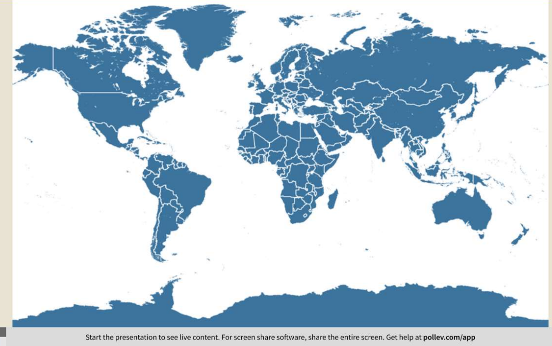
TCSS 422: OPERATING SYSTEMS

INTRODUCTION

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

Where are you joining us from? (WORLD VERSION)



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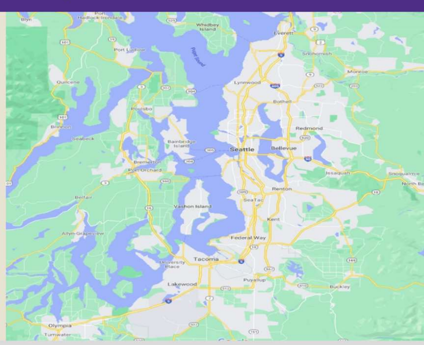
Where are you joining us from? (PUGET SOUND REGION)



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INTRODUCTIONS: What is your name? nickname / alias? and list one or more areas of interest in Computer Science:

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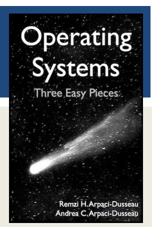
OBJECTIVES – 3/30



- **Syllabus, Course Introduction**

- C Review Survey
- Background Survey

- Chapter 4: Operating Systems – Three Easy Pieces
  - Introduction to operating systems
  - Management of resources
  - Concepts of virtualization/abstraction
  - Three Easy Pieces: CPU, Memory, I/O
  - Concurrency
  - Operating system design goals

TCSS 422 – Spring 2021

TCSS 422 SPRING 2021

- ***Online is green…***
  - **100%** reduction of carbon footprint from transit
- Saves commuting time
  - Less fuel expenses
- Easier to achieve perfect attendance – *all lectures streamed LIVE, recorded for 24/7 availability*
- 20 class meetings
  - 1 Monday holiday in Spring: May 31
- Final exam Thursday June 10th

SILVER LINING FOR ONLINE LEARNING

- ONLINE LEARNING: practice use of technology for remote collaborative work
- Professor conducted Masters thesis research at VA Tech on distributed remote work in early 2000s
- Computer Science is a unique field where you can work in a job entirely remotely from home or from any location
- Colleague from undergrad, Scott Teresi, MS in CS from Univ of Illinois – works for British company remotely for over a decade
  - Well paid!
  - Never physically met boss until company was recently bought
  - Before covid – now making occasional trips to the UK

RESOURCES FOR SPRING 2021

- **Low Cost or Free Technology Services from UW Tacoma:**
- https://www.tacoma.uw.edu/about-uw-tacoma/low-cost-or-free-technology-services
- **Resources for students during the Coronavirus pandemic:**
- https://www.tacoma.uw.edu/chancellor/resources-students-during-coronavirus-pandemic
  https://www.tacoma.uw.edu/uwt/it/it-resources-telework-and-attending-class-remotely
- **UW Tacoma Information Technology & Library Laptops for loan:**
- https://itconnect.uw.edu/work/working-remotely/technology-for-working-remotely/acquiring-computers-and-hardware-for-working-remotely/
- https://www.tacoma.uw.edu/learning-research-commons/laptops-available-checkout

RESOURCES - 2

- **Textbook coupon 10% off "WRITER10" until Friday at 11:59pm**
- http://www.lulu.com/shop/remzi-arpaci-dusseau-and-andrea-arpaci-dusseau/operating-systems-three-easy-pieces-softcover-version-100/paperback/product-23779877.html

