CHAPTER 1

1Q.What is operating system and how it works?

1A.Operating system is a resource allocator and it also allow to control program making efficient use of hardware and managing execution of user programs.

2Q.What is computer system architecture

2A. computer architecture is a set of rules and methods that describe the functionality, organization, and implementation of computer systems. It is divided into 4 components

1.Hardware :provides basic computing resources

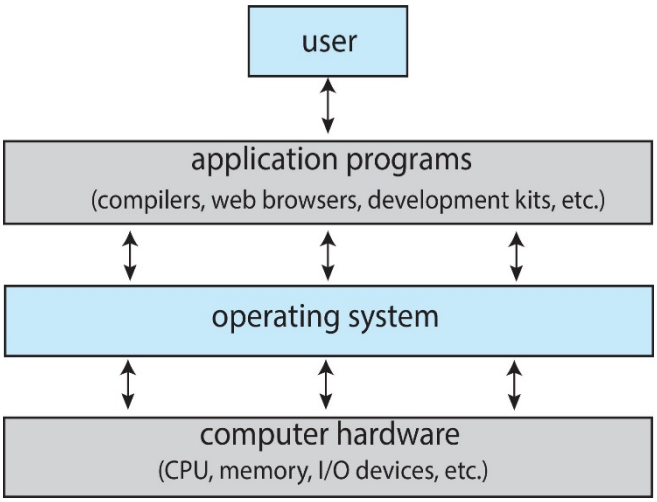
Ex : CPU, Memory, I/O devices

2.Operating systems :Controls and coordinates use of hardware among various applications and users

3.Application programs : Define the ways in which the system resources are used to solve the computing problem of the users

Ex : database systems,Web browser,video games

Users :people,machines and other computers

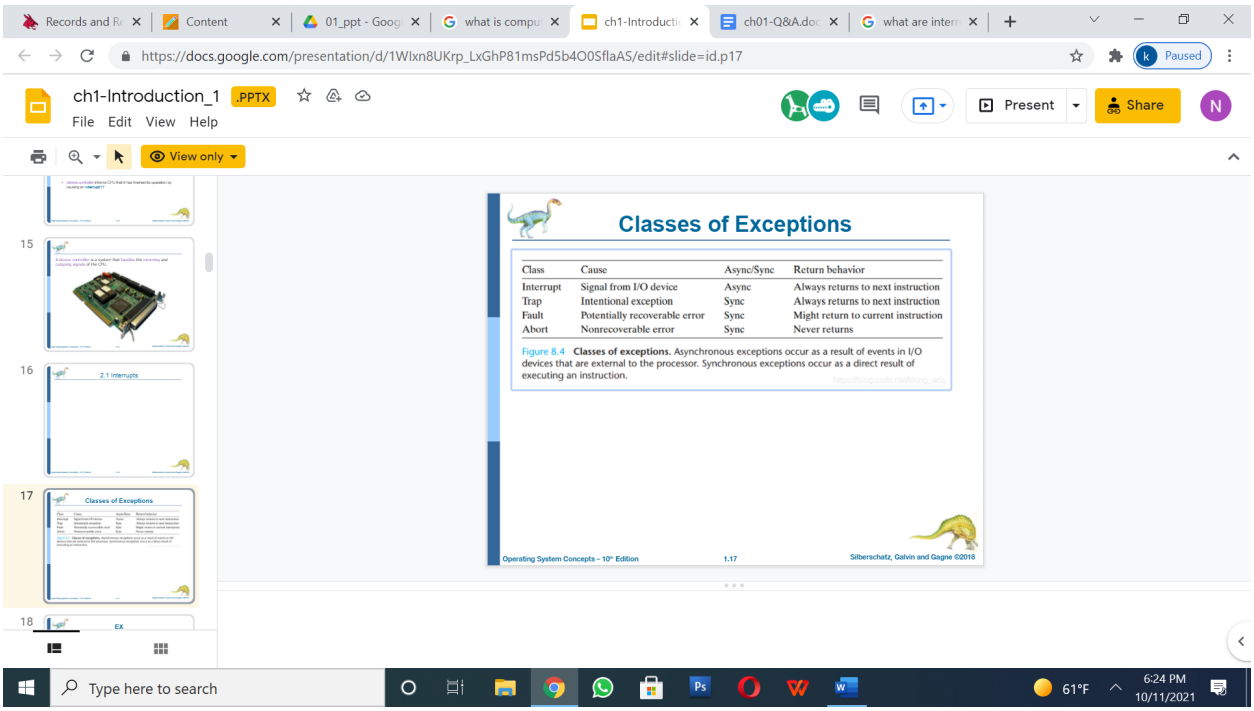


3Q .What is interrupts?

3A.Interrupt is an event that alters the sequence in which the processor executes instructions.An interrupt may be planned or unplanned

Ex of planned interrupt : software instructions

EX of unplanned interrupt : Program errors while executing



4Q : What is storage structure?

