TCSS 422: OPERATING SYSTEMS

INTRODUCTION TO OPERATING SYSTEMS, PROCESSES

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TCSS422: Operating Systems [Spring 2020]
School of Engineering and Technology, University of Washington - Tacoma

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CHAPTER 2: INTRODUCTION TO OPERATING SYSTEMS

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MATERIAL / PACE

- Please classify your perspective on material covered in today's class (52 respondents):
- 1-mostly review, 5-equal new/review, 10-mostly new
- <u>Average – 5.83 (-)</u>

- Please rate the pace of today's class:
- 1-slow, 5-just right, 10-fast
- <u>Average – 5.17 (-)</u>

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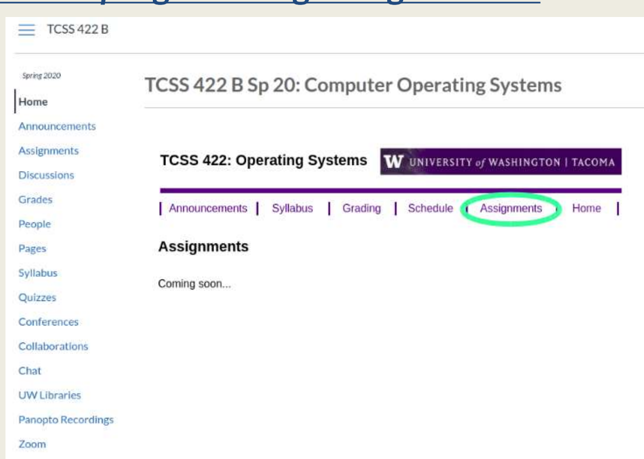
FEEDBACK FROM 3/31

- ***<u>What are the actual programming Assignments?</u>***
- In Canvas… →



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FEEDBACK - 2

- *I am not sure if I could just use VSCode to develop the program since I prefer it over VM?*
- How to install VSCode on Ubuntu 18.04: https://linuxize.com/post/how-to-install-visual-studio-code-on-ubuntu-18-04/

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FEEDBACK - 3

- *How to invoke concurrency through the use of PIDs?*
- In Linux, concurrency (*multiple things happening at the same time*) is implementing using either PROCESSES or THREADS
- When we create a new PROCESS or THREAD Linux assigns a Process ID (PID) as a unique identifier
- Linux then creates data records that capture lots of state information regarding PROCESSES and THREADS that are indexed by the PID
- This data is exposed using "virtual files" that are generated on-the-fly by Linux which can be found under a directory on the filesystem, (one for each PID) here → "/proc/{pid}/
  - `cd /proc/1`
  - `ls`

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WORKING WITH PROCESSES IN LINUX

- CTRL-C - CANCEL/EXIT a process
- CTRL-Z - SUSPEND/PAUSE process, return to command prompt
- `bg` – SEND paused process to background and RESUME
  - Disconnects the standard input (keyboard)
  - Standard output still written to console
- `fg` – BRINGS top most process from jobs list to foreground
  - Reconnects the standard input (keyboard)
- `jobs` – shows list of suspended/backgrounded jobs
- `jobs -p` – shows PID of suspended/backgrounded jobs
- `top` – "task manager" like User Interface that shows PIDs
- `htop` – another "task manager" alternative
- `ps`– command to inspect processes in Linux

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COURSE BACKGROUND SURVEY

- Please complete the Course Background Survey:

  Computer science, demographics, employment, goals, covid-19, etc.

- https://forms.gle/MucS87eDQSs4B3328

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"QUIZ" 0 – C PROGRAMMING BACKGROUND SURVEY

- Available via Canvas System
- Under:
  Assignments → Tutorials/Quizzes/In-class Activities
- Please disregard grade assigned by Canvas
- All submissions will receive 10 pts after assignment closes

VIRTUAL MACHINE SURVEY

- Please complete the Virtual Machine Survey to request a "School of Engineering and Technology" remotely hosted Ubuntu VM
- Requires log-in to UW Google for verification:
- https://forms.gle/R8N4HTjx6qKf1VJ88

Have you previously used Oracle Virtual Box to create a Virtual Machine?

