.0   0:00.00 stopper/0
    6 root      RT   0     0    0    0 S  0.0  0.0   1:07.62 watchdog/0
    7 root      RT   0     0    0    0 S  0.0  0.0 154:31.02 migration/1
    8 root      RT   0     0    0    0 S  0.0  0.0   0:00.00 stopper/1
    9 root      20   0     0    0    0 S  0.0  0.0  22:22.33 ksoftirqd/1
   10 root      RT   0     0    0    0 S  0.0  0.0   0:38.57 watchdog/1
   11 root      RT   0     0    0    0 S  0.0  0.0 130:03.04 migration/2
   12 root      RT   0     0    0    0 S  0.0  0.0   0:00.00 stopper/2
```



COMPUTER BOOT SEQUENCE: OS WITH DIRECT EXECUTION

- What if programs could directly control the CPU / system?

OS	Program
1. Create entry for process list	
2. Allocate memory for program	
3. Load program into memory	
4. Set up stack with `argc` / `argv`	
5. Clear registers	7. Run `main()`
6. Execute call `main()`	8. Execute `return` from `main()`
9. Free memory of process	
10. Remove from process list	

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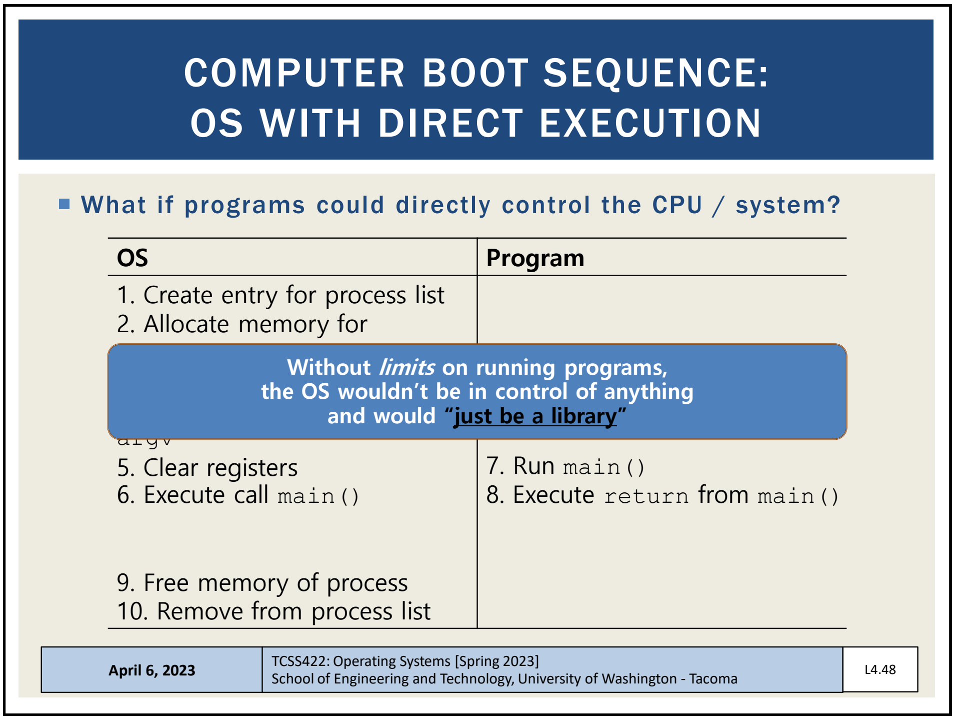

COMPUTER BOOT SEQUENCE: OS WITH DIRECT EXECUTION

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OS	Program
1. Create entry for process list	
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`argv`	
5. Clear registers	7. Run `main()`
6. Execute call `main()`	8. Execute `return` from `main()`
9. Free memory of process	
10. Remove from process list	

Without *limits* on running programs, the OS wouldn't be in control of anything and would "just be a library"

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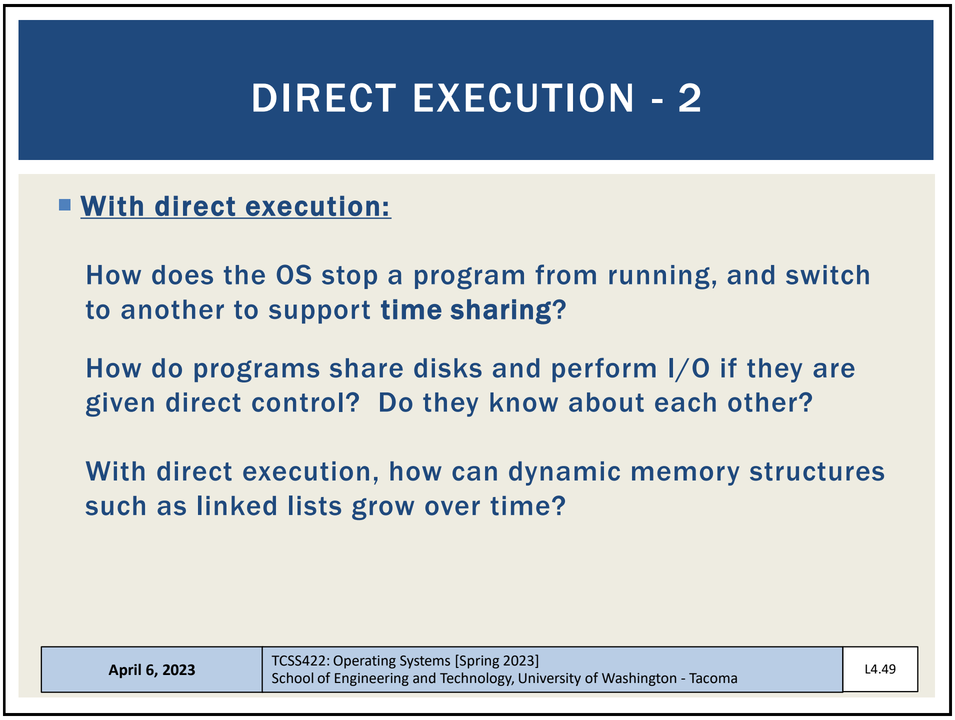