TCSS422 – SPRING 2021 COMPUTER OPERATING SYSTEMS

- Syllabus
- Grading
- Schedule
- Assignments

See website at:
http://faculty.washington.edu/wlloyd/courses/tcss422

Enables access using mobile device w/o logging into Canvas

Website also integrated into Canvas

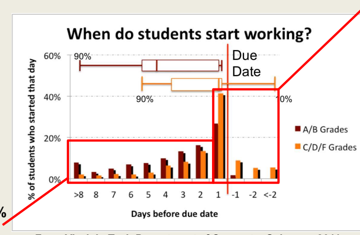
TCS422 COURSE WORK

- Assignments (45%)
  - 4 Assignments: roughly every two weeks
  - Submit ALL programming assignments via Canvas – no email
    - Email submissions are prone to be lost
- Tutorials/Quizzes/In-class activities (15%)
  - ~ 5-6 quizzes
  - Drop lowest two
  - Variety of formats: collaborative in class (*via Zoom breakout rooms*), online, reading, tutorial
- Exams: Midterm and Final (40%)
  - Online via the Canvas system
  - 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: PROGRAMS

- *Tentative - subject to change*
- **Assignment 0:**
  Introduction to Linux, Ubuntu Virtual Machine
- **Assignment 1:**
  Programming with multiple processes (in C)
- **Assignment 2:**
  Multithreaded programming and concurrency (C or Java)
- **Assignment 3:**
  Kernel (real) mode programming (in C)

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 CSS lab mentors (*checking on availability for Spring 2021)*
    - If less familiar with C/pointers (TCSS 333/380), ***BUDGET MORE TIME***

UBUNTU 20.04 – VIRTUAL MACHINE

- Ubuntu 20.04
  - 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 20.04 – VIRTUAL MACHINE INSTALLATION

- Ubuntu 20.04 on Oracle VirtualBox
- HOW-TO installation videos:
- Windows 10
- **https://youtu.be/x3Zpe1rIPFE**
- Mac OS X
- **https://youtu.be/Hzji7w882OY**
- > AFTER VirtualBox, INSTALL THE **Guest Additions**
  - IMPORTANT USABILITY ADD-ON: Provides file system sharing, clipboard integration, mouse tricks
- **https://youtu.be/Kbez-XdXqrw**

C PROGRAMING IN TCSS 422

- Many OSes are coded primarily in C and Assembly Language
- C is a particularly useful language for working with hardware / hardware drivers and operating systems
- C allows writing programs that can directly access the computer's physical memory (in kernel/real mode) providing nearly the power and speed of assembly language
  - *But in a much easier to write high-level language*
- Ideally, all university operating system courses are taught in C/C++. Our textbook is in C/C++
  - *This quarter we will offer the option of assignment of completing assignment 2 in Java (multithreaded programming)*

C MENTORING

- https://www.tacoma.uw.edu/institute-technology/student-support-workshops-mentors
- School of Engineering and Technology Mentors
- Office hours held online via Zoom
- Varied hours and availability based on mentors schedules
- Monday – Thursday: ~9:30 am – 9:00 pm
- Friday: ~ 9:30 - 3:30 pm
- Spring quarter hours will be posted once available
- Student mentors managed by SET Monika Sobolewska

INSTRUCTOR HELP

- Office hours: tentative 5:40p TR after class
  - Additional hours based on survey results
  - Also available by appointment
- 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 on zoom !! *****
  - 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!
  - This instructor appreciates questions at all levels – there is no judgement for any question
- **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**

OBJECTIVES – 3/30

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C REVIEW SURVEY

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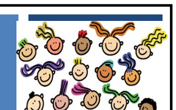
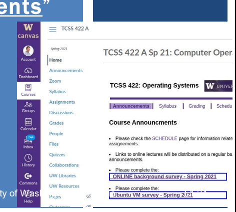
BACKGROUND & VM SURVEYS



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

or in *Canvas* under "**Announcements**"

we will resume at ~4:50pm



WE WILL RETURN AT 4:50PM

March 30, 2021 | TCSS422: Operating Systems [Spring 2021] School of Engineering and Technology, University of Washington - Tacoma | L1.25

STUDENT BACKGROUND SURVEY

- Please complete the Student Background Survey
- https://forms.gle/yr6Dc9x9rX516U6t6

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VIRTUAL MACHINE SURVEY

- Please complete the Virtual Machine Survey to request a “School of Engineering and Technology” remote hosted Ubuntu VM
- https://forms.gle/BR2G1wr9RDBVB9AK8

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OBJECTIVES – 3/30

- Syllabus, Course Introduction
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- Chapter 4: Operating Systems – Three Easy Pieces
  - **Introduction to operating systems**
  - Management of resources
  - Concepts of virtualization/abstraction
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INTRODUCTION TO OPERATING SYSTEMS

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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

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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.