4A. Storage structure is divided into 4 types

1.Main memory :It is a large storage are where only CPU can access directly

- Ex : Random access(pinpoint any point of address)(RAM)
- Typically volatile
- Typically random-access memory in the form of Dynamic Random-access Memory (DRAM)

2. Secondary storage – extension of main memory that provides large nonvolatile storage capacity

- Hard Disk Drives (HDD) – rigid metal or glass platters covered with magnetic recording material
  - Disk surface is logically divided into tracks, which are subdivided into sectors
  - The disk controller determines the logical interaction between the device and the computer
- Non-volatile memory (NVM)(SSD drive) devices– faster than hard disks, nonvolatile
  - Various technologies
  - Becoming more popular as capacity and performance increases, price drops

5Q.Computer system architecture?
5A.

- 1.Single-Processor Systems (single-pc) : Most systems use a single general-purpose processor

Most systems have special-purpose processors as well

2.Multiprocessor Systems(single-pc) :

- Multiprocessors systems growing in use and importance
  - Also known as parallel systems, tightly-coupled systems
  - Advantages include:
    1. Increased throughput
    2. Economy of scale(1+1>2)
    3. Increased reliability – graceful degradation or fault tolerance

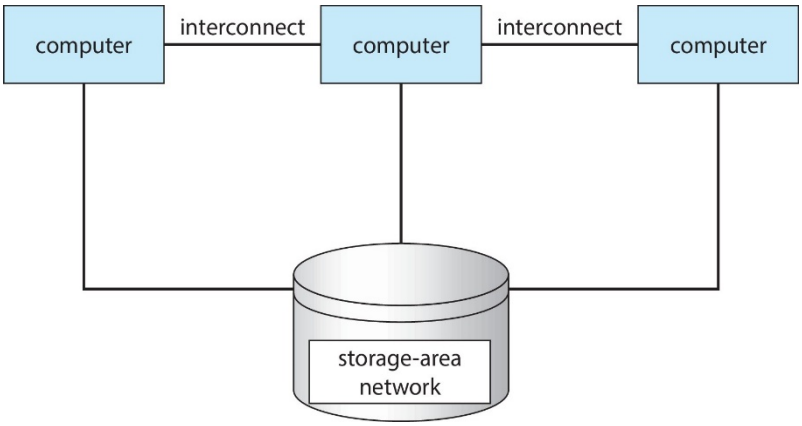
  - Two types:
    1. Asymmetric Multiprocessing – each processor is assigned a specie task.

Symmetric Multiprocessing – each processor performs all tasks(but time-slice)

3.Clustered Systems(multi-pc)

- Like multiprocessor systems, but multiple systems working together
  - Usually sharing storage via a storage-area network (SAN)
  - Provides a high-availability service which survives failures
    - Asymmetric clustering has one machine in hot-standby mode?
    - Symmetric clustering has multiple nodes running applications, monitoring each other?

  - Some clusters are for high-performance computing (HPC)
    - Applications must be written to use parallelization
  - Some have distributed lock manager (DLM) to avoid conflicting operations



What is Macro and micro?
Macro and micro

In macro, all the processes(apps) are running parallel in the CPU.

In micro, all the processes are synchronized(one after another)(time-slice)

Timer: to prevent infinite loop (or process hogging resources)

Timer is set to interrupt the computer after some time period

From one process to another.

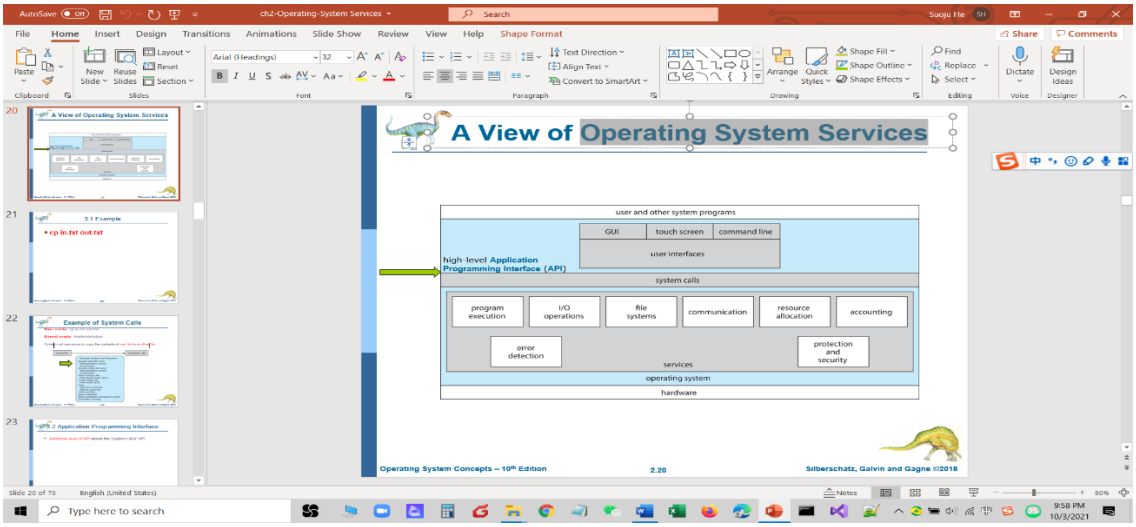
CHAPTER 2

1Q :What are operating system services and Relation among GUI, system call and service?

