TCSS 422: OPERATING SYSTEMS

INTRODUCTION

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TCSS 422 – Winter 2019

- ***Going green…***
  - 10% reduction of carbon footprint
- 18 class meetings
  - In contrast to usual 20
  - 2 Monday holidays: Jan 21, Feb 18
- Saves commuting time
  - Less fuel expenses
- Easier to achieve perfect attendance
- Final exam Monday March 18th

TCSS 422 WINTER 2019

OBJECTIVES

- Syllabus, Course Introduction
- C Review
- Demographics Survey
- Chapter 4: Operating Systems – Three Easy Pieces
  - Introduce operating systems
  - Management of resources
  - Concepts of virtualization/abstraction
  - CPU, Memory, I/O
  - Operating system design goals

TCSS422 – WINTER 2019 COMPUTER OPERATING SYSTEMS

- Syllabus
- Grading
- Schedule
- Assignments

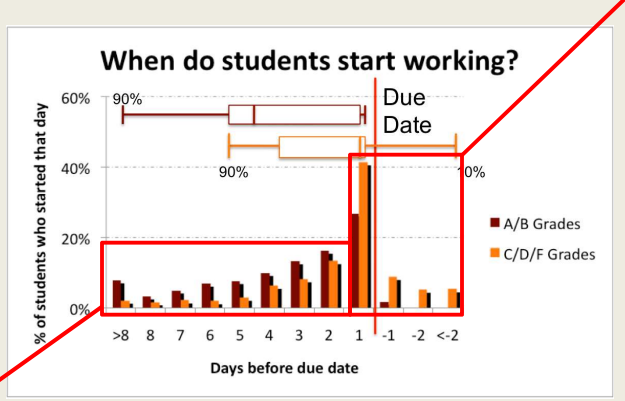
TCS422 COURSE WORK

- **Assignments**
  - Assignment 0: Linux /scripting
  - Assignments 1 – 3 *(4)*: roughly every two weeks
  - Submit ALL programming assignments via Canvas – no email
    - Email submissions are prone to be lost
- **Quizzes**
  - ~ 5-6 quizzes
  - Drop lowest two
  - Variety of formats: in class, online, reading, tutorial / activity
- **Exams: Midterm and Final**
  - Two pages of notes, calculator
  - Final exam is comprehensive, with emphasis on new material

TCSS 422: PROGRAM DUE DATES

- Programs - please start early:

Less than 50% chance of A/B



Better than 50% chance of A/B

From Virginia Tech Department of Computer Science - 2011

TCSS 422: PROGRAM DUE DATES

- **Programs - please start early**
  - Work as if deadline is several days earlier
  - Allows for a "buffer" for running into unexpected problems
    - Underestimation of the task at hand
    - Allows time to seek C help from SCI 106/108 lab mentors
    - If less familiar with C/pointers (TCSS 333), ***BUDGET MORE TIME***

UBUNTU 18.04 – VIRTUAL MACHINE

- Ubuntu 18.04
  - Open source version of Debian-package based Linux
  - Package management: "apt get" repositories
    - See: https://packages.ubuntu.com/
- Ubuntu Advantages
  - Enterprise Linux Distribution
  - Free, widely used by developers
  - Long term releases (LTS) every 2 years, good for servers
  - 6 month feature releases, good for sharing new features with the community

UBUNTU 18.04 – VIRTUAL MACHINE INSTALLATION

- Ubuntu 18.04 on Oracle VirtualBox
- HOW-TO installation videos:
- Windows 10
- https://www.youtube.com/watch?v=QbmRXJJKsvs
- Mac OS X (not specific to 18.04)
- https://www.youtube.com/watch?v=sNixOS6mHIU
- Guest Additions
  - Provides file system sharing, clipboard integration, mouse tricks
- https://www.youtube.com/watch?v=qNecdUsuTPw

C PROGRAMING IN TCSS 422

- Many OSes are coded primarily in C and Assembly Language
- Computerworld, 2017 Tech Forecast Survey

What legacy platforms do you still support and hire for?