Yes

no

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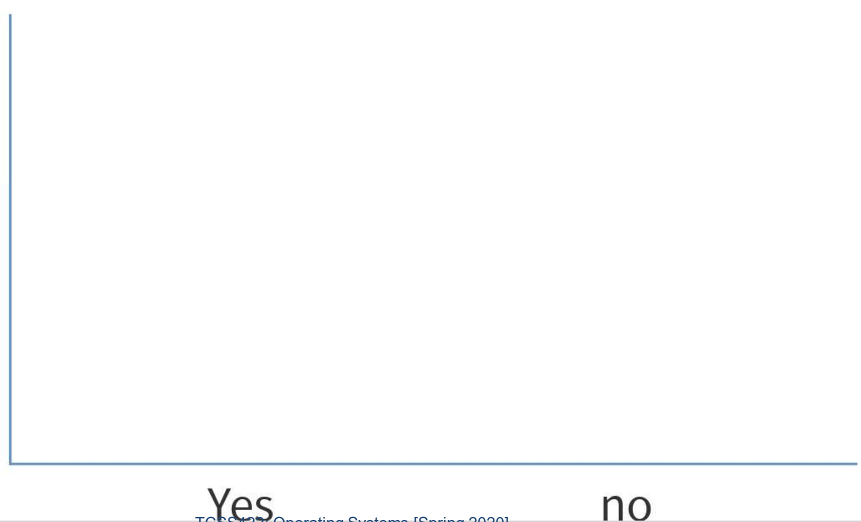
Have you previously used Oracle Virtual Box to create a Virtual Machine?



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Have you previously used Oracle Virtual Box to create a Virtual Machine?

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OBJECTIVES – 4/2

- Chapter 2: Operating Systems – Three Easy Pieces
  - Introduction to operating systems
  - Management of resources
  - Concepts of virtualization/abstraction
  - THREE EASY PIECES:
    - Virtualizing the CPU
    - Virtualizing Memory
    - Virtualizing I/O
  - Operating system design goals
- Chapter 4: Processes
  - Process states, context switches
  - Kernel data structures for processes and threads

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RESOURCE MANAGEMENT

- The OS is a resource manager
- Manages CPU, disk, network I/O
- Enables many programs to
  - **Share** the CPU
  - **Share** the underlying physical memory (RAM)
  - **Share** physical devices
    - Disks
    - Network Devices
    - …

VIRTUALIZATION

- Operating systems present **physical resources** as **virtual representations** to the programs sharing them
    - Physical resources: CPU, disk, memory, …
  - The virtual form is "**abstract**"
  - The OS presents an illusion that each user program runs in isolation on its own hardware
  - This virtual form is general, powerful, and easy-to-use

ABSTRACTIONS

- What form of abstraction does the OS provide?
  - CPU
    - Processes and threads
  - Memory
    - Address space
    - → large array of bytes
    - All programs see the same "size" of RAM
  - Disk
    - Files, file systems

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ABSTRACTION CHALLENGES

- What level of abstraction?
  - How much of the underlying hardware should be exposed?
    - What if **too much**?
    - What if **too little**?
- What are the correct abstractions?
  - Security concerns

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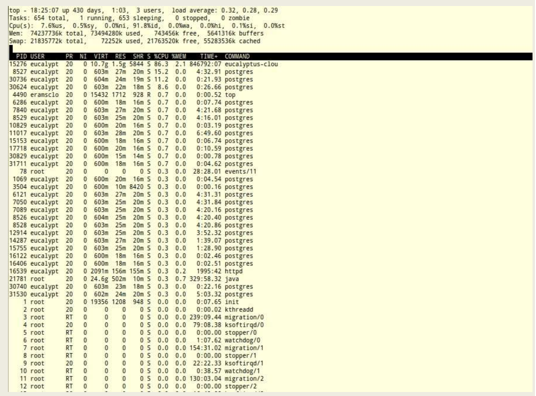
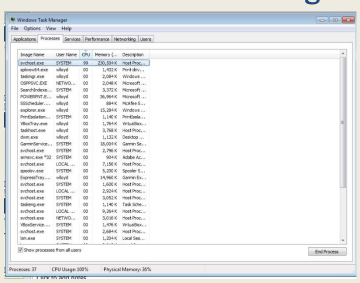
VIRTUALIZING THE CPU

- Each running program gets its own “virtual” representation of the CPU
- Many programs seem to run at once
- Linux: “top” command shows process list
- Windows: task manager