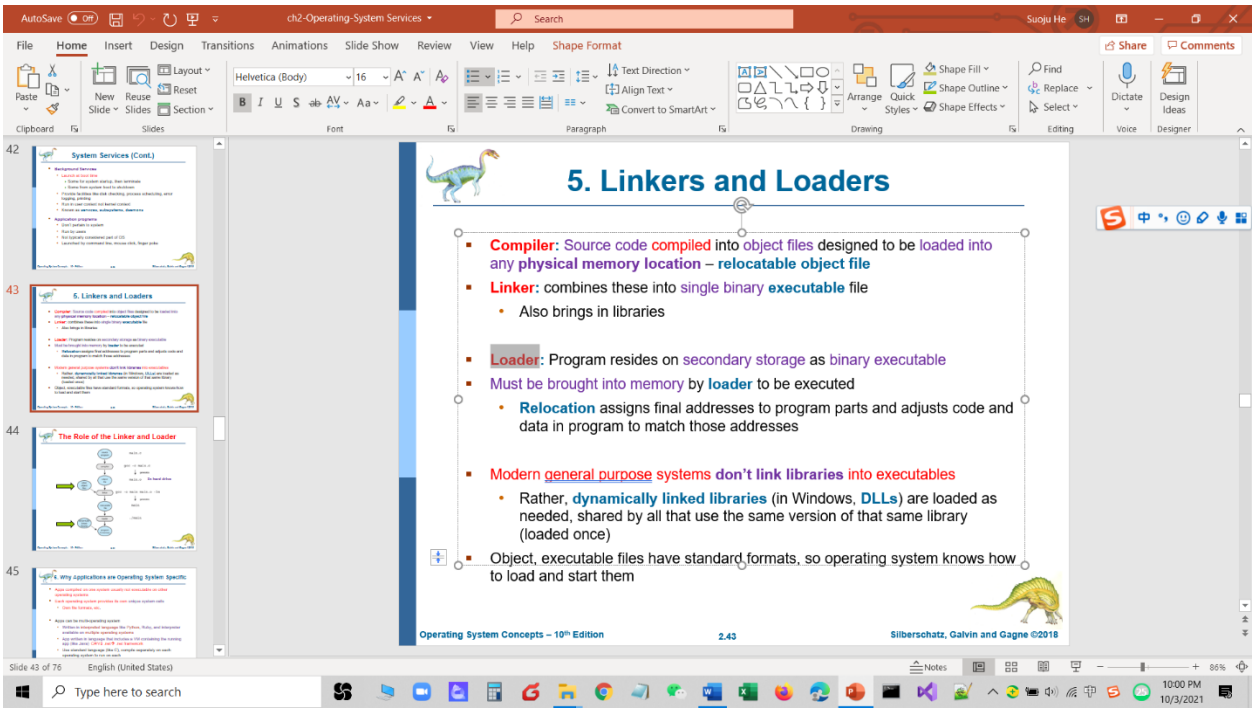
1A. Operating systems provide an environment for execution of programs and services to programs and users

- **User interface**（nothing to do with services） - Almost all operating systems have a user interface (UI).
  - Varies between Command-Line (CLI), Graphics User Interface (GUI), touch-screen, Batch
- **Program execution** - The system must be able to load a program into memory and to run that program, end execution, either normally or abnormally (indicating error)
- **I/O operations** - A running program may require I/O, which may involve a file or an I/O device

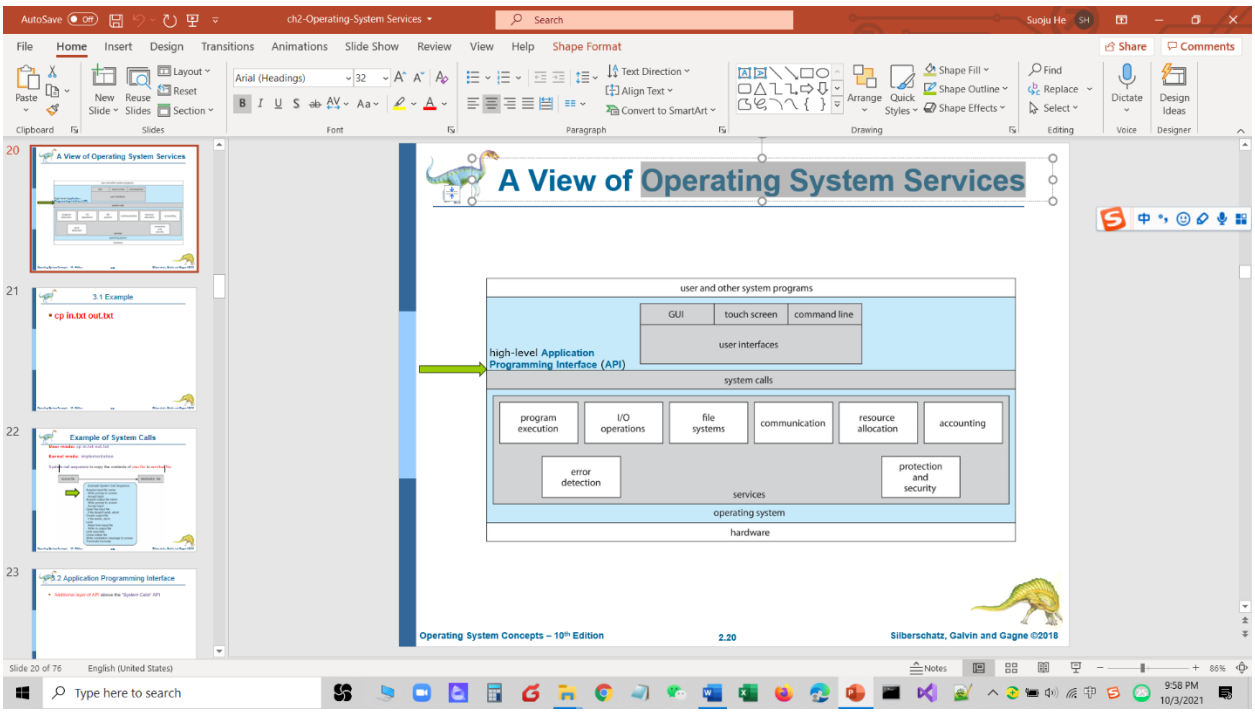
File-system manipulation - The file system is of particular interest. Programs need to read and write files and directories, create and delete them, search them, list file Information, permission management.