None	65%
DB2	13%
C	10%
Cobol	9%
Assembly language	8%
Perl	5%
Delphi Object Pascal	3%
Fortran	3%
REXX	3%
Pascal	2%
Other	9%

C MENTORING

- https://www.tacoma.uw.edu/institute-technology/student-support-workshops-mentors
- School of Engineering and Technology Mentors
- Located in Science 106 / 108 Labs
- Monday – Thursday: ~9:30 am – 7:30 pm
- Friday: ~ 11-3pm
- Fall quarter hours to be posted

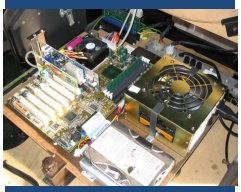
INSTRUCTOR HELP

- Office hours: to be announced - set by survey results
  - Also available by appointment
- End of class: good for quick questions, assignment Q&A
- It will be difficult to tutor ***all*** students individually on C
- Take ***ownership*** of your educational outcome
  - 10 weeks spent in TCSS 422 is very small relative to entire IT career
  - Make the most of this ***limited*** opportunity
    - Maximize your educational investment
  - *** Ask questions in class ***
  - Also questions after class, email, Canvas discussion boards
  - Seek help using UWT resources, the internet, YouTube videos (video.google.com) and online tutorials

CLASS PARTICIPATION

- **Questions and discussion are strongly encouraged**
  - Leverage your educational investment
  - All questions are encouraged! All are good!
  - This instructor does not mind repeat questions – better to be sure than sorry!
- **Daily feedback surveys**
  - How much is new vs. review?
  - Checking the pace…
  - What is unclear? It's helpful to know when topics are not clear
  - Use the survey to write questions and feedback that come to you during the lecture
- **Poll-EV**

C REVIEW

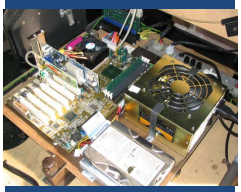


DEMOGRAPHICS SURVEY

SEE LINK AT:

http://faculty.washington.edu/wlloyd/courses/tcss422/announcements.html

INTRODUCTION TO OPERATING SYSTEMS



VIRTUAL MACHINE SURVEY

- Please complete the Virtual Machine Survey to request a "School of Engineering and Technology" remote hosted Ubuntu VM
- https://goo.gl/forms/SC8GzWAglUfHZ0g33

OBJECTIVES

- 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

OPERATING SYSTEMS

- Responsible for:
  - Making it easy to **run** programs
  - Allowing programs to **share** memory
  - Enabling programs to **interact** with devices

OS is in charge of making sure the system operates correctly and efficiently.

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
    - Process and/or thread
  - Memory
    - Address space
    - → large array of bytes
    - All programs see the same "size" of RAM
  - Disk
    - Files

WHY ABSTRACTION?

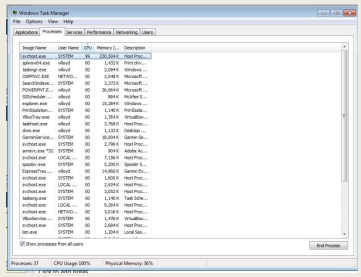
- Allow applications to reuse common facilities
- Make different devices look the same
  - Easier to write common code to use devices
    - Linux/Unix Block Devices
- Provide higher level abstractions
- More useful functionality