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VIRTUALIZING THE CPU - 2

- Simple Looping C Program

```
#include <stdio.h>
#include <stdlib.h>
#include <sys/time.h>
#include <assert.h>
#include "common.h"

int
main(int argc, char *argv[])
{
        if (argc != 2) {
                fprintf(stderr, "usage: cpu <string>\n");
                exit(1);
        }
        char *str = argv[1];
        while (1) {
                Spin(1); // Repeatedly checks the time and
                returns once it has run for a second
                printf("%s\n", str);
        }
        return 0;
}
```


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VIRTUALIZING THE CPU - 3

```
prompt> gcc -o cpu cpu.c -Wall
prompt> ./cpu "A"
A
A
A
ˆC
prompt>
```

- **Runs forever, must Ctrl-C to halt…**

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VIRTUALIZATION THE CPU - 4

```
prompt> ./cpu A & ; ./cpu B & ; ./cpu C & ; ./cpu D &
[1] 7353
[2] 7354
[3] 7355
[4] 7356
A
B
D
C
A
B
D
C
A
C
B
D
...
```

Even though we have only one processor, all four instances of our program seem to be running at the same time!

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VIRTUALIZING MEMORY

- Computer memory is treated as a large array of bytes
- Programs store all data in this large array

  - Read memory (load)
  - Specify an address to read data from

  - Write memory (store)
  - Specify data to write to an address

VIRTUALIZING MEMORY - 2

- Program to read/write memory (mem.c):

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

int
main(int argc, char *argv[])
{
        int *p = malloc(sizeof(int));  // a1: allocate some memory
        assert(p != NULL);
        printf("(%d) address of p: %08x\n",
                getpid(), (unsigned) p);  // a2: print out the address of the memmory
        *p = 0;  // a3: put zero into the first slot of the memory
        while (1) {
                Spin(1);
                *p = *p + 1;
                printf("(%d) p: %d\n", getpid(), *p); // a4
        }
        return 0;
}
```

VIRTUALIZING MEMORY - 3

- Output of mem.c

```
prompt> ./mem
(2134) memory address of p: 00200000
(2134) p: 1
(2134) p: 2
(2134) p: 3
(2134) p: 4
(2134) p: 5
^C
```

- int value stored at virtual memory address: 00200000
- program increments int value

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VIRTUALIZING MEMORY - 4

- Multiple instances of mem.c

```
prompt> ./mem &; ./mem &
[1] 24113
[2] 24114
(24113) memory address of p: 00200000
(24114) memory address of p: 00200000
(24113) p: 1
(24114) p: 1
(24114) p: 2
(24113) p: 2
(24113) p: 3
(24114) p: 3
...
```

- THE BOOK IS WRONG – Linux has changed !!
- What could be wrong about having malloc() return the same virtual memory address for every program instance?

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VIRTUALIZING MEMORY - 5

- Multiple instances of mem.c

```
prompt> ./mem &; ./mem &
[1] 24113
[2] 24114
(24113) memory address of p: 00200000
(24114) memory address of p: 00200000
(24113) p: 1
(24114) p: 1
(24114) p: 2
(24113) p: 2
(24113) p: 3
(24114) p: 3
...
```

- **ORIGINALLY:** (int*)p receives the same memory location 00200000
- Why does modifying (int*)p in program #1 (PID=24113), not interfere with (int*)p in program #2 (PID=24114) ?
  - The OS has "virtualized" memory. Each program has it's own virtual address space

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INSPECTING THE VIRTUAL MEMORY MAP OF A PROCESS

- cat /proc/$$/maps
- $$ is the current process, can replace with an PID