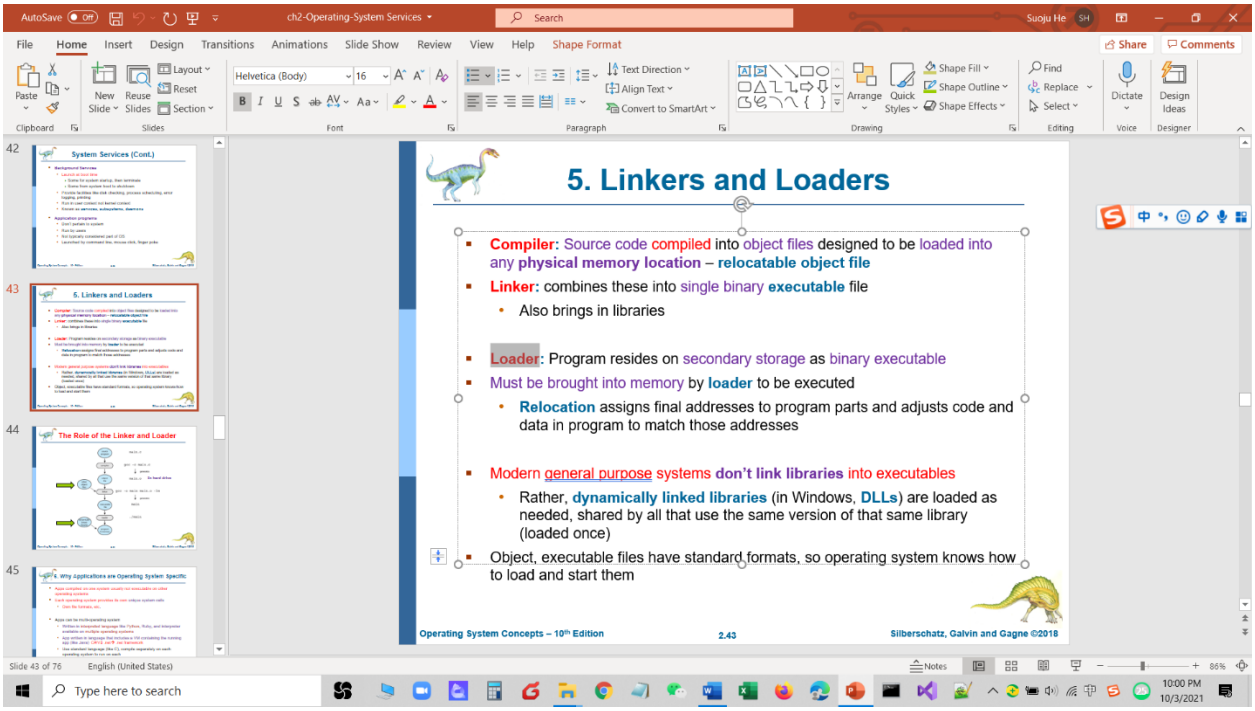
2Q: Relation among Compiler, Linker and Loader?