DIRECT EXECUTION - 2

- **With direct execution:**

  How does the OS stop a program from running, and switch to another to support **time sharing?**

  How do programs share disks and perform I/O if they are given direct control? Do they know about each other?

  With direct execution, how can dynamic memory structures such as linked lists grow over time?

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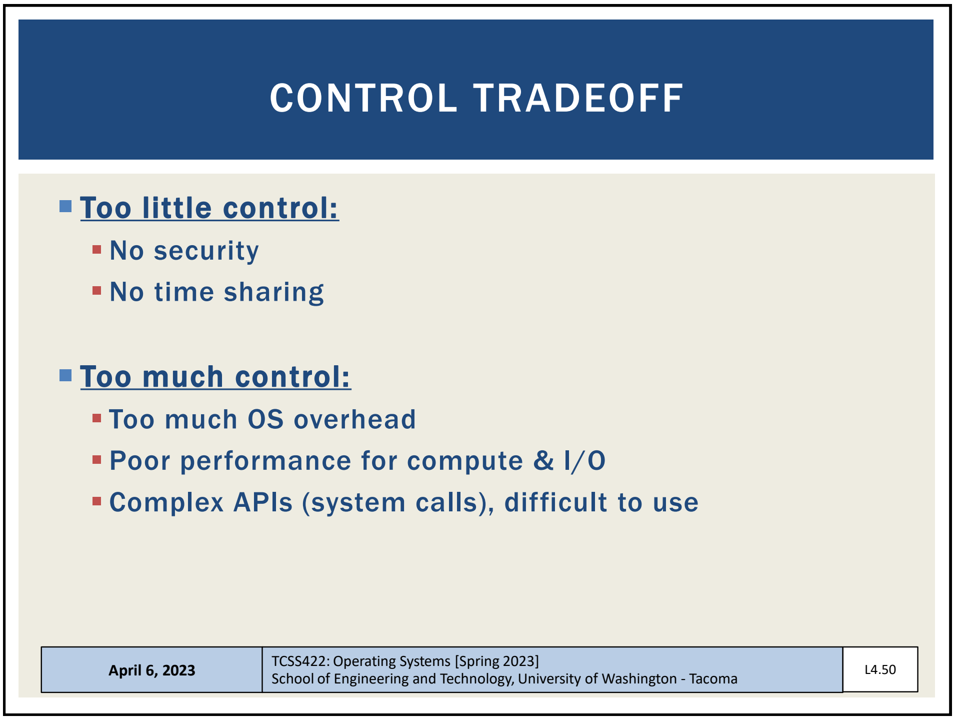

CONTROL TRADEOFF

- **Too little control:**
  - No security
  - No time sharing

- **Too much control:**
  - Too much OS overhead
  - Poor performance for compute & I/O
  - Complex APIs (system calls), difficult to use

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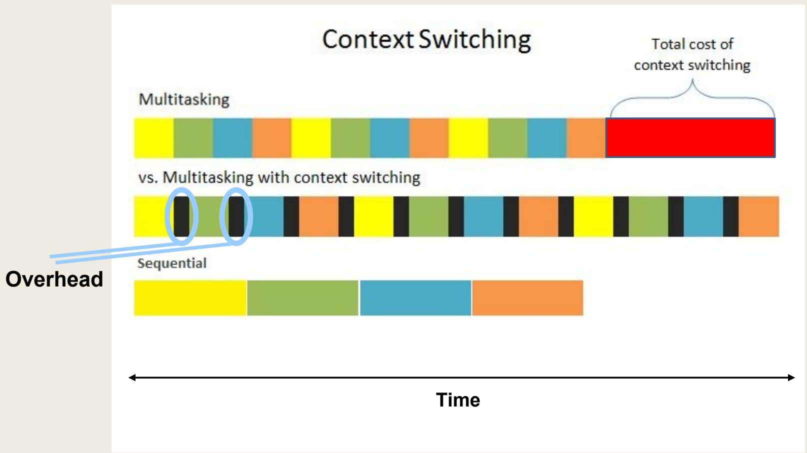
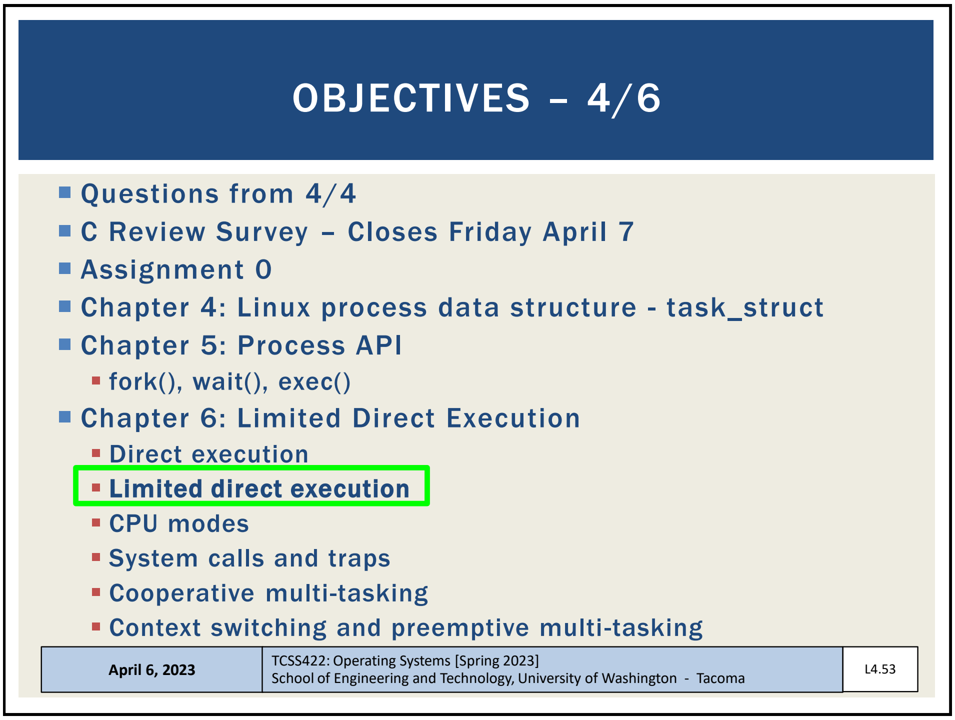
CONTEXT SWITCHING OVERHEAD


Context Switching
Total cost of context switching
Multitasking
vs. Multitasking with context switching
Overhead
Sequential
Time

WE WILL RETURN AT 2:40PM



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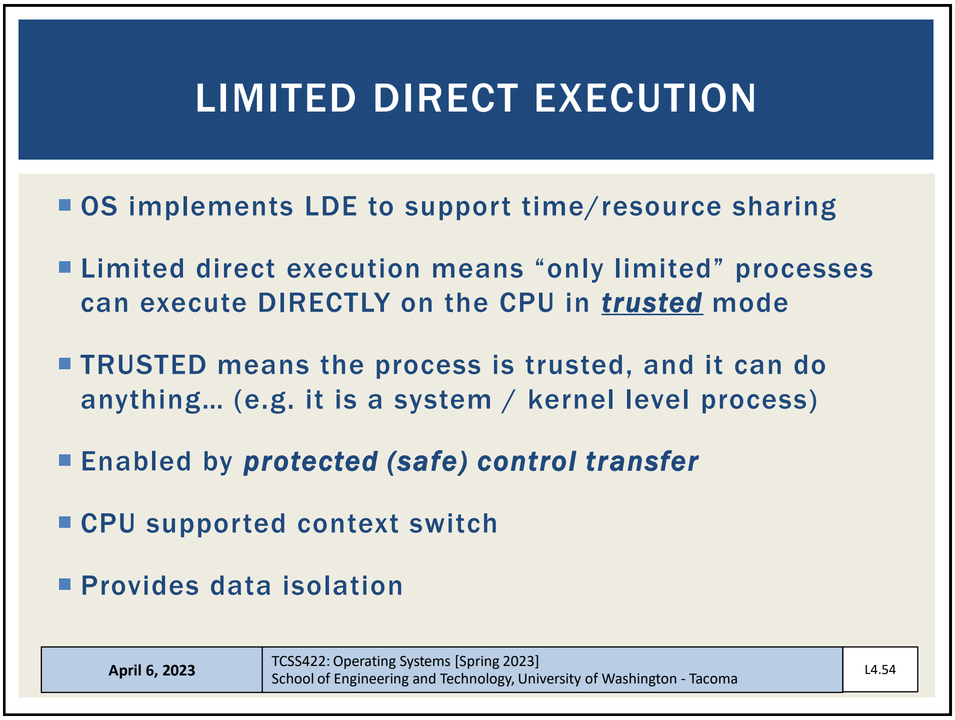
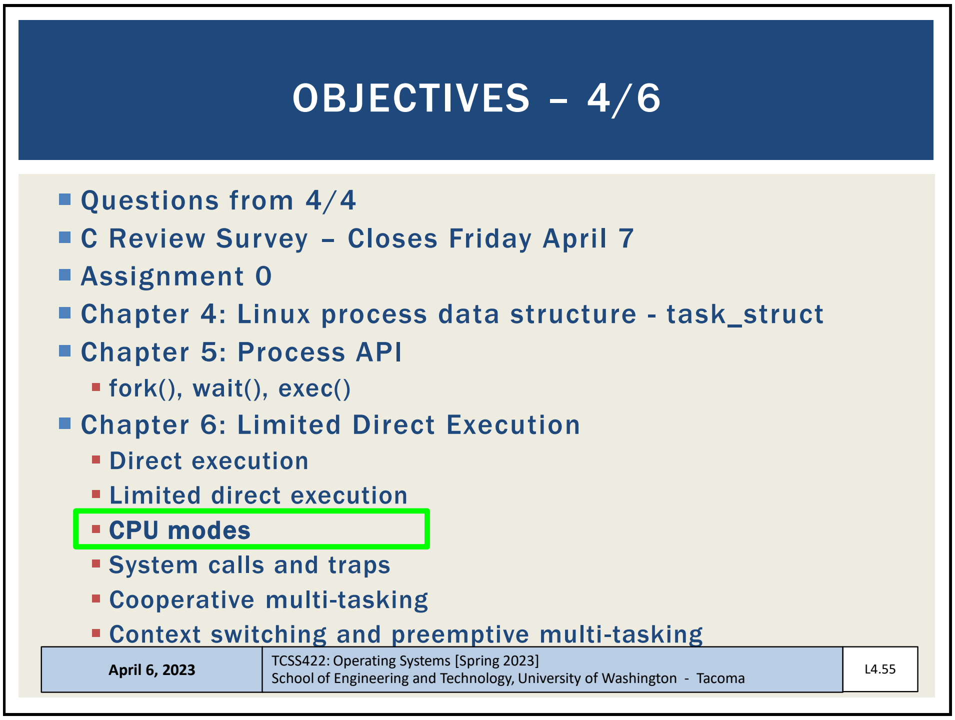
  - **Limited direct execution**
  - CPU modes
  - System calls and traps
  - Cooperative multi-tasking
  - Context switching and preemptive multi-tasking



LIMITED DIRECT EXECUTION

- OS implements LDE to support time/resource sharing
- Limited direct execution means "only limited" processes can execute DIRECTLY on the CPU in ***trusted*** mode
- TRUSTED means the process is trusted, and it can do anything… (e.g. it is a system / kernel level process)
