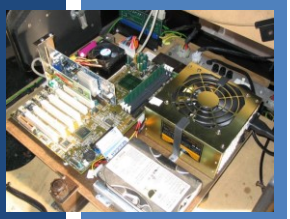
TCSS 422: OPERATING SYSTEMS



Processes & The Process API

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School of Engineering and Technology
University of Washington - Tacoma

1

OBJECTIVES – 4/2

- **Questions from 3/28**
- C Review Survey – Available thru Friday Apr 5
- Student Background Survey
- Virtual Machine Survey: VM requests sent to S. Miasishchev
- Assignment 0
- Chapter 4: Processes
  - Process states, context switches
  - Kernel data structures for processes and threads
- Chapter 5: Process API
  - fork(), wait(), exec()

2

VIRTUAL MACHINE SUPPORT ON APPLE M1

- Installing a Ubuntu Virtual Machine on Apple M1 MacBooks:
- FREE
- https://mac.getutm.app/
- MACs have switched to using ARM-based CPUs
  - Motivation: faster, less expensive than Intel-based CPUs

3

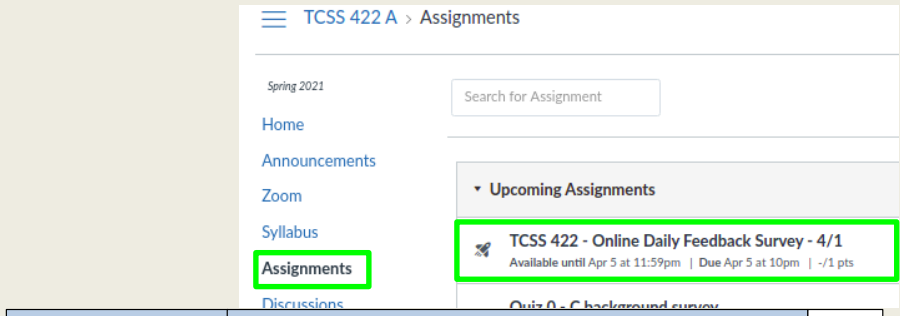
TEXT BOOK COUPON

- 15% off textbook code: **POETRY15** (*through Friday Apr 5*)
- https://www.lulu.com/shop/andrea-arpaci-dusseau-and-remzi-arpaci-dusseau/operating-systems-three-easy-pieces-hardcover-version-110/hardcover/product-15gjeeky.html?q=three+easy+pieces+operating+systems&page=1&pageSize=4
- With coupon textbook is only $33.79 + tax & shipping

4

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 @ 9p, closes 11:59p
- Thursday surveys: due ~ Mon @ 9p, closes 11:59p



5

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

6

MATERIAL / PACE

- Please classify your perspective on material covered in today's class (35 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- **Average – 6.49 (↑ - previous 5.44)**

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- **Average – 5.31 (↓ - previous 5.22)**

7

FEEDBACK FROM 3/28

- ***What are threads and processes from the perspective of a programmer?***
- - - - > when should a programmer use threads ?
  - - - > when should a programmer use processes ?

- ***How are concurrency and parallel programming related?***
  - **Concurrency** - two or more things (processes or threads) executing at the same time.
  - **Parallel programming** – writing code which splits a problem into smaller tasks that can be executed at the same time. Tasks will then be executed in parallel using multiple threads or processes

8

FEEDBACK - 2

- ***What will the quizzes and exams look like in this course? Will they be in-person or though Canvas?***
- Quizzes are primarily held as in-class group activities
  - Remote participants can interact via Zoom breakout rooms
- Exams are in-person, w/ a few pages of notes allowed and basic calculator

9

MOTIVATION FOR LINUX

- It is worth noting the importance of Linux for today's developers and computer scientists.
- The CLOUD runs many virtual machines, recently in 2019 a key milestone was reached.
- Even on Microsoft Azure (the Microsoft Cloud), there were more Linux Virtual Machines (> 50%) than Windows.
- https://www.zdnet.com/article/microsoft-developer-reveals-linux-is-now-more-used-on-azure-than-windows-server/
- https://www.zdnet.com/article/it-runs-on-the-cloud-and-the-cloud-runs-on-linux-any-questions/
- The majority of application back-ends (server-side), cloud or not, run on Linux.
- This is due to licensing costs, example:

10

MOTIVATION FOR LINUX - 2

- Consider an example where you're asked to develop a web services backend that requires 10 x 8-CPU-core virtual servers
- Your organization investigates hosting costs on Amazon cloud
- 8-core VM is "c5d.2xlarge"

Name	Instance type	Memory	vCPUs	Linux On Demand cost	Windows On Demand cost
C5 High-CPU Extra Large	c5d.xlarge	8.0 GiB	4 vCPUs	$0.192000 hourly	$0.376000 hourly
C5 High-CPU 18xlarge	c5d.18xlarge	144.0 GiB	72 vCPUs	$3.456000 hourly	$6.768000 hourly
C5 High-CPU Large	c5d.large	4.0 GiB	2 vCPUs	$0.096000 hourly	$0.188000 hourly
C5 High-CPU 24xlarge	c5d.24xlarge	192.0 GiB	96 vCPUs	$4.608000 hourly	$9.024000 hourly
C5 High-CPU Quadruple Extra Large	c5d.4xlarge	32.0 GiB	16 vCPUs	$0.768000 hourly	$1.504000 hourly
C5 High-CPU Metal	c5d.metal	192.0 GiB	96 vCPUs	$4.608000 hourly	$9.024000 hourly
C5 High-CPU Double Extra Large	c5d.2xlarge	16.0 GiB	8 vCPUs	$0.384000 hourly	$0.752000 hourly
C5 High-CPU 12xlarge	c5d.12xlarge	96.0 GiB	48 vCPUs	$2.304000 hourly	$4.512000 hourly
C5 High-CPU 9xlarge	c5d.9xlarge	72.0 GiB	36 vCPUs	$1.728000 hourly	$3.384000 hourly

- Windows hourly price 75.2¢
- Linux hourly price 38.4¢
- See: https://instances.vantage.sh/

11

MOTIVATION FOR LINUX - 2

One year cloud hosting cost:

WINDOWS
10 VMs x 8,760 hours x $.752 = $65,875.20

Linux
10 VMs x 8,760 hours x $.384 = $33,638.40

Windows comes at a 95.8% price premium

- See: https://www.ec2instances.info/

12

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13

C REVIEW SURVEY - AVAILABLE THRU 4/5

14

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15

STUDENT BACKGROUND SURVEY

- **39 of 43 Responses** as of 4/1 @ ~11pm
- Current Standings:
  - Best Office Hours times so far:
    - Rank #1: Tuesday after class (>5:40pm) √ **(53.1%)**
    - Rank #2: Thursday after class (>5:40p) **(50%)**
  - Best lecture format:
    - Rank #1: Hybrid synchronous w/ recordings √ **(89.2%)**
    - Rank #2: In-person w/ recordings **(40.5%)**

16

TCSS 422 – OFFICE HRS – SPRING 2024

- **Tuesdays after class until 7:00pm**
  Hybrid (In-person/Zoom)
  - This session will be in person in CP 229.
  - Zoom will be monitored when no student is in CP 229.
- Thursdays after class until 7:00pm – Hybrid (In-person/Zoom)
  - Additional office time will be held on Thursdays after class when there is high demand indicated by a busy Tuesday office hour
  - When Thursday Office Hours are planned, Zoom links will be shared via Canvas
  - Questions after class on Thursdays are always entertained even when the formal office hour is not scheduled

17

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18

VIRTUAL MACHINE SURVEY

- Please complete the Virtual Machine Survey to request a "School of Engineering and Technology" remote hosted Ubuntu VM
- https://forms.gle/V2sg4iW1awvhFx4W8
- VM requests have been sent to SET sys admin Slava Miasishchev for set up
- If you missed the survey, please reach out

19

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20

CHAPTER 2 SUMMARY : OPERATING SYSTEM DESIGN GOALS

- **ABSTRACTING THE HARDWARE**
  - Makes programming code easier to write
  - Automate sharing resources – save programmer burden
- **PROVIDE HIGH PERFORMANCE**
  - Minimize overhead from OS abstraction (Virtualization of CPU, RAM, I/O)
  - Share resources fairly
  - Attempt to tradeoff performance vs. fairness → consider priority
- **PROVIDE ISOLATION**
  - User programs can't interfere with each other's virtual machines, the underlying OS, or the sharing of resources