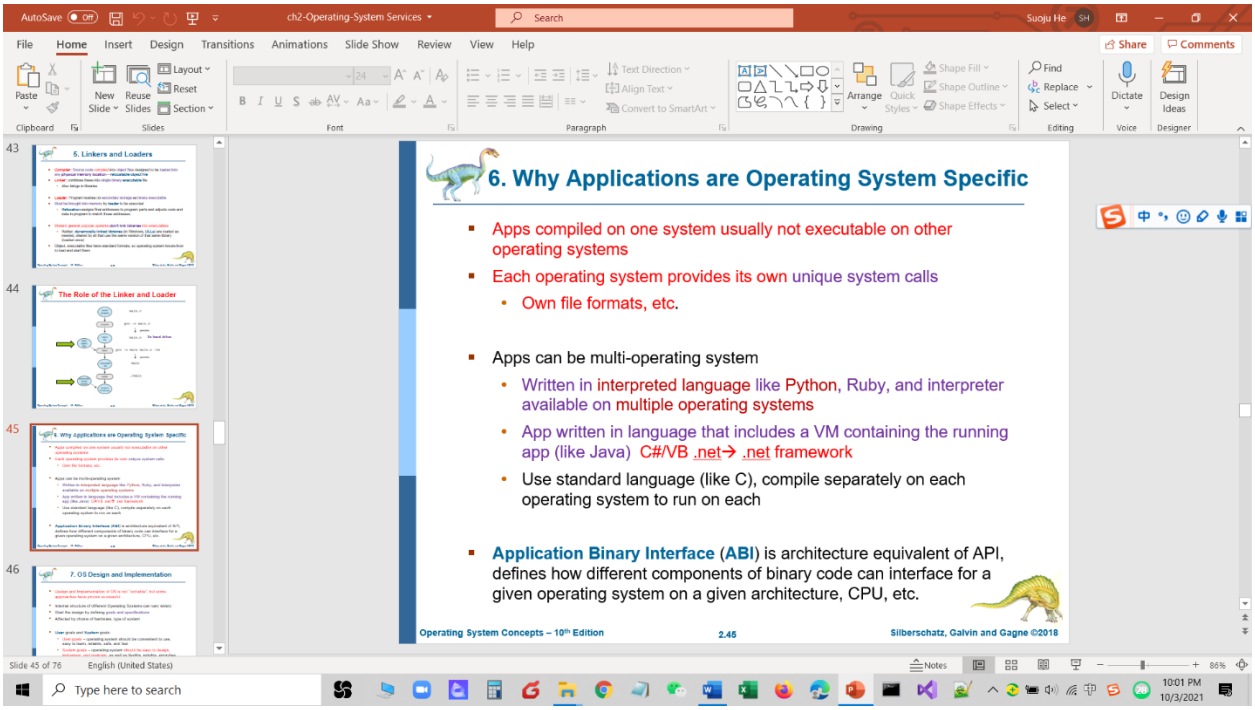
Why Applications are Operating System Specific?



Relation among Compiler, Linker and Loader?

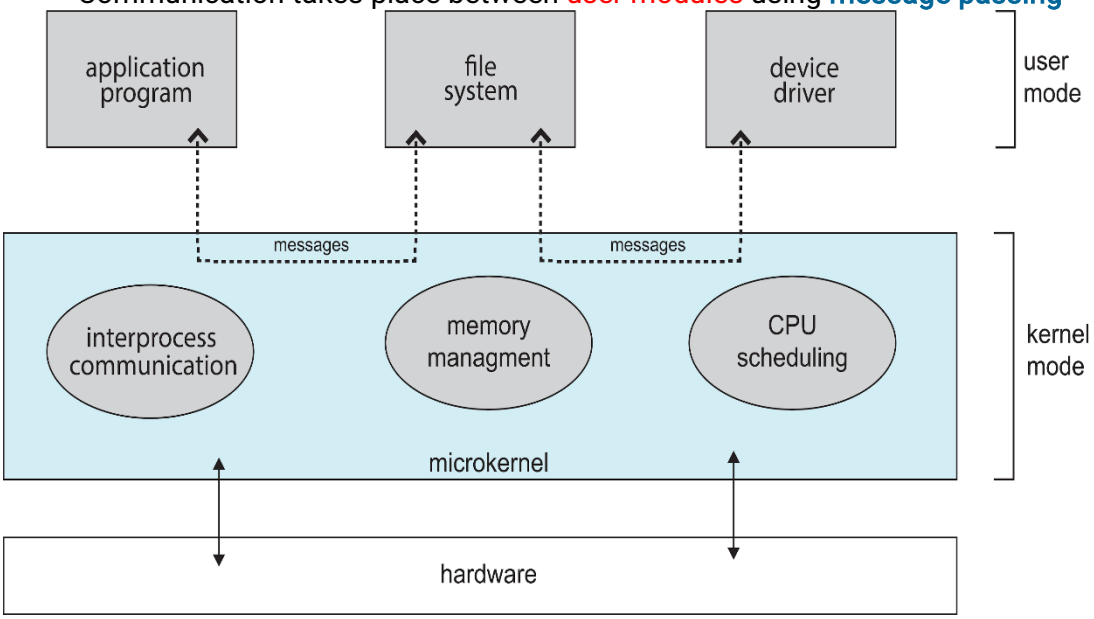


Why Applications are Operating System Specific?



What is Microkernels OS Operating System and its Structure?

- We have already seen that the original UNIX system had a monolithic structure.
- As UNIX expanded, the kernel became large and difficult to manage.
- In the mid-1980s, researchers at Carnegie Mellon University developed an operating system called **Mach** that modularized the kernel using the **microkernel** approach.
- This method structures the operating system by removing all nonessential components from the kernel and implementing them as user-level programs that reside in separate address spaces. The result is a smaller kernel.
- Moves as much from the kernel into user space
- **Mach** is an example of **microkernel**
  - Mac OS X kernel (**Darwin**) partly based on Mach
- Communication takes place between user modules using **message passing**



CHAPTER 3

What is the Process ?

a program in execution (in the RAM, with CPU/no CPU);

process execution must progress in sequential fashion.

No parallel execution of instructions of a single process

Program（code） is passive entity stored on disk

Difference between process and program?

Process: process is **active，** program becomes process when an executable file is loaded into memory.

Program（code） is **passive** entity stored on disk (**executable file**); process is **active**

Process States and their transition?