- Enabled by ***protected (safe) control transfer***
- CPU supported context switch
- Provides data isolation



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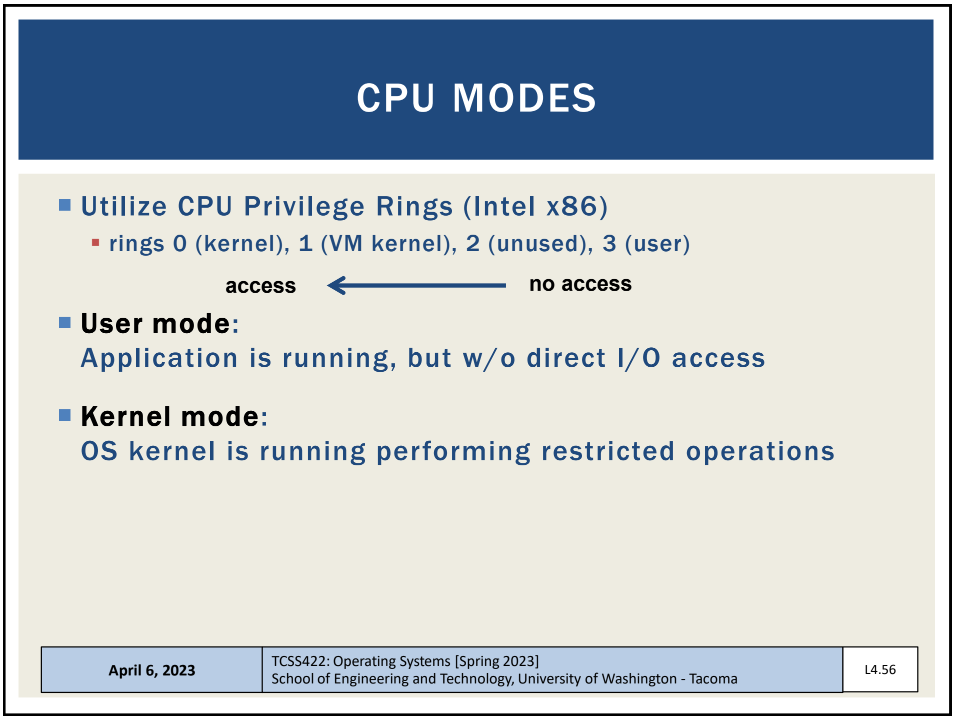


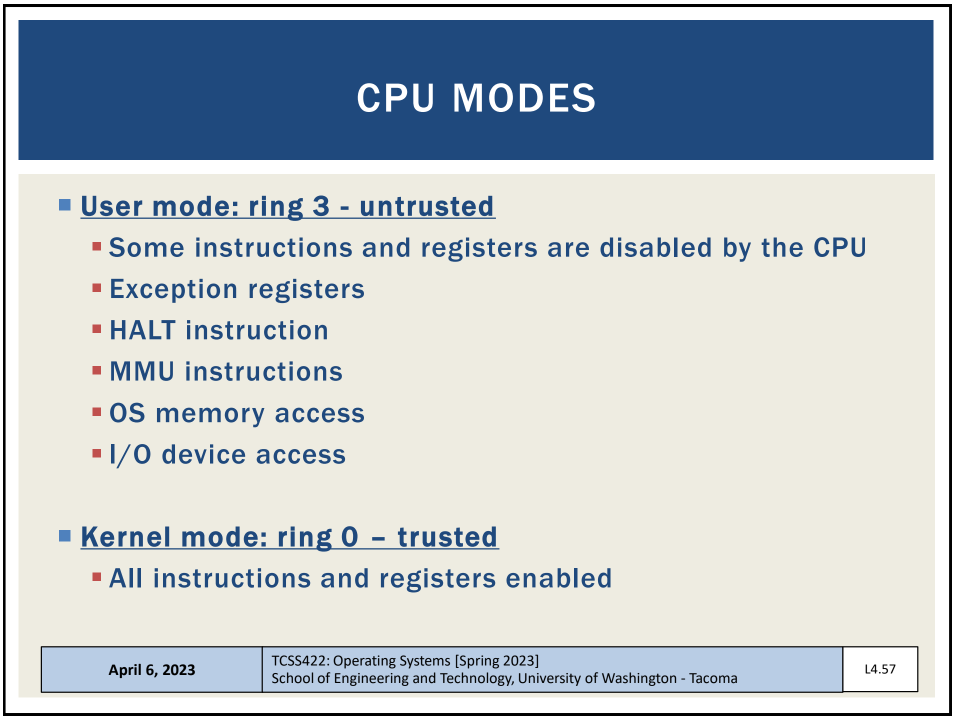
CPU MODES

- Utilize CPU Privilege Rings (Intel x86)
  - rings 0 (kernel), 1 (VM kernel), 2 (unused), 3 (user)

access ← **no access**

- **User mode**:
  Application is running, but w/o direct I/O access

- **Kernel mode**:
  OS kernel is running performing restricted operations



CPU MODES

- **User mode: ring 3 - untrusted**
  - Some instructions and registers are disabled by the CPU
  - Exception registers
  - HALT instruction
  - MMU instructions
  - OS memory access
  - I/O device access

- **Kernel mode: ring 0 – trusted**
  - All instructions and registers enabled

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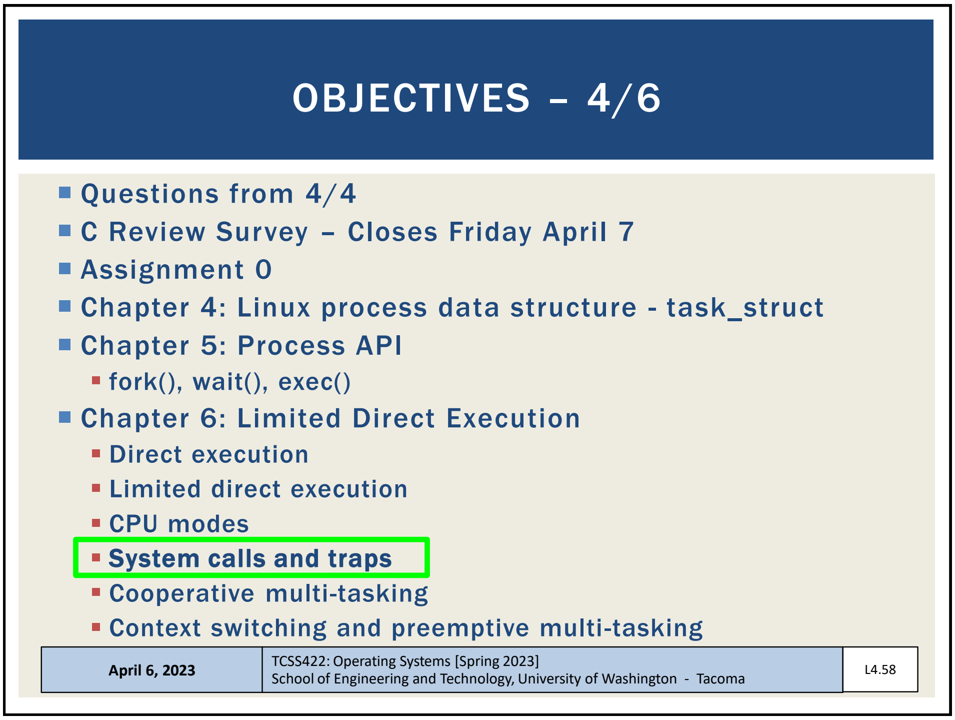

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  - **System calls and traps**
  - Cooperative multi-tasking
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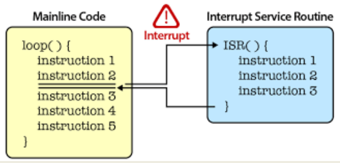
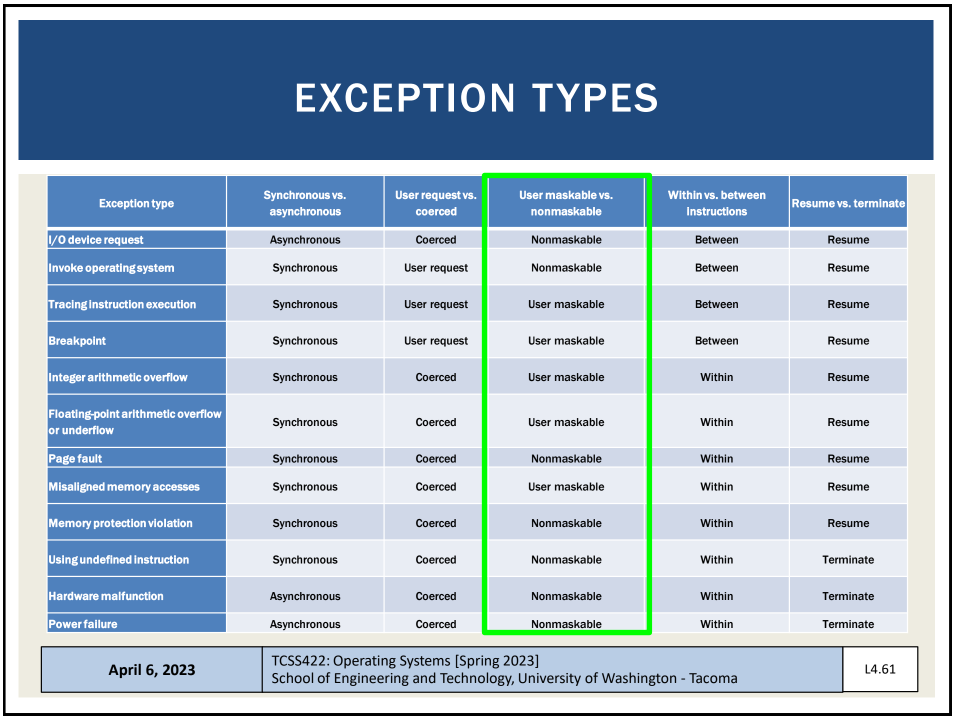
SYSTEM CALLS

- Implement restricted "OS" operations
- Kernel exposes key functions through an API:
  - Device I/O (e.g. file I/O)
  - Task swapping: context switching between processes
  - Memory management/allocation: malloc()
  - Creating/destroying processes

TRAPS: SYSTEM CALLS, EXCEPTIONS, INTERRUPTS



- Trap: any transfer to kernel mode
- Three kinds of traps
  - **System call:** (planned) user → kernel
    - SYSCALL for I/O, etc.