CHAPTER 2 SUMMARY : OPERATING SYSTEM DESIGN GOALS - 2

- **RELIABILITY**
  - OS must not crash, 24/7 Up-time
  - Poor user programs must not bring down the system:

    Blue Screen

- ***Other Issues:***
  - Energy-efficiency
  - Security (of data)
  - Cloud: Virtual Machines

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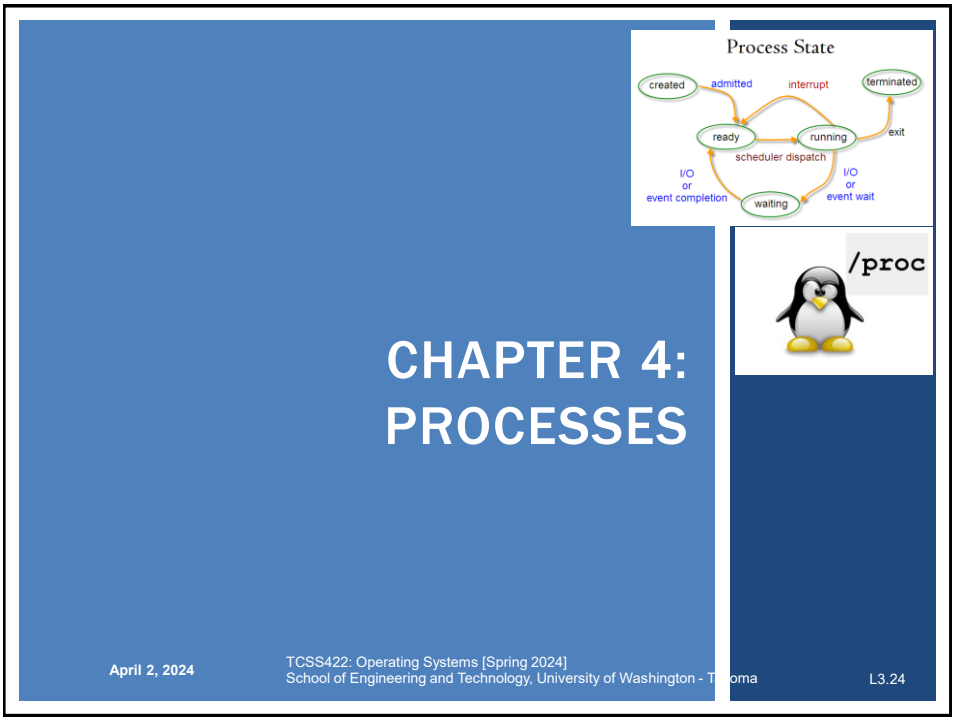
23



24

VIRTUALIZING THE CPU

- How should the CPU be shared?
- Time Sharing:
  Run one process, pause it, run another
- The act of swapping process A out of the CPU to run process B is called a:
  - **CONTEXT SWITCH**
- How do we SWAP processes in and out of the CPU efficiently?
  - Goal is to minimize **overhead** of the swap
- **OVERHEAD** is time spent performing OS management activities that don't help accomplish real work

25

PROCESS

A process is a running program.

- Process comprises of:
  - Memory
    - Instructions ("the code")
    - Data (heap)
  - Registers
    - PC: Program counter
    - Stack pointer

26

PROCESS API

- Modern OSes provide a Process API for process support
- Create
  - Create a new process
- Destroy
  - Terminate a process (ctrl-c)
- Wait
  - Wait for a process to complete/stop
- Miscellaneous Control
  - Suspend process (ctrl-z)
  - Resume process (fg, bg)
- Status
  - Obtain process statistics: (top)

27

PROCESS API: CREATE

1. Load program code (and static data) into memory
   - Program executable code (binary): loaded from disk
   - Static data: also loaded/created in address space
   - **Eager loading**: Load entire program before running
   - **Lazy loading**: Only load what is immediately needed
     - Modern OSes: Supports paging & swapping
2. Run-time stack creation
   - Stack: local variables, function params, return address(es)