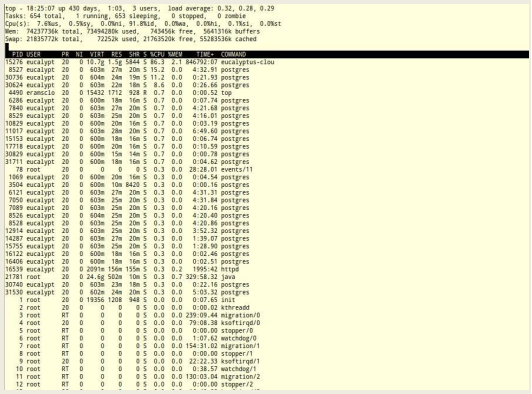
ABSTRACTION CHALLENGES

- 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

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





VIRTUALIZING THE CPU - 2

- Simple Looping C Program

```
1       #include <stdio.h>
2       #include <stdlib.h>
3       #include <sys/time.h>
4       #include <assert.h>
5       #include "common.h"
6
7       int
8       main(int argc, char *argv[])
9       {
10              if (argc != 2) {
11                      fprintf(stderr, "usage: cpu <string>\n");
12                      exit(1);
13              }
14              char *str = argv[1];
15              while (1) {
16                      Spin(1); // Repeatedly checks the time and
                        returns once it has run for a second
17                      printf("%s\n", str);
18              }
19              return 0;
20      }
```

VIRTUALIZING THE CPU - 3

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

- Runs forever, must Ctrl-C to halt…

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!

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:

```
1       #include <unistd.h>
2       #include <stdio.h>
3       #include <stdlib.h>
4       #include "common.h"
5
6       int
7       main(int argc, char *argv[])
8       {
9               int *p = malloc(sizeof(int));  // a1: allocate some
                                                  memory
10              assert(p != NULL);
11              printf("(%d) address of p: %08x\n",
12                      getpid(), (unsigned) p);  // a2: print out the
                                                     address of the memmory
13              *p = 0;  // a3: put zero into the first slot of the memory
14              while (1) {
15                      Spin(1);
16                      *p = *p + 1;
17                      printf("(%d) p: %d\n", getpid(), *p); // a4
18              }
19              return 0;
20      }
```

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 00200000
- program increments int value

VIRTUALIZING MEMORY - 4

- Multiple instances of mem.c

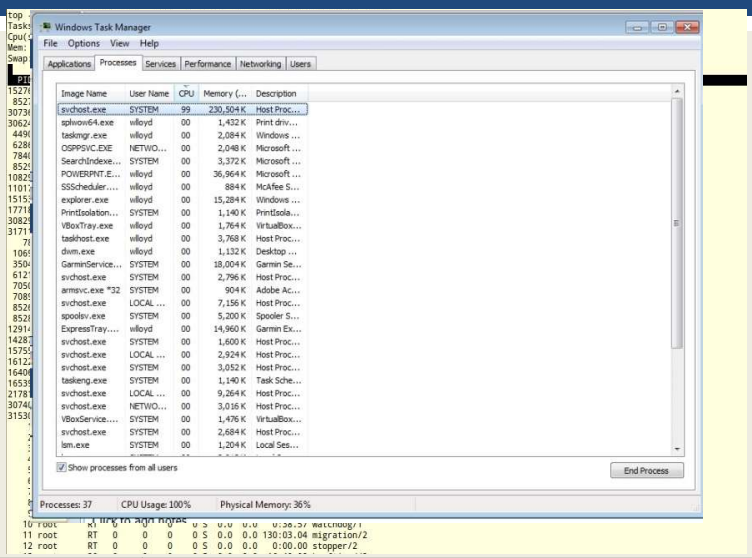
```
prompt> ./mem &; ./mem &
[1] 24113
[2] 24114
(24113) memory address of p: 00200000
(24114) memory address of p: 00200000
(24113) p: 1
(24114) p: 1
(24114) p: 2
(24113) p: 2
(24113) p: 3
(24114) p: 3
...
```

- (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, and provides a "virtual" address

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

CONCURRENCY



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?***

CONCURRENCY - 2

```
1       #include <stdio.h>
2       #include <stdlib.h>
3       #include "common.h"
4
5       volatile int counter = 0;
6       int loops;
7
8       void
9
10
11
12
13
14  }
15  ...
```

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 …

CONCURRENCY - 3

```
16      int
17      main(int argc, char *argv[])
18      {
19              if (argc != 2) {
20                      fprintf(stderr, "usage: threads <value>\n");
21                      exit(1);
22              }
23              loops = atoi(argv[1]);
24              pthread_t p1, p2;
25              printf("Initial value : %d\n", counter);
26
27              Pthread_create(&p1, NULL, worker, NULL);
28              Pthread_create(&p2, NULL, worker, NULL);
29              Pthread_join(p1, NULL);
30              Pthread_join(p2, NULL);
31              printf("Final value : %d\n", counter);
32              return 0;
33      }
```

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

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.