  - **Exception:** (error) user → kernel
    - Div by zero, page fault, page protection error
  - **Interrupt:** (event) user → kernel
    - Non-maskable vs. maskable
    - Keyboard event, network packet arrival, timer ticks
    - Memory parity error (ECC), hard drive failure



EXCEPTION TYPES

Exception type	Synchronous vs. asynchronous	User request vs. coerced	User maskable vs. nonmaskable	Within vs. between instructions	Resume vs. terminate
I/O device request	Asynchronous	Coerced	Nonmaskable	Between	Resume
Invoke operating system	Synchronous	User request	Nonmaskable	Between	Resume
Tracing instruction execution	Synchronous	User request	User maskable	Between	Resume
Breakpoint	Synchronous	User request	User maskable	Between	Resume
Integer arithmetic overflow	Synchronous	Coerced	User maskable	Within	Resume
Floating-point arithmetic overflow or underflow	Synchronous	Coerced	User maskable	Within	Resume
Page fault	Synchronous	Coerced	Nonmaskable	Within	Resume
Misaligned memory accesses	Synchronous	Coerced	User maskable	Within	Resume
Memory protection violation	Synchronous	Coerced	Nonmaskable	Within	Resume
Using undefined instruction	Synchronous	Coerced	Nonmaskable	Within	Terminate
Hardware malfunction	Asynchronous	Coerced	Nonmaskable	Within	Terminate
Power failure	Asynchronous	Coerced	Nonmaskable	Within	Terminate

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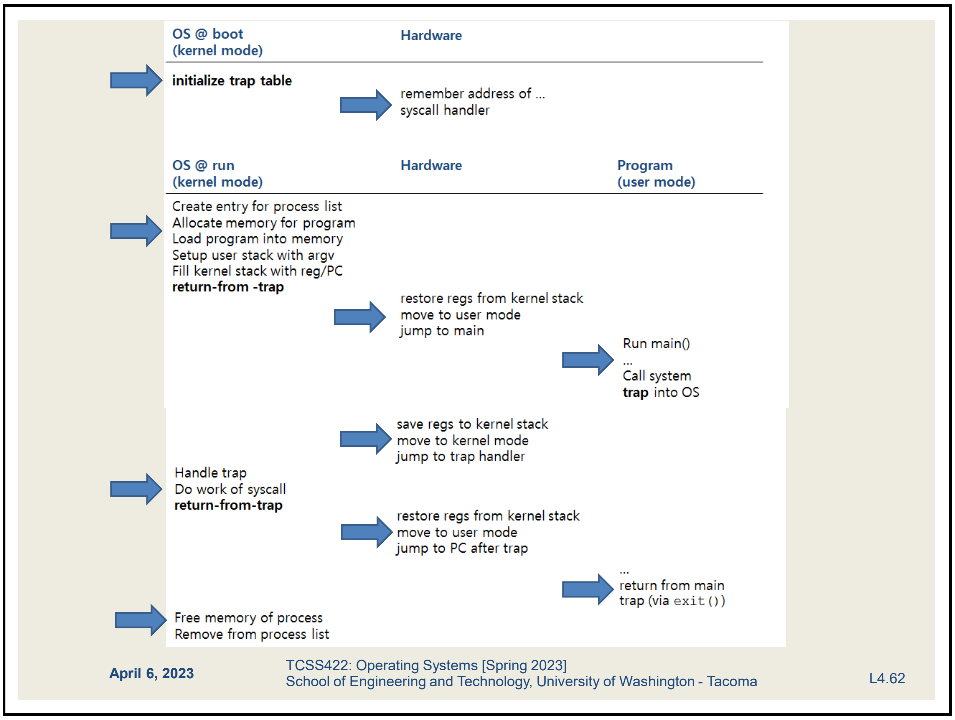

OS @ boot (kernel mode) | Hardware

initialize trap table

remember address of …
syscall handler

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
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

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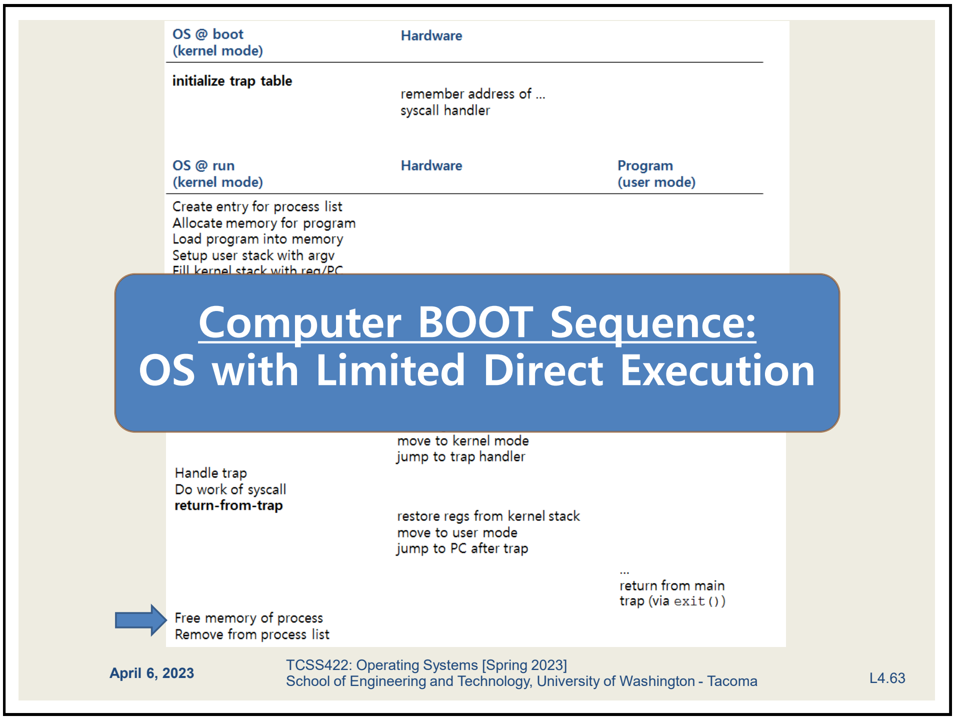

OS @ boot (kernel mode)	Hardware
initialize trap table	
	remember address of ... syscall handler

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		
	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		

Computer BOOT Sequence:
OS with Limited Direct Execution

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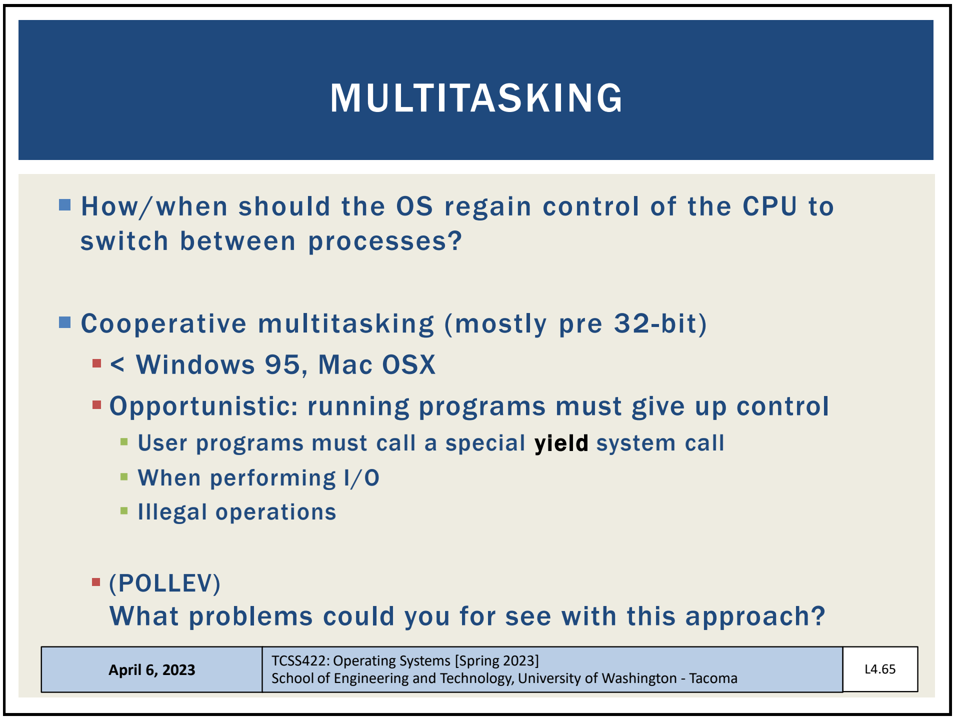

MULTITASKING

- How/when should the OS regain control of the CPU to switch between processes?
- Cooperative multitasking (mostly pre 32-bit)
  - < Windows 95, Mac OSX
  - Opportunistic: running programs must give up control
    - User programs must call a special **yield** system call
    - When performing I/O
    - Illegal operations
  - (POLLEV)
    What problems could you for see with this approach?