28

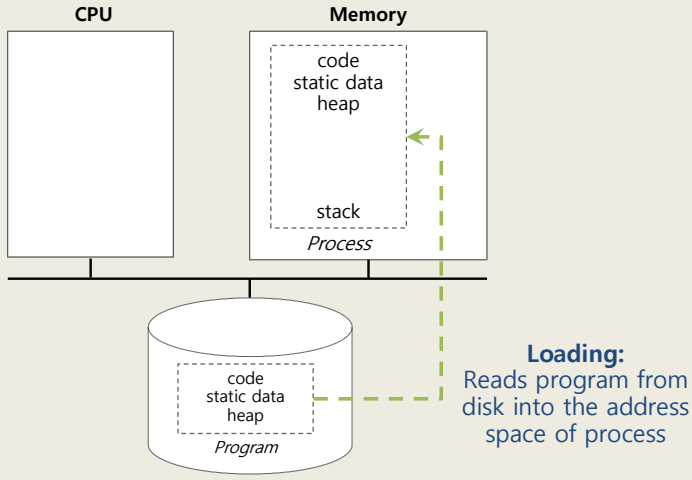
PROCESS API: CREATE

3. Create program's heap memory
   - For dynamically allocated data

4. Other initialization
   - I/O Setup
     - Each process has three open file descriptors: Standard Input, Standard Output, Standard Error

5. Start program running at the entry point: `main()`
   - OS transfers CPU control to the new process

29



30

WE WILL RETURN AT 4:50PM

31

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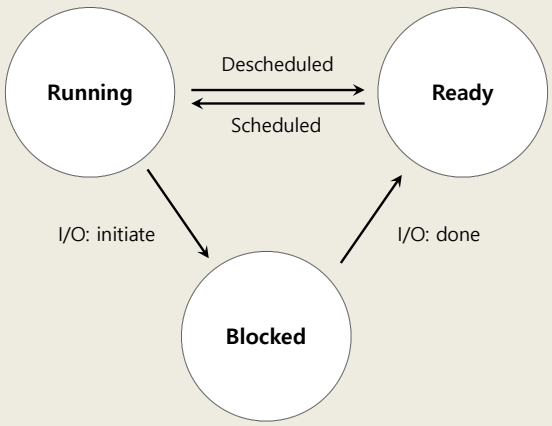
32

PROCESS STATES

- **RUNNING**
  - Currently executing instructions
- **READY**
  - Process is ready to run, but has been preempted
  - CPU is presently allocated for other tasks
- **BLOCKED**
  - Process is **not** ready to run. It is waiting for another event to complete:
    - Process has already been initialized and run for awhile
    - Is now waiting on I/O from disk(s) or other devices

33

PROCESS STATE TRANSITIONS



34

OBSERVING PROCESS META-DATA

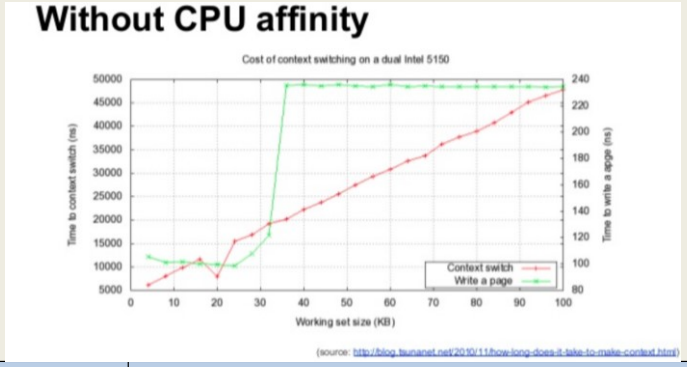
- Can inspect the number of **CONTEXT SWITCHES** made by a process
- Let's run mem.c (from chapter 2)
- cat /proc/{process-id}/status