```
wlloyd@dione:/$ cat proc/30492/maps
00400000-00401000 r-xp 00000000 fc:00 6611568                    /home/wlloyd/Dropbox/courses/tcss422/examples/mem
00600000-00601000 r--p 00000000 fc:00 6611568                    /home/wlloyd/Dropbox/courses/tcss422/examples/mem
00601000-00602000 rw-p 00001000 fc:00 6611568                    /home/wlloyd/Dropbox/courses/tcss422/examples/mem
02483000-024a4000 rw-p 00000000 00:00 0                          [heap]
7f2b4596c000-7f2b45b2c000 r-xp 00000000 fc:00 15730979           /lib/x86_64-linux-gnu/libc-2.23.so
7f2b45b2c000-7f2b45d2c000 ---p 001c0000 fc:00 15730979           /lib/x86_64-linux-gnu/libc-2.23.so
7f2b45d2c000-7f2b45d30000 r--p 001c0000 fc:00 15730979           /lib/x86_64-linux-gnu/libc-2.23.so
7f2b45d30000-7f2b45d32000 rw-p 001c4000 fc:00 15730979           /lib/x86_64-linux-gnu/libc-2.23.so
7f2b45d32000-7f2b45d36000 rw-p 00000000 00:00 0
7f2b45d36000-7f2b45d4e000 r-xp 00000000 fc:00 15730966           /lib/x86_64-linux-gnu/libpthread-2.23.so
7f2b45d4e000-7f2b45f4d000 ---p 00018000 fc:00 15730966           /lib/x86_64-linux-gnu/libpthread-2.23.so
7f2b45f4d000-7f2b45f4e000 r--p 00017000 fc:00 15730966           /lib/x86_64-linux-gnu/libpthread-2.23.so
7f2b45f4e000-7f2b45f4f000 rw-p 00018000 fc:00 15730966           /lib/x86_64-linux-gnu/libpthread-2.23.so
7f2b45f4f000-7f2b45f53000 rw-p 00000000 00:00 0
7f2b45f53000-7f2b45f79000 r-xp 00000000 fc:00 15730965           /lib/x86_64-linux-gnu/ld-2.23.so
7f2b4614f000-7f2b46153000 rw-p 00000000 00:00 0
7f2b46178000-7f2b46179000 r--p 00025000 fc:00 15730965           /lib/x86_64-linux-gnu/ld-2.23.so
7f2b46179000-7f2b4617a000 rw-p 00026000 fc:00 15730965           /lib/x86_64-linux-gnu/ld-2.23.so
7f2b4617a000-7f2b4617b000 rw-p 00000000 00:00 0
7ffc83735000-7ffc83756000 rw-p 00000000 00:00 0                  [stack]
7ffc837d2000-7ffc837d4000 r--p 00000000 00:00 0                  [vvar]
7ffc837d4000-7ffc837d6000 r-xp 00000000 00:00 0                  [vdso]
ffffffffff600000-ffffffffff601000 r-xp 00000000 00:00 0          [vsyscall]
```

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VIRTUAL MEMORY

- Key take-aways:
- Each process (program) has its own ***virtual address space***
- The OS maps virtual ***address spaces*** onto ***physical memory***
- A memory reference from one process can not affect the address space of others.
  - ***Isolation***
- Physical memory, a shared resource, is managed by the OS

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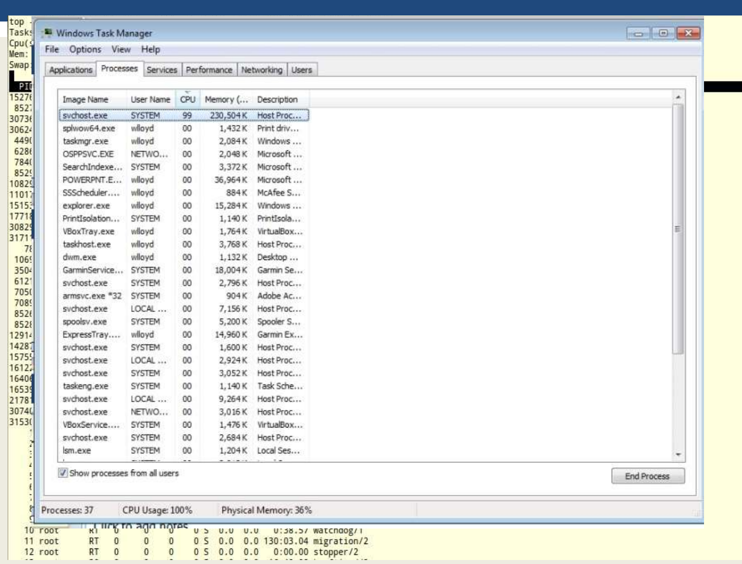
CONCURRENCY



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CONCURRENCY

- Linux: 654 tasks
- Windows: 37 processes

- The **OS** appears to run many programs at once, juggling them

- **Modern multi-threaded** programs feature concurrent threads and processes

- ***What is a key difference between a process and a thread?***

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CONCURRENCY - 2