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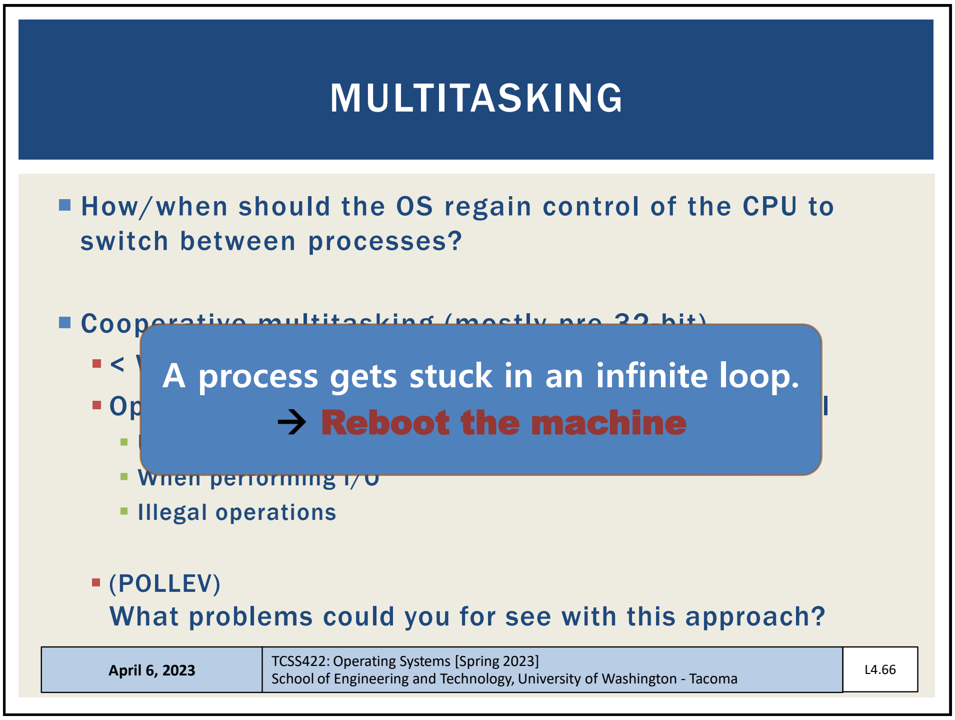

MULTITASKING

- How/when should the OS regain control of the CPU to switch between processes?
- Cooperative multitasking (mostly pre 32-bit)
  - < V
  - Op l
    - When performing I/O
    - Illegal operations
  - (POLLEV)
    What problems could you for see with this approach?

A process gets stuck in an infinite loop.
→ **Reboot the machine**

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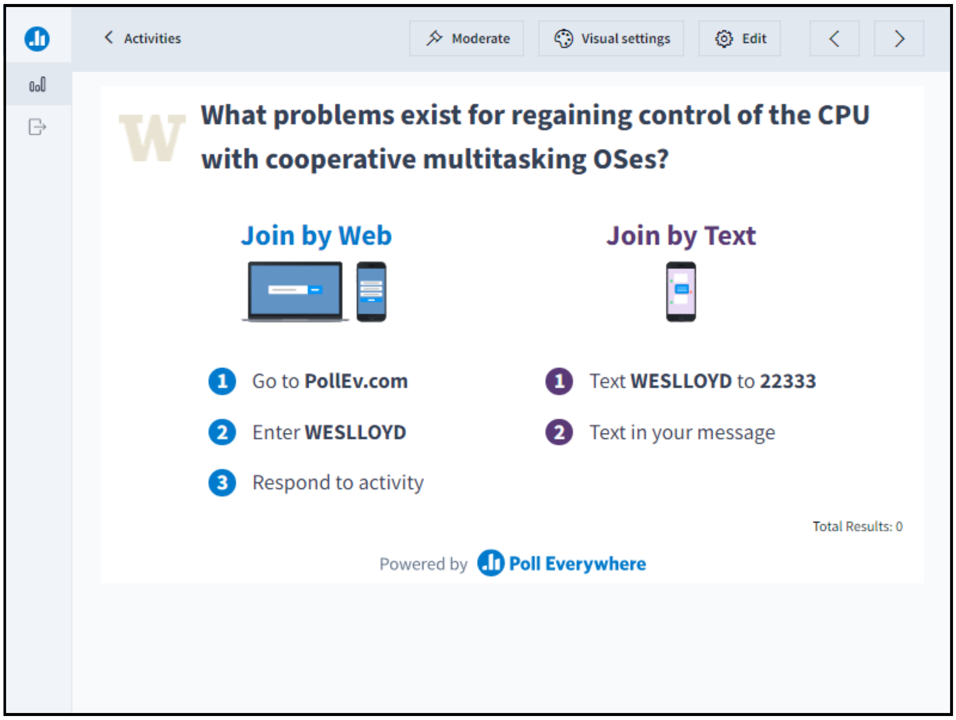

What problems exist for regaining control of the CPU with cooperative multitasking OSes?

Join by Web

1. Go to **PollEv.com**
2. Enter **WESLLOYD**
3. Respond to activity

Join by Text

1. Text **WESLLOYD** to **22333**
2. Text in your message

Total Results: 0

Powered by Poll Everywhere

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QUESTION: MULTITASKING

- What problems exist for regaining the control of the CPU with cooperative multitasking OSes?

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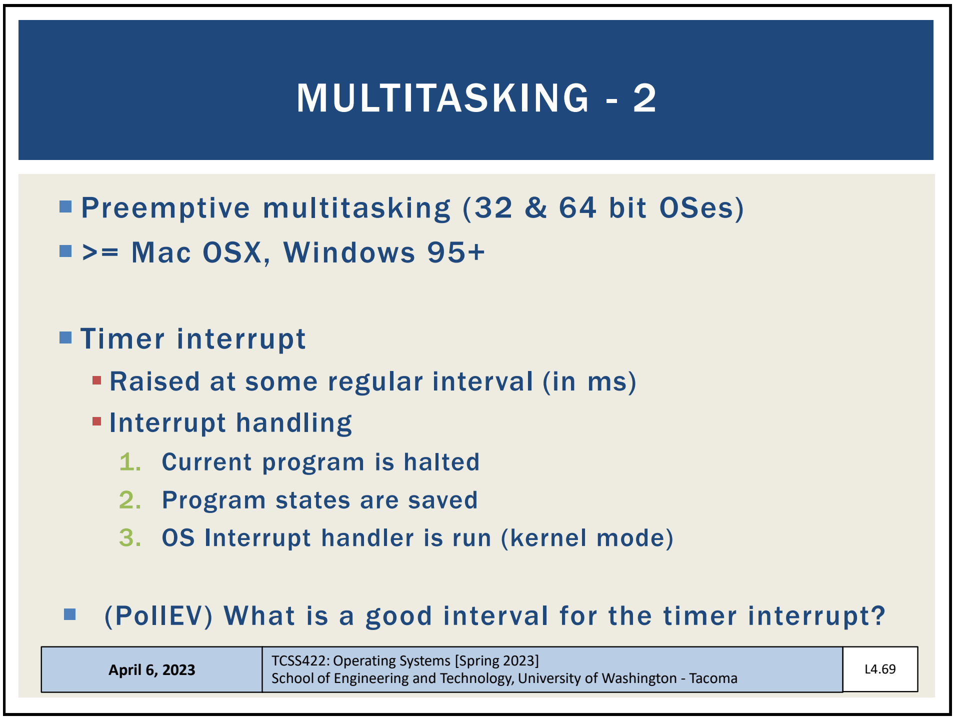

MULTITASKING - 2

- Preemptive multitasking (32 & 64 bit OSes)
- >= Mac OSX, Windows 95+

- Timer interrupt
  - Raised at some regular interval (in ms)
  - Interrupt handling
    1. Current program is halted
    2. Program states are saved
    3. OS Interrupt handler is run (kernel mode)

- (PollEV) What is a good interval for the timer interrupt?

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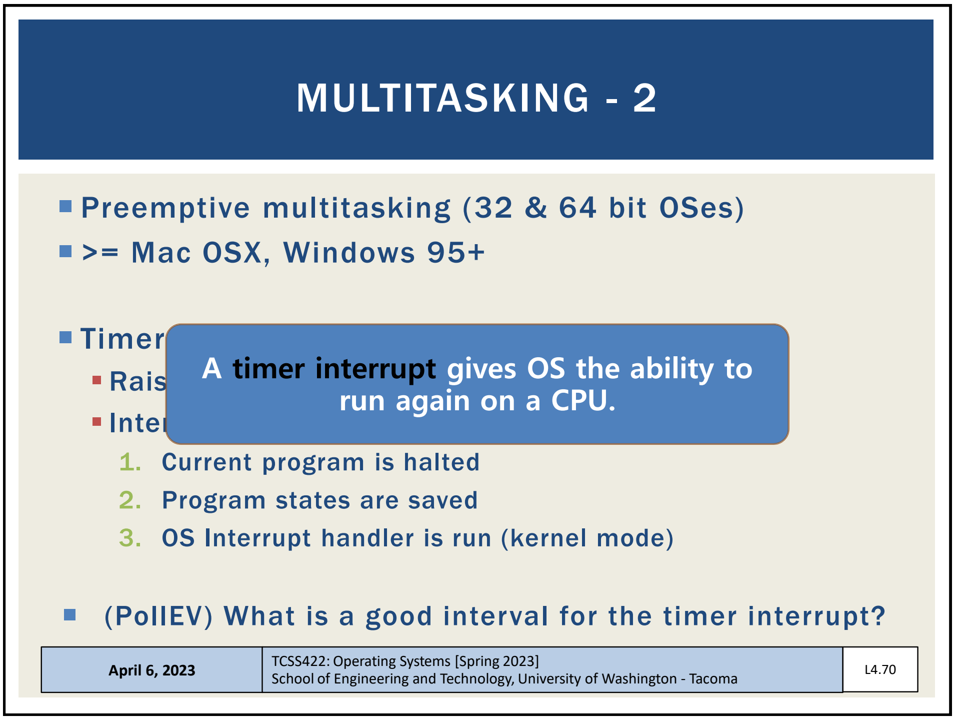

MULTITASKING - 2

- Preemptive multitasking (32 & 64 bit OSes)
- >= Mac OSX, Windows 95+

- Timer
  - Rais
  - Inte
    1. Current program is halted
    2. Program states are saved
    3. OS Interrupt handler is run (kernel mode)

A **timer interrupt** gives OS the ability to run again on a CPU.