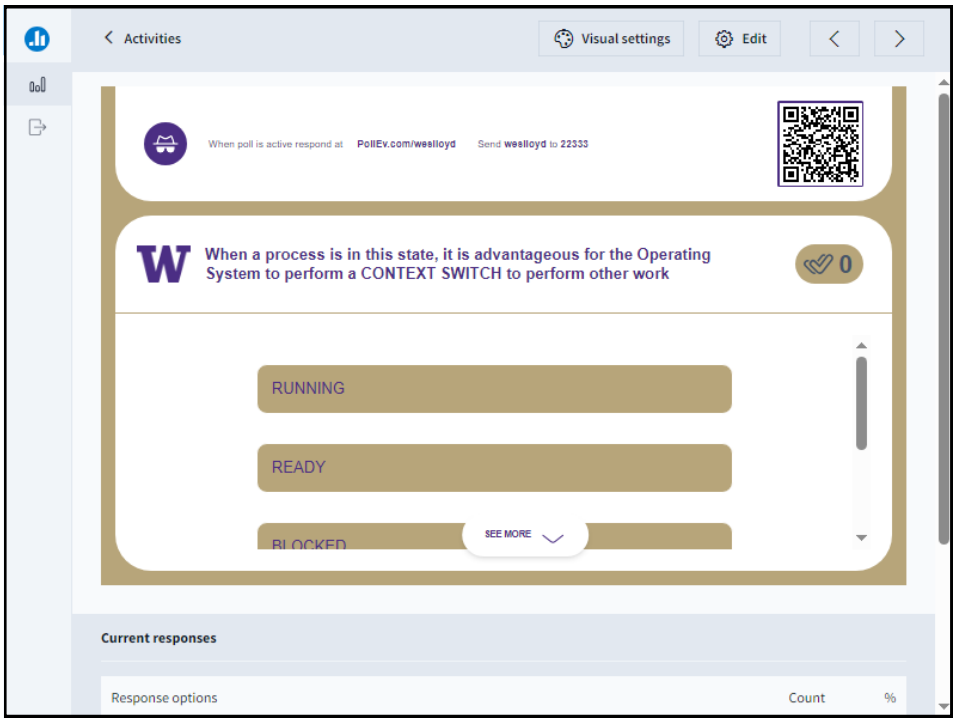
```
Speculation_Store_Bypass:       thread vulnerable
Cpus_allowed:   ff
Cpus_allowed_list:      0-7
Mems_allowed:   00000000,00000001
Mems_allowed_list:      0
voluntary_ctxt_switches:        1372
nonvoluntary_ctxt_switches:     18
wllo
```

- proc "status" is a virtual file generated by Linux
- Provides a report with process related meta-data
- **What appears to happen to the number of context switches the longer a process runs? (mem.c)**

CONTEXT SWITCH

- ***How long does a context switch take?***
- 10,000 to 50,000 ns (.01 to .05 ms)
- 2,000 context switches is near 100ms





37

QUESTION: WHEN TO CONTEXT SWITCH

- When a process is in this state, it is advantageous for the Operating System to perform a CONTEXT SWITCH to perform other work:

- (a) RUNNING
- (b) READY
- (c) BLOCKED
- (d) All of the above
- (e) None of the above

38

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39

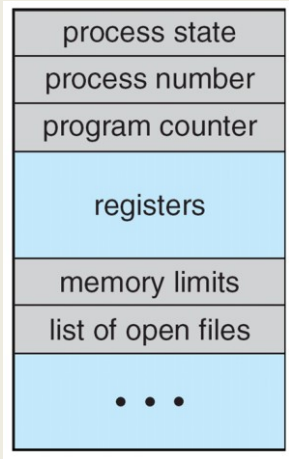
PROCESS DATA STRUCTURES

- OS provides data structures to track process information
  - Process list
    - Process Data
    - State of process: Ready, Blocked, Running
  - Register context
- PCB (Process Control Block)
  - A C-structure that contains information about each process

40

STRUCT TASK_STRUCT PROCESS CONTROL BLOCK

- Process Control Block (PCB)
- Key data regarding a process



41

XV6 KERNEL DATA STRUCTURES

- xv6: pedagogical implementation of Linux
- Simplified structures shown in book

```
// the registers xv6 will save and restore
// to stop and subsequently restart a process
struct context {
    int eip;    // Index pointer register
    int esp;    // Stack pointer register
    int ebx;    // Called the base register
    int ecx;    // Called the counter register
    int edx;    // Called the data register
    int esi;    // Source index register
    int edi;    // Destination index register
    int ebp;    // Stack base pointer register
};

// the different states a process can be in
enum proc_state { UNUSED, EMBRYO, SLEEPING,
                  RUNNABLE, RUNNING, ZOMBIE };
```