New: The process is being created

Running: Instructions are being executed

Waiting: The process is waiting for some event to occur

Ready: The process is waiting to be assigned to a processor

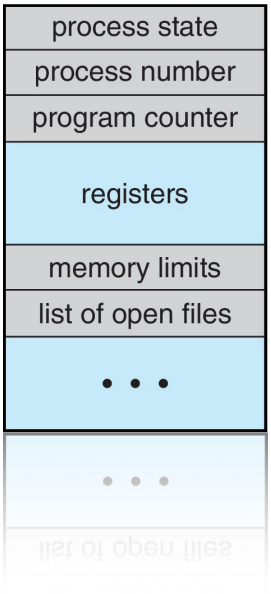
Terminated: The process has finished execution

Process Control Block (PCB)(ID of process) ?

Information associated with each process(also called **task control block**)

- Process state – running, waiting, etc.

- Program counter – location of instruction to next execute
- CPU registers – contents of all process-centric registers?
- CPU scheduling information- priorities, scheduling queue pointers
- Memory-management information – memory allocated to the process
- Accounting information – CPU used, clock time elapsed since start, time limits
- I/O status information – I/O devices allocated to process, list of open files



Process Threads ?

- So far, process has a single thread of execution
- Consider having multiple program counters per process(TCB)?
    - Multiple locations can execute at once
        - Multiple threads of control -> **threads**

- Must then have storage for thread details, multiple program counters in PCB

Process Scheduling ?

Ready queue – set of all processes residing in main memory, ready and waiting to execute

Wait queues – set of processes waiting for an event (i.e., I/O)

Processes migrate among the various queues

Context Switch ?

When CPU switches to another process, the system must save the state of the old process and load the saved state for the new process via a context switch

Context of a process represented in the PCB

Interprocess Communication ?

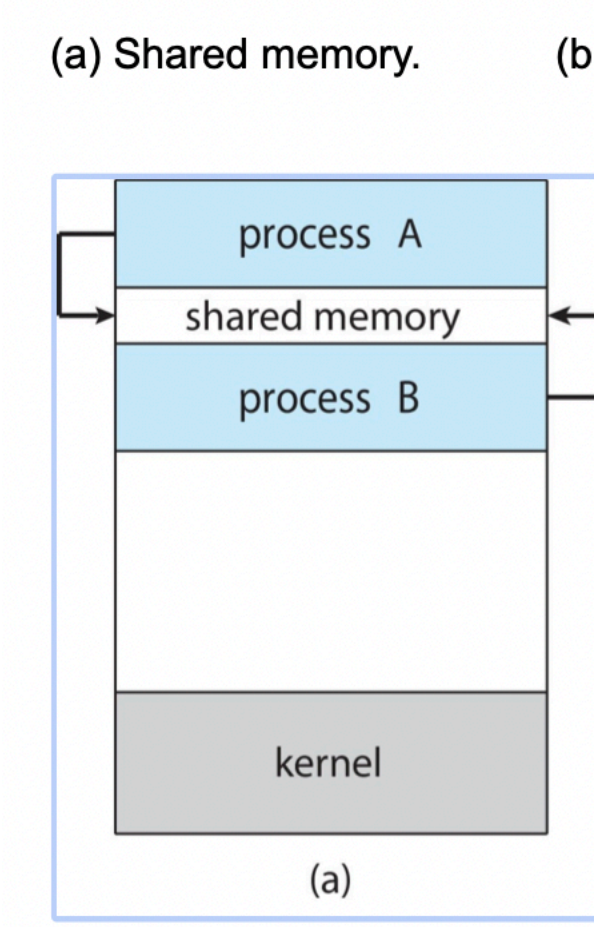
- Processes within a system(**local pc/remote**) may be ***independent*** or ***cooperating***
- Cooperating process(ex: **google/google map in ios**) can affect or be affected by other processes, including sharing data
- Reasons for cooperating processes:
  - Information sharing
  - Computation speedup

- Modularity
- Convenience

- Cooperating processes need **interprocess communication** (**IPC**)
- Two models of IPC
  - **Shared memory**
  - **Message passing**

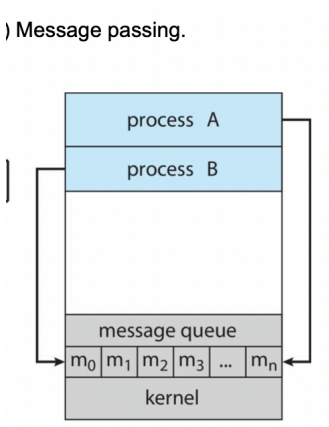
The process would be app, object, or function

Shared Memory ?



- Shared memory can be faster than message passing(*exchanging larger amounts of data*), since message-passing systems are typically implemented using system calls and thus require the more time-consuming task of kernel intervention.

Message Passing ?



- Message passing is useful for exchanging smaller amounts of data, because no conflicts need be avoided?.