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

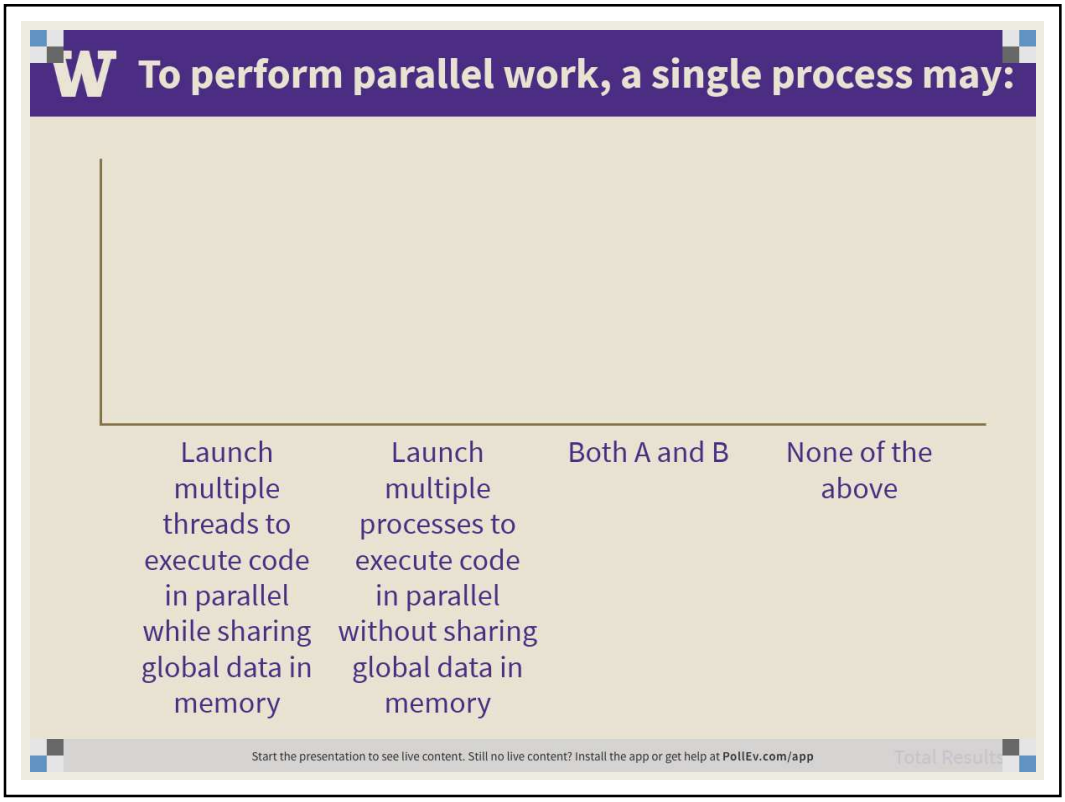
```
prompt> ./thread 100000
Initial value : 0
Final value : 143012 // huh??
prompt> ./thread 100000
Initial value : 0
Final value : 137298 // what the??
```

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*



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

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

```
1       #include <stdio.h>
2       #include <unistd.h>
3       #include <assert.h>
4       #include <fcntl.h>
5       #include <sys/types.h>
6
7       int
8       main(int argc, char *argv[])
9       {
10              int fd = open("/tmp/file", O_WRONLY | O_CREAT
                                | O_TRUNC, S_IRWXU);
11              assert(fd > -1);
12              int rc = write(fd, "hello world\n", 13);
13              assert(rc == 13);
14              close(fd);
15              return 0;
16      }
```

- 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

QUESTIONS