```
#include <stdio.h>
#include <stdlib.h>
#include "common.h"

volatile int counter = 0;
int loops;

void *worker(void *arg) {
}
...
```

Not the same as Java volatile:
Provides a compiler hint than an object may change value unexpectedly (in this case by a separate thread) so aggressive optimization must be avoided.

thread.c listing continues …

Good article on Java volatile keyword:
(*hint–not enough to ensure correctness w/ concurrent threads in JAVA*)
http://tutorials.jenkov.com/java-concurrency/volatile.html

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CONCURRENCY - 3

```
int
main(int argc, char *argv[])
{
        if (argc != 2) {
                fprintf(stderr, "usage: threads <value>\n");
                exit(1);
        }
        loops = atoi(argv[1]);
        pthread_t p1, p2;
        printf("Initial value : %d\n", counter);

        Pthread_create(&p1, NULL, worker, NULL);
        Pthread_create(&p2, NULL, worker, NULL);
        Pthread_join(p1, NULL);
        Pthread_join(p2, NULL);
        printf("Final value : %d\n", counter);
        return 0;
}
```

- Program creates two threads
- Check documentation: "man pthread_create"
- worker() method counts from 0 to argv[1] (loop)

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Linux "man" page

example

```
PTHREAD_CREATE(3)        Linux Programmer's Manual        PTHREAD_CREATE(3)

NAME       top

       pthread_create - create a new thread

SYNOPSIS       top

       #include <pthread.h>

       int pthread_create(pthread_t *thread, const pthread_attr_t *attr,
                          void *(*start_routine) (void *), void *arg);

       Compile and link with -pthread.

DESCRIPTION       top

       The pthread_create() function starts a new thread in the calling
       process.  The new thread starts execution by invoking
       start_routine(); arg is passed as the sole argument of
       start_routine().

       The new thread terminates in one of the following ways:

       * It calls pthread_exit(3), specifying an exit status value that is
         available to another thread in the same process that calls
         pthread_join(3).

       * It returns from start_routine().  This is equivalent to calling
         pthread_exit(3) with the value supplied in the return statement.

       * It is canceled (see pthread_cancel(3)).

       * Any of the threads in the process calls exit(3), or the main thread
         performs a return from main().  This causes the termination of all
         threads in the process.

       The attr argument points to a pthread_attr_t structure whose contents
       are used at thread creation time to determine attributes for the new
       thread; this structure is initialized using pthread_attr_init(3) and
       related functions.  If attr is NULL, then the thread is created with
       default attributes.
```


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CONCURRENCY - 4

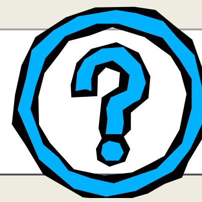
- Command line parameter argv[1] provides loop length
- Defines number of times the shared counter is incremented

- Loops: 1000

```
prompt> gcc -o thread thread.c -Wall -pthread
prompt> ./thread 1000
Initial value : 0
Final value : 2000
```

- Loops 100000