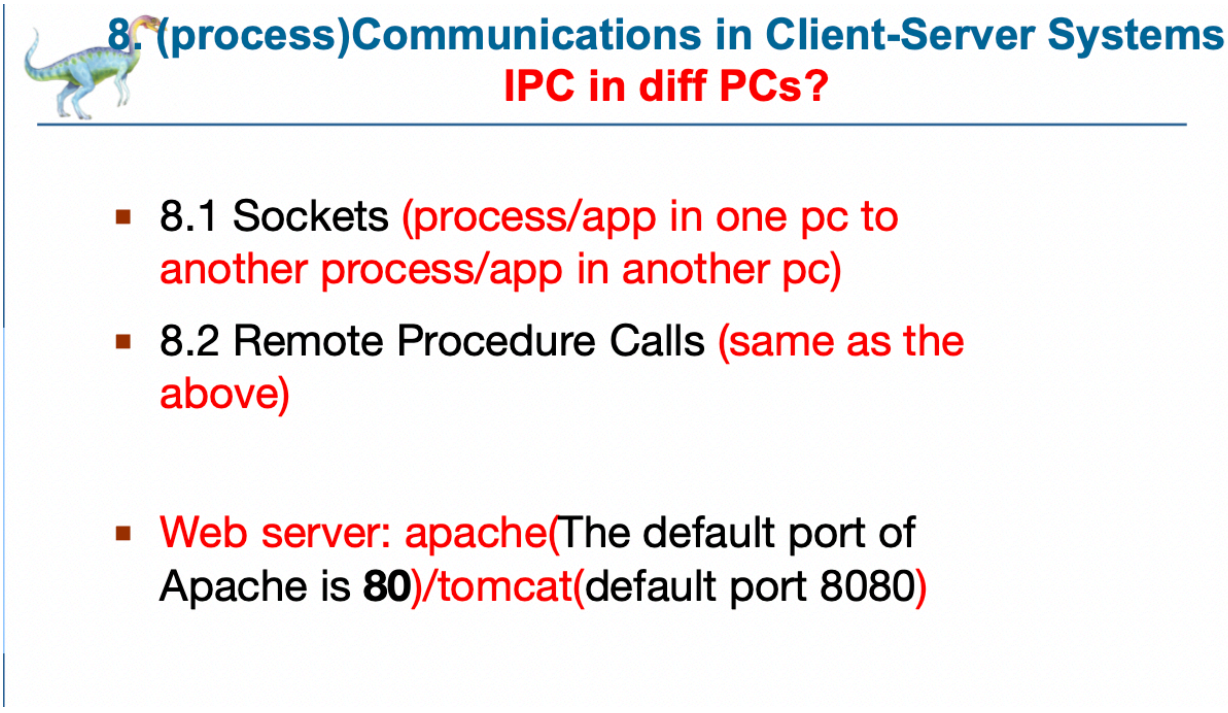
Producer-Consumer Problem ?

- Paradigm for cooperating processes:
  - *producer* process produces information that is consumed by a *consumer* process
- Two variations:
  - **unbounded-buffer** places no practical limit on the size of the buffer:
    - Producer never waits

        - Consumer waits if there is no buffer to consume
    - **bounded-buffer** assumes that there is a fixed buffer size
        - Producer must wait if all buffers are full
        - Consumer waits if there is no buffer to consume

Why we say that Interprocess Communication is a Producer-Consumer Problem?

Process Communications in Client-Server Systems, IPC in diff PCs?



8.2 Remote Procedure Calls

- Remote procedure call (RPC) abstracts procedure calls between processes on networked systems
  - Again uses ports for service differentiation
- **Stubs** – client-side proxy for the actual procedure on the server
- The client-side stub locates the server and **marshalls** the parameters
- The server-side stub receives this message, unpacks the marshalled parameters, and performs the procedure on the server
- On Windows, stub code compile from specification written in **Microsoft Interface Definition Language** (**MIDL**)

Remote Procedure Calls ?

Remote Procedure Calls (Cont.) ?

- Data representation handled via **External Data Representation** (**XDL**) format to account for different architectures
  - **Big-endian** and **little-endian**
- Remote communication has more failure scenarios than local
  - Messages can be delivered ***exactly once*** rather than ***at most once***
- OS typically provides a rendezvous (or **matchmaker**) service to connect client and server

Advance Operating Systems

CHAPTER-4

1. Contrast or differ threads and processes?

Answer:

- Most modern applications are multithreaded.
- Thread: Threads run within application （process）
- Process: A process is a program under execution i.e., an active program.

- Multiple tasks with the application (process) can be implemented by separate threads (sub-contractor, multi-program counter）
- Update display
- Fetch data
- Spell checking
- Answer a network request

- Process creation is heavy-weight while thread creation is light-weight
- Can simplify code, increase efficiency
- Kernels are generally multithreaded
- Most software applications that run on modern computers and mobile devices are multithreaded.
- An application typically is implemented as a separate process with several threads of control.

2. Examples of multithreaded applications?

Answer:

An application that creates photo thumbnails from a collection of images may use a separate thread to generate a thumbnail from each separate image.

A web browser might have：

- one thread display images or text
- another thread retrieves data from the network.

A word processor may have：

- a thread for displaying graphics,
- another thread for responding to keystrokes from the user,
- and a third thread for performing spelling and grammar checking in the background.

3. Why we say there is no process scheduling, but thread scheduling?

Answer:

A thread is a **lightweight process that can be managed independently by a scheduler**. Processes require more time for context switching as they are heavier. Threads require less time for context switching as they are lighter than processes. Processes are totally independent and don't share memory.