42

XV6 KERNEL DATA STRUCTURES - 2

```
// the information xv6 tracks about each process
// including its register context and state
struct proc {
    char *mem;                  // Start of process memory
    uint sz;                    // Size of process memory
    char *kstack;               // Bottom of kernel stack
                                // for this process
    enum proc_state state;      // Process state
    int pid;                    // Process ID
    struct proc *parent;        // Parent process
    void *chan;                 // If non-zero, sleeping on chan
    int killed;                 // If non-zero, have been killed
    struct file *ofile[NOFILE]; // Open files
    struct inode *cwd;          // Current directory
    struct context context;     // Switch here to run process
    struct trapframe *tf;       // Trap frame for the
                                // current interrupt
};
```


43

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: 721 - 1507**
    - Ubuntu kernel version 5.11, **LOC: 657 – 1394**
    - Ubuntu kernel version 4.4, **LOC: 1391 – 1852**

44

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 #943
- **Process State**
- `/* -1 unrunnable, 0 runnable, >0 stopped: */`
- `unsintgned long __state;` LOC #729
- **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 #778
  - `unsigned int time_slice;` LOC #567

45

STRUCT TASK_STRUCT - 2

- **Address space of the process:**
- "mm" is short for "memory map"
- `struct mm_struct *mm;` LOC #857
- **Parent process**, that launched this one
- `struct task_struct __rcu *parent;` LOC #960
- **Child processes** (as a list)
- `struct list_head children;` LOC #965
- **Open files**
- `struct files_struct *files;` LOC #1070

46

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

47

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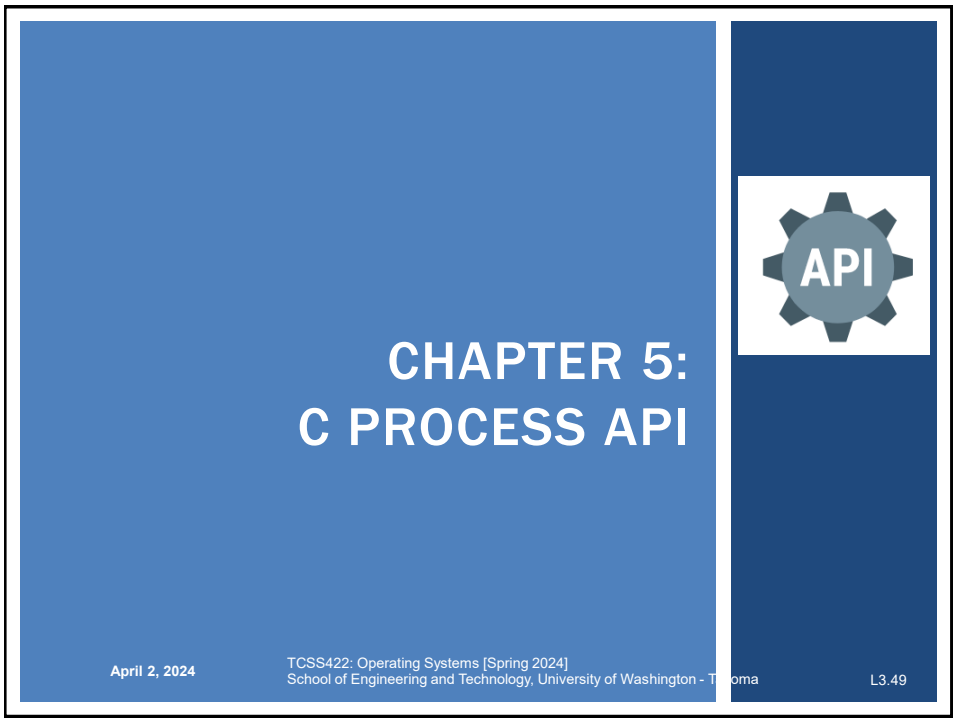
48



49

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50

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

51

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;
}
```


52

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>
```