```
prompt> ./thread 100000
Initial value : 0
Final value : 143012 // huh??
prompt> ./thread 100000
Initial value : 0
Final value : 137298 // what the??
```



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CONCURRENCY - 5

- When loop value is large why do we not achieve 200000 ?

- C code is translated to (3) assembly code operations

1. Load counter variable into register
2. Increment it
3. Store the register value back in memory

- These instructions happen concurrently and VERY FAST
- (P1 || P2) write incremented register values back to memory, While (P1 || P2) read same memory
- Memory access here is **unsynchronized** (**non-atomic**)
- *Some of the increments are lost*

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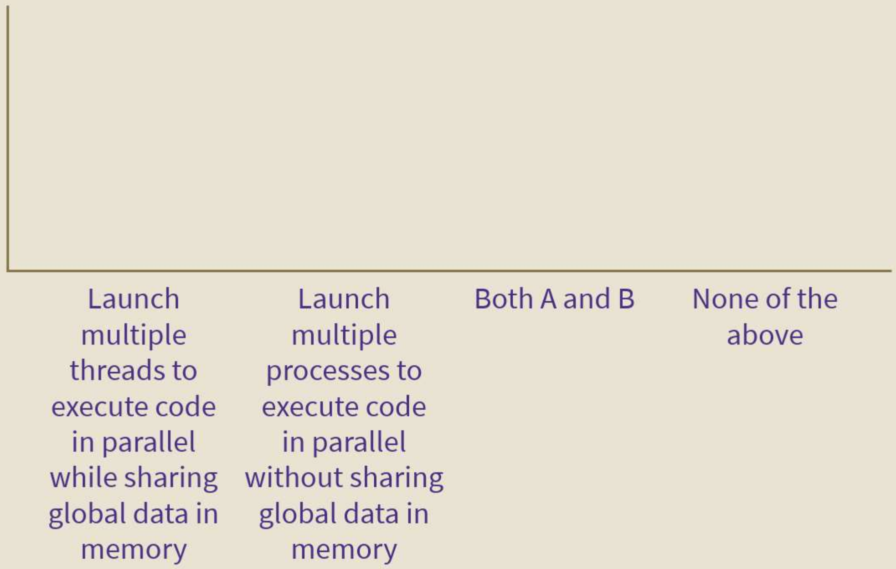
To perform parallel work, a single process may:



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PARALLEL PROGRAMMING

- To perform parallel work, a single process may:
- A. Launch multiple threads to execute code in parallel while sharing global data in memory
- B. Launch multiple processes to execute code in parallel without sharing global data in memory
- C. Both A and B
- D. None of the above

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PERSISTENCE

- DRAM: Dynamic Random Access Memory: DIMMs/SIMMs
  - Stores data while power is present
  - When power is lost, data is lost (*volatile*)
- Operating System helps "persist" data more **permanently**
  - I/O device(s): hard disk drive (HDD), solid state drive (SSD)
  - File system(s): "catalog" data for storage and retrieval

PERSISTENCE - 2

```
#include <stdio.h>
#include <unistd.h>
#include <assert.h>
#include <fcntl.h>
#include <sys/types.h>