OBJECTIVES – 3/30

- Syllabus, Course Introduction
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- Chapter 4: Operating Systems – Three Easy Pieces
  - Introduction to operating systems
  - **Management of resources**
  - Concepts of virtualization/abstraction
  - Three Easy Pieces: CPU, Memory, I/O
  - Concurrency
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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
    - …

OBJECTIVES – 3/30

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  - Management of resources
  - **Concepts of virtualization/abstraction**
  - Three Easy Pieces: CPU, Memory, I/O
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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

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  - **Three Easy Pieces: CPU,** Memory, I/O
  - Concurrency
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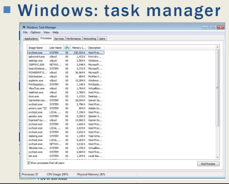
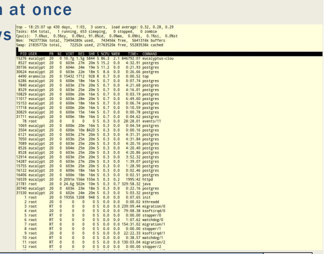
VIRTUALIZING THE CPU

- 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

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;
}
```


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!

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  - Concurrency
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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:

```
#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 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

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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

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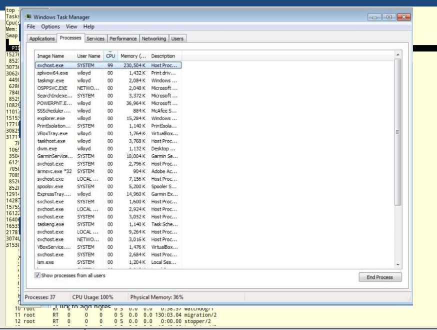
CONCURRENCY



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

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

volatile int counter = 0;
int loops;

void
}
...
```

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

```
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)

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.

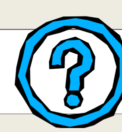
CONCURRENCY - 4

- 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??
```



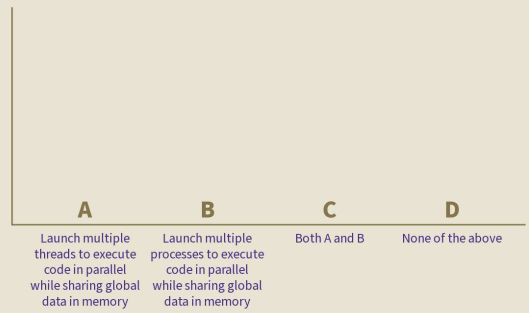
CONCURRENCY - 5

- 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*

To perform parallel work, a single process may:



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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  - **Operating system design goals**

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

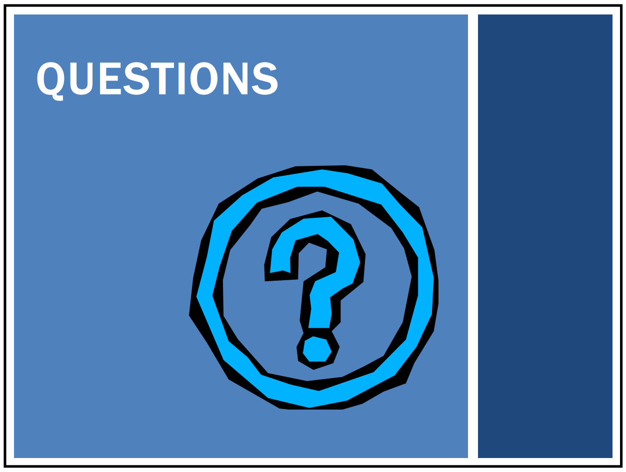
- **PROVIDE ISOLATION**
  - User programs can't interfere with each other's virtual machines, the underlying OS, or the sharing of resources

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