- (PollEV) What is a good interval for the timer interrupt?

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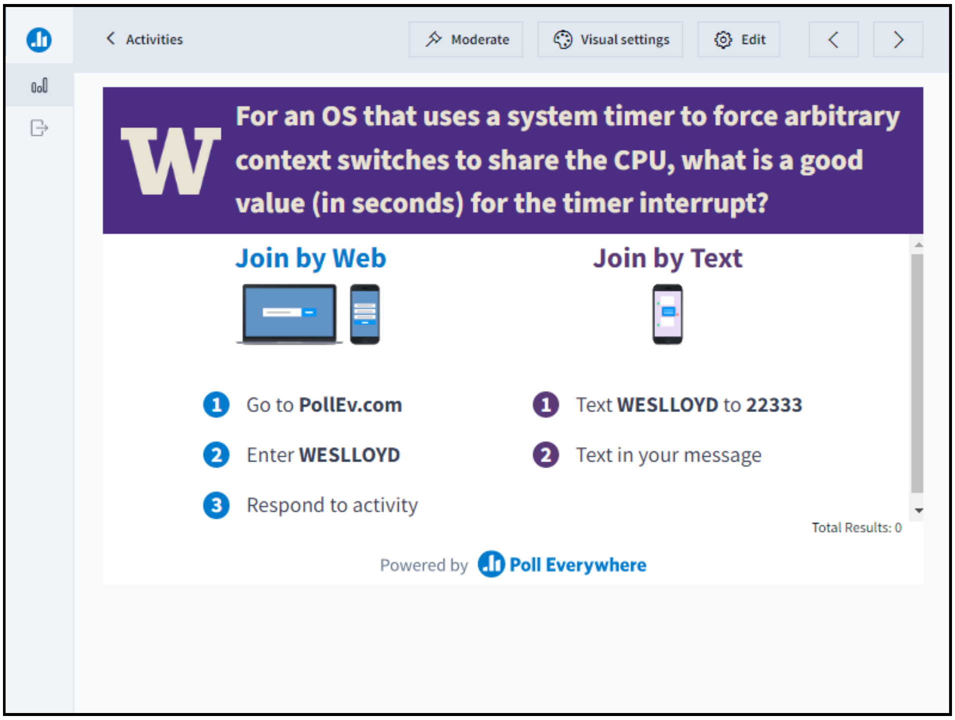

For an OS that uses a system timer to force arbitrary context switches to share the CPU, what is a good value (in seconds) for the timer interrupt?

Join by Web

1. Go to **PollEv.com**
2. Enter **WESLLOYD**
3. Respond to activity

Join by Text

1. Text **WESLLOYD** to **22333**
2. Text in your message

Total Results: 0

Powered by Poll Everywhere

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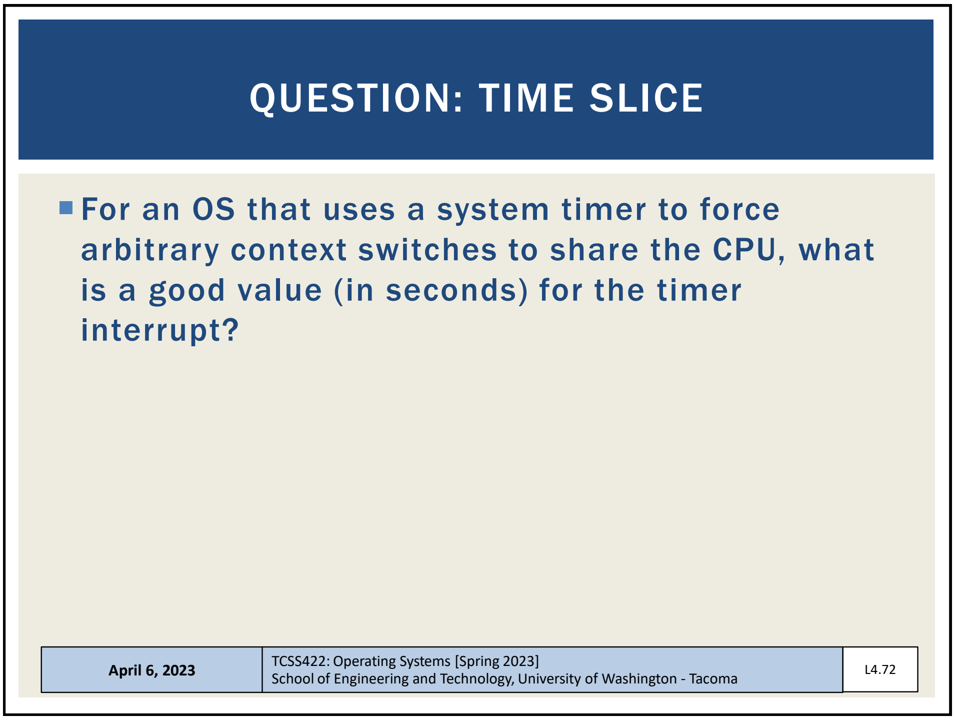

QUESTION: TIME SLICE

- For an OS that uses a system timer to force arbitrary context switches to share the CPU, what is a good value (in seconds) for the timer interrupt?

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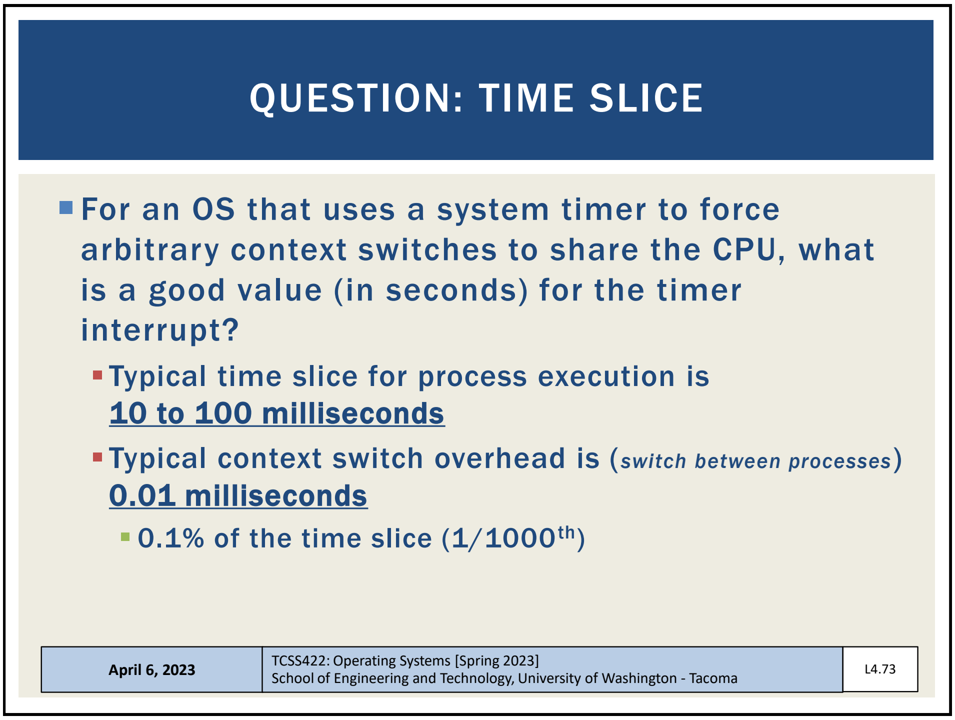

QUESTION: TIME SLICE

- For an OS that uses a system timer to force arbitrary context switches to share the CPU, what is a good value (in seconds) for the timer interrupt?