int
main(int argc, char *argv[])
{
        int fd = open("/tmp/file", O_WRONLY | O_CREAT
                      | O_TRUNC, S_IRWXU);
        assert(fd > -1);
        int rc = write(fd, "hello world\n", 13);
        assert(rc == 13);
        close(fd);
        return 0;
}
```

- open(), write(), close(): OS system calls for device I/O
- Note: man page for open(), write() require page number: `"man 2 open"`, `"man 2 write"`, `"man close"`

PERSISTENCE - 3

- To write to disk, OS must:
  - Determine where on disk data should reside
  - Perform sys calls to perform I/O:
    - Read/write to file system (*inode record*)
    - Read/write data to file
- Provide fault tolerance for system crashes
  - Journaling: Record disk operations in a journal for replay
  - Copy-on-write - replicating shared data - *see ZFS*
  - Carefully order writes on disk

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

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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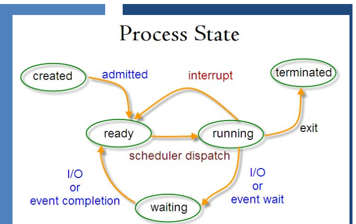

CHAPTER 4: PROCESSES

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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

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PROCESS

A process is a running program.

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

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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)

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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)

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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

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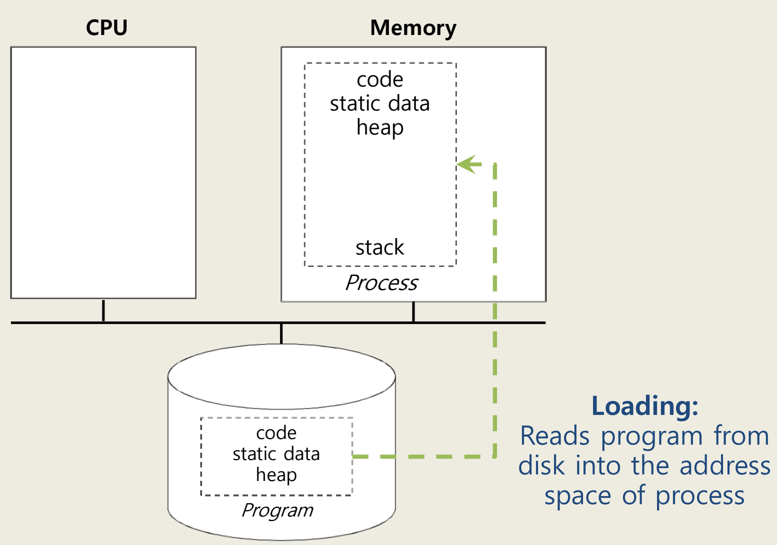

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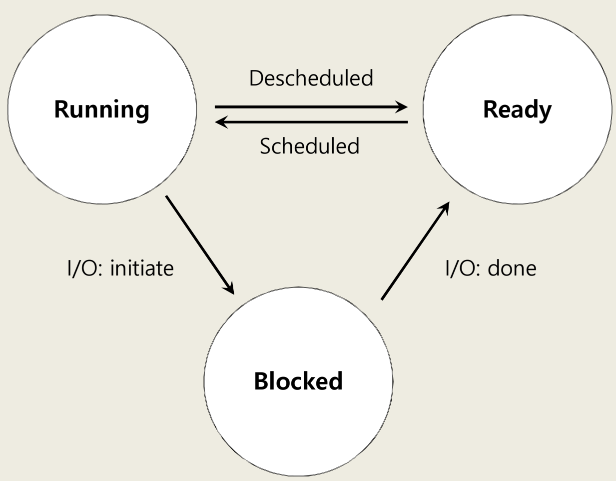
PROCESS STATES

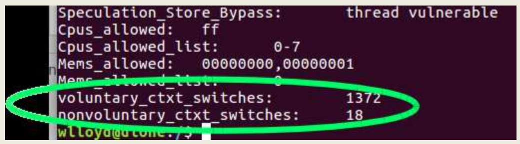
- **RUNNING**
  - Currently executing instructions
- **READY**
  - Process is ready to run, but has been preempted
  - CPU is presently allocated for other tasks
- **BLOCKED**
  - Process is not ready to run. It is waiting for another event to complete:
    - Process has already been initialized and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

PROCESS STATE TRANSITIONS



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



- 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)**

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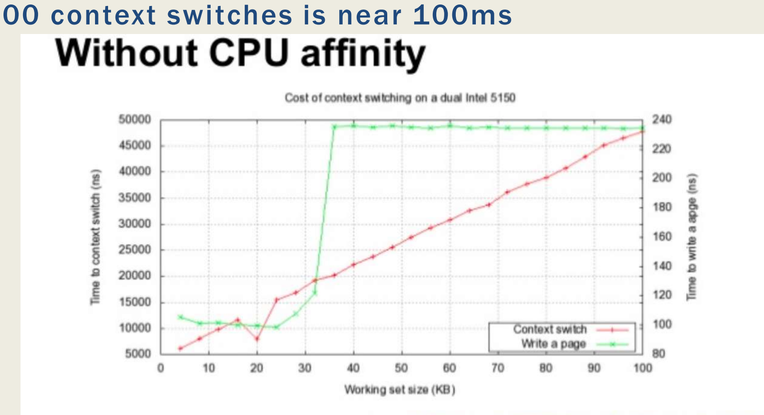
CONTEXT SWITCH

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



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

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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

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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

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XV6 KERNEL DATA STRUCTURES

- xv6: pedagogical implementation of Linux
- Simplified structures

```
// 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 };
```


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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
};
```


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LINUX: STRUCTURES

- **struct task_struct**, equivalent to struct proc
  - Provides process description
  - Large: 10,000+ bytes
  - /usr/src/linux-headers-{kernel version}/include/linux/sched.h
    - ~ LOC 1391 – 1852 (4.4.0-170)
      earlier was LOC 1227 – 1587
- **struct thread_info**, provides “context”
  - thread_info.h is at:
  /usr/src/linux-headers-{kernel version} /arch/x86/include/asm/

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LINUX: THREAD_INFO

```
struct thread_info {
        struct task_struct      *task;          /* main task structure */
        struct exec_domain      *exec_domain;   /* execution domain */
        __u32                   flags;          /* low level flags */
        __u32                   status;         /* thread synchronous flags */
        __u32                   cpu;            /* current CPU */
        int                     preempt_count;  /* 0 => preemptable,
                                                   <0 => BUG */
        mm_segment_t            addr_limit;
        struct restart_block    restart_block;
        void __user             *sysenter_return;
#ifdef CONFIG_X86_32
        unsigned long           previous_esp;   /* ESP of the previous stack in
                                                   case of nested (IRQ) stacks
                                                */
        __u8                    supervisor_stack[0];
#endif
        int                     uaccess_err;
};
```

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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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QUESTIONS

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WE WILL RETURN AT 2:40PM

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