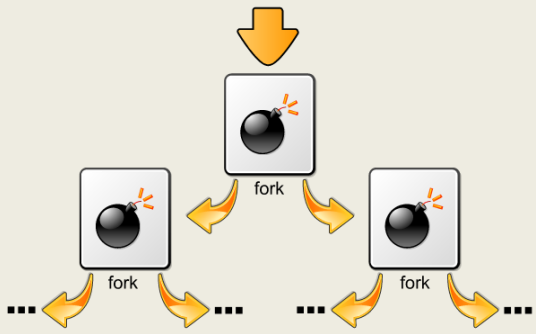
or

```
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

53

:(){ :|: & };:



54

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55

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

56

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;
}
```


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>
```

FORK EXAMPLE

- Linux example

59

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60

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)***

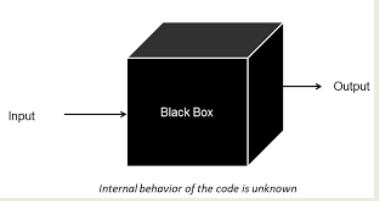
  Provide cmd and args as an Array of pointers to strings

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

61

EXEC() - 2

- Common use case:
- Write a new program which wraps a legacy one
- Provide a new interface to an old system: Web services
- Legacy program thought of as a "black box"
- We don't want to know what is inside…



62

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
        …
```


63

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>
```


64

EXEC WITH FILE REDIRECTION (OUTPUT)

```
#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);
        …
```


FILE MODE BITS

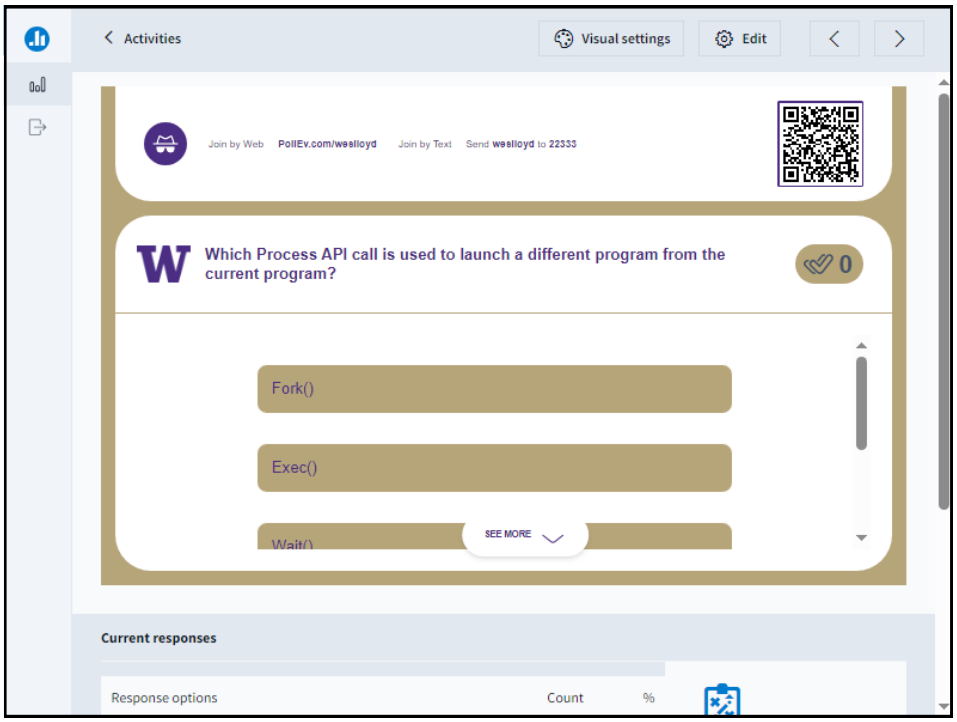
```
S_IRWXU
read, write, execute/search by owner
S_IRUSR
read permission, owner
S_IWUSR
write permission, owner
S_IXUSR
execute/search permission, owner
S_IRWXG
read, write, execute/search by group
S_IRGRP
read permission, group
S_IWGRP
write permission, group
S_IXGRP
execute/search permission, group
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>
```


67



68

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

69

QUESTIONS

70