  - Typical time slice for process execution is **10 to 100 milliseconds**
  - Typical context switch overhead is (*switch between processes*) **0.01 milliseconds**
    - 0.1% of the time slice (1/1000th)

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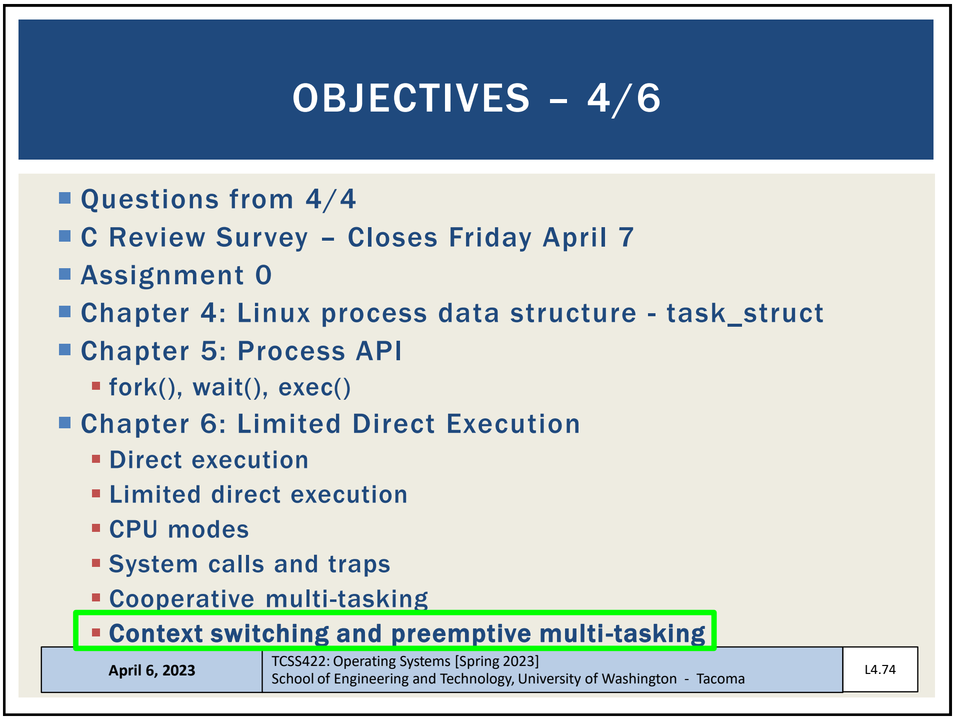

OBJECTIVES – 4/6

- Questions from 4/4
- C Review Survey – Closes Friday April 7
- Assignment 0
- Chapter 4: Linux process data structure - task_struct
- Chapter 5: Process API
  - fork(), wait(), exec()
- Chapter 6: Limited Direct Execution
  - Direct execution
  - Limited direct execution
  - CPU modes
  - System calls and traps
  - Cooperative multi-tasking
  - **Context switching and preemptive multi-tasking**

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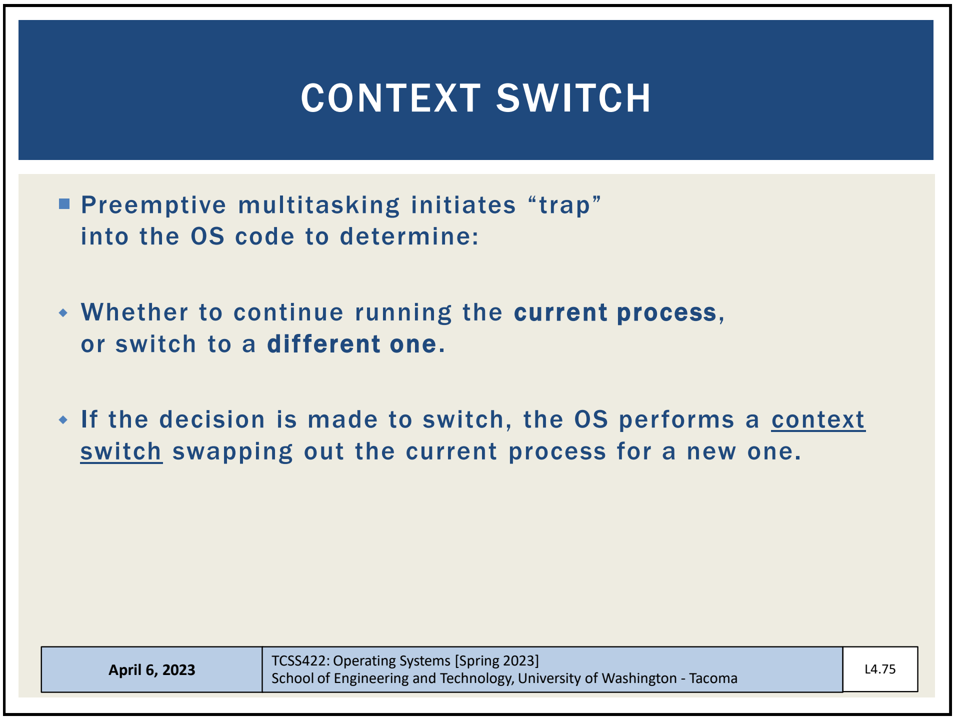
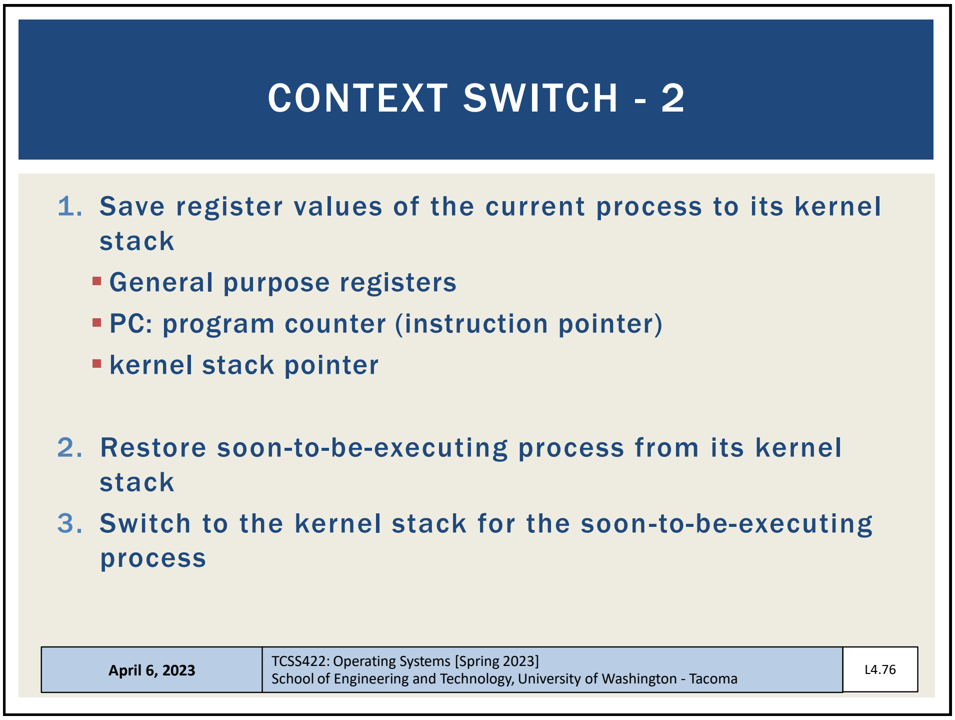


CONTEXT SWITCH

- Preemptive multitasking initiates "trap" into the OS code to determine:

- Whether to continue running the **current process**, or switch to a **different one**.

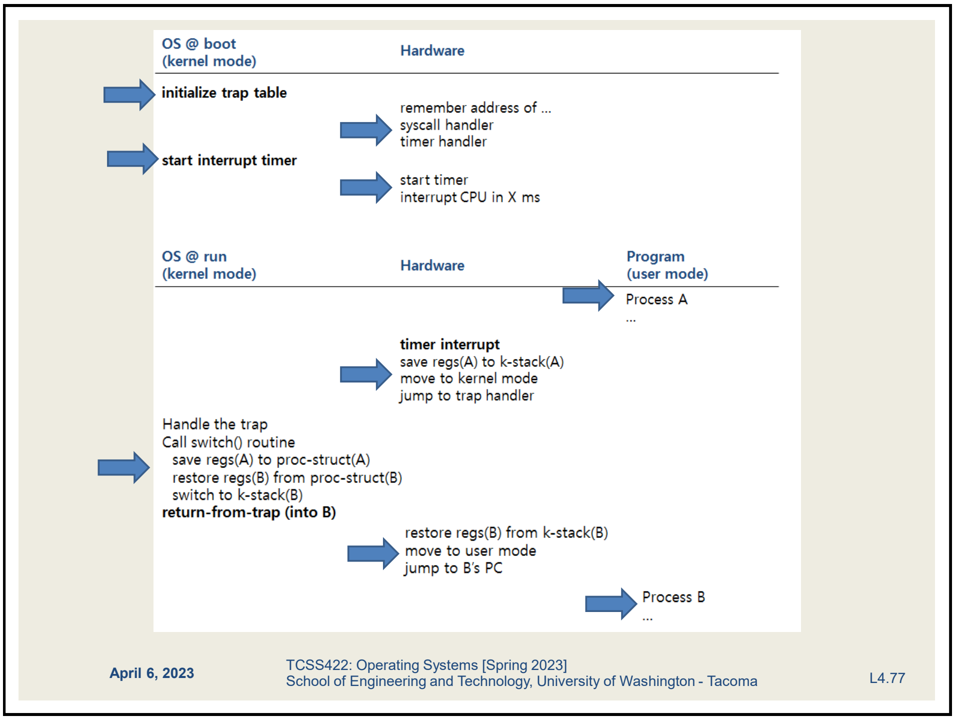
- If the decision is made to switch, the OS performs a context switch swapping out the current process for a new one.



CONTEXT SWITCH - 2

1. Save register values of the current process to its kernel stack
   - General purpose registers
   - PC: program counter (instruction pointer)
   - kernel stack pointer

2. Restore soon-to-be-executing process from its kernel stack
3. Switch to the kernel stack for the soon-to-be-executing process



OS @ boot (kernel mode)	Hardware	
initialize trap table		
	remember address 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 …

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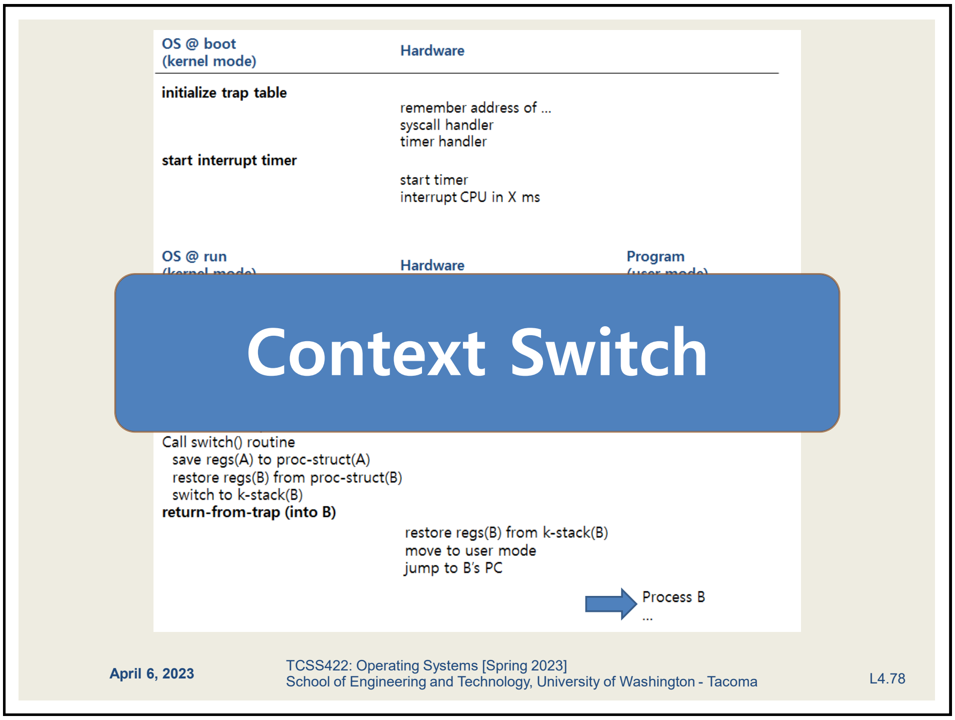

OS @ boot (kernel mode)	Hardware	
initialize trap table		
	remember address of … syscall handler timer handler	
start interrupt timer		
	start timer interrupt CPU in X ms	

OS @ run (kernel mode)	Hardware	Program (user mode)

Context Switch

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 …

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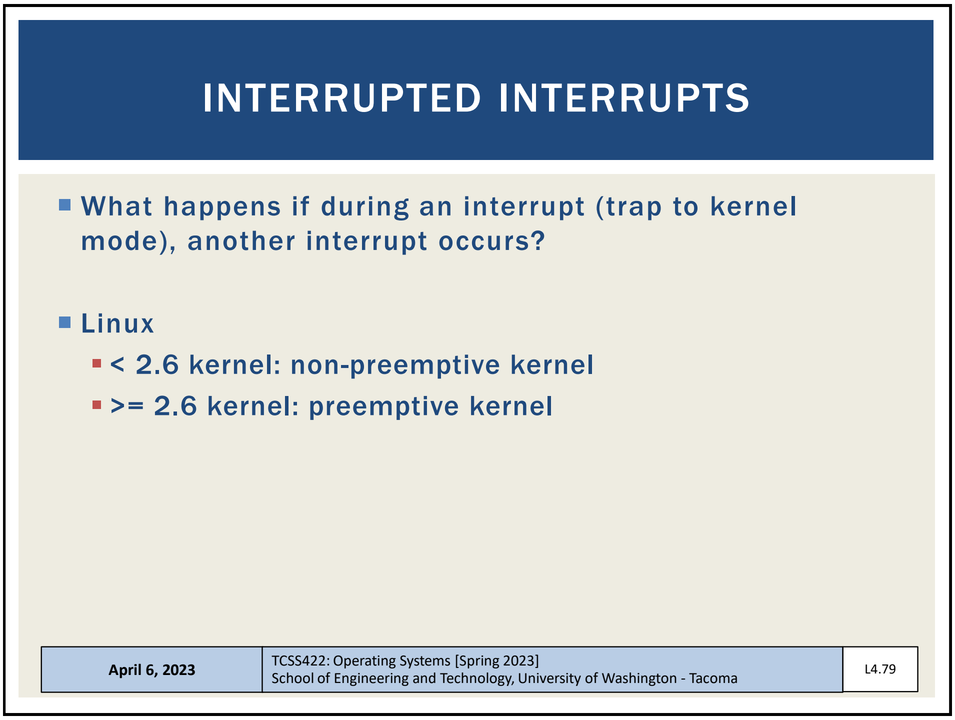

INTERRUPTED INTERRUPTS

- What happens if during an interrupt (trap to kernel mode), another interrupt occurs?
- Linux
  - < 2.6 kernel: non-preemptive kernel
  - >= 2.6 kernel: preemptive kernel

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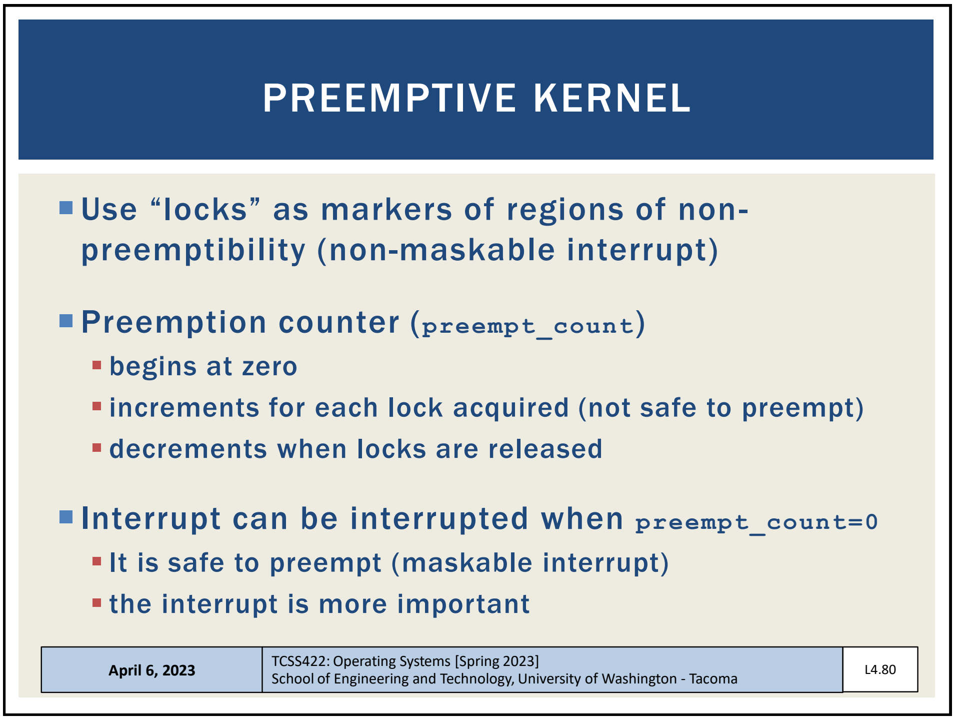

PREEMPTIVE KERNEL

- Use “locks” as markers of regions of non-preemptibility (non-maskable interrupt)
- Preemption counter (`preempt_count`)
  - begins at zero
  - increments for each lock acquired (not safe to preempt)
  - decrements when locks are released
- Interrupt can be interrupted when `preempt_count=0`
  - It is safe to preempt (maskable interrupt)
  - the interrupt is more important

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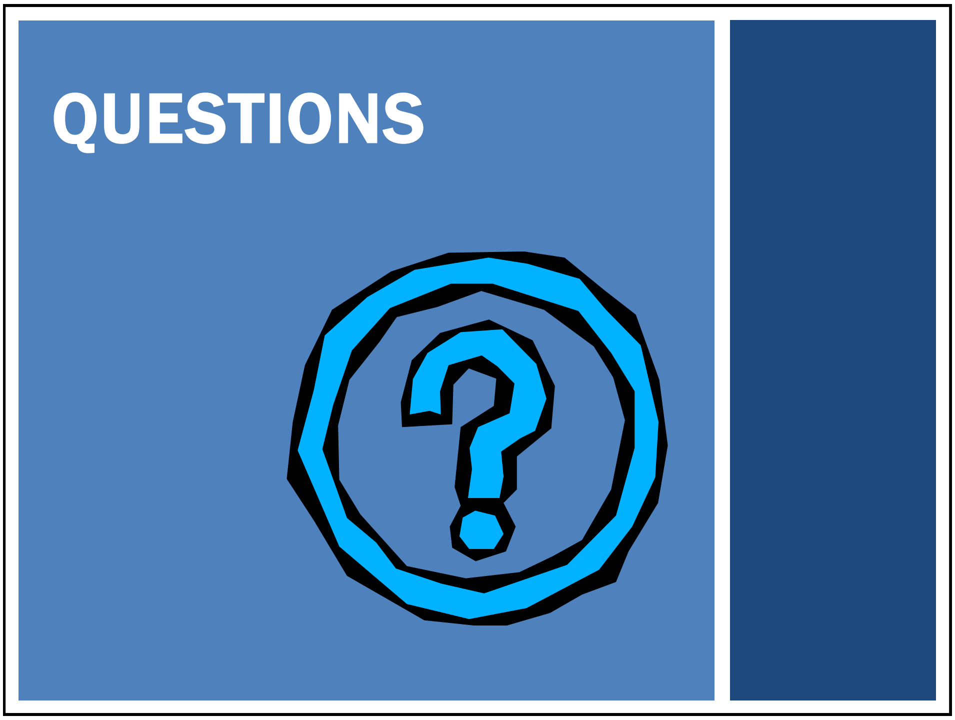

QUESTIONS