4. User Threads and Kernel Threads

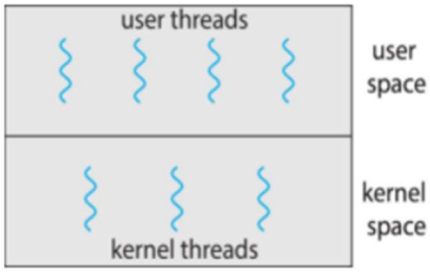
Answer:

- User threads - management done by user-level threads library
- Three primary thread libraries:
    - POSIX Pthreads
    - Windows threads
    - Java threads
- Kernel threads - Supported by the Kernel

- Examples – virtually all general -purpose operating systems, including:
- Windows, Linux, Mac OS X, iOS, Android
- Support for threads may be provided either at the user level, for user threads, or by the kernel, for kernel threads.
- User threads are supported above the kernel and are managed without kernel support, whereas kernel threads are supported and managed directly by the operating system.

- Virtually all contemporary operating systems—including Windows, Linux, and macOS—support kernel threads

User and Kernel Threads



5. Multithreading Models and pro and con of each model

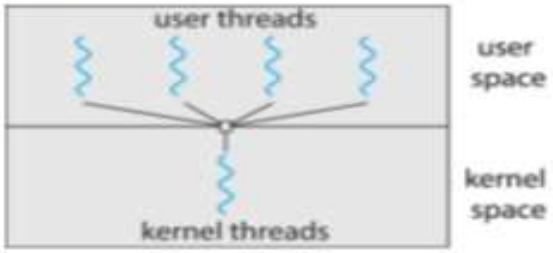
Many-to-One

Answer:

3.1 Many-to-One

- Many user-level threads mapped to single kernel thread
- One thread blocking causes all to block(if one user's thread use kernel thread and block, and another user's thread want to call the kernel thread)
- Multiple threads may not run in parallel on muticore system because only one may be in kernel at a time?
- Few systems currently use this model
- Examples:
  - Solaris Green Threads
  - GNU Portable Threads

Multiple user threads
Share one kernel thread
(like one cpu), scheduling is required



- The many-to-one model (Figure 4.7) maps many user-level threads to one kernel thread.
- Thread management is done by the thread library in user space, so it is efficient (we discuss thread libraries in Section 4.4).

- However, the entire process(own multi-threads) will block if a thread makes a blocking system call (ex:read(), only after this, another user thread can call kernel thread).
- Also, because only one thread can access the kernel at a time, multiple threads are unable to run

- However, very few systems continue to use the model because of its inability to take advantage of multiple processing cores(**in the kernel**), which have now become standard on most computer systems in parallel on multicore systems.

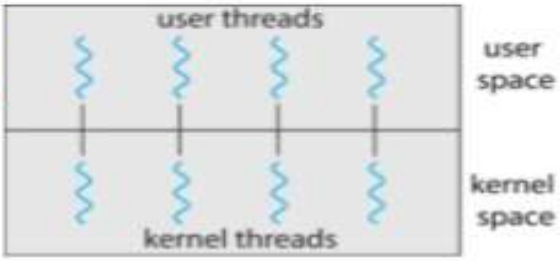
One-to-One

Answer:

3.2 One-to-One

- Each user-level thread maps to kernel thread
- Creating a user-level thread creates a kernel thread
- More concurrency than many-to-one
- Number of threads per process sometimes restricted due to overhead (thread context switch?)
- Examples
  - Windows
  - Linux

Threads belongs to single process



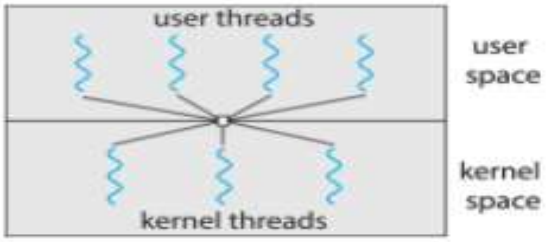
- It provides more concurrency than the many-to-one model by allowing another thread to run when a thread makes **a blocking system call**.
- It also allows multiple threads(kernel) to run in parallel on **multiprocessors**.
- The only drawback to this model:
  - is that creating a user thread requires creating the corresponding kernel thread, and a large number of kernel threads**(assign resource)** may burden the performance of a system.
- Linux, along with the family of Windows operating systems, implement the one-to-one model.

Many-to-Many

Answer:

3.3 Many-to-Many Model

- Allows many user level threads to be mapped to many kernel threads
- Allows the operating system to create a sufficient number of kernel threads
- Windows with the *ThreadFiber* package
- Otherwise not very common

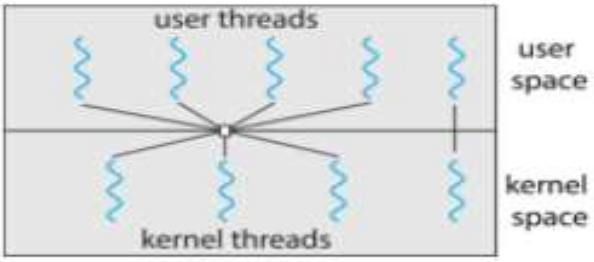


Two-level Model

Answer:

Two-level Model

- Similar to M:M, except that it allows a user thread to be **bound** to kernel thread



One variation on the many-to-many model still multiplexes many userlevel threads to a smaller or equal number of kernel threads but also allows **a user-level thread to be bound to a kernel thread.** This variation is sometimes referred to as the two-level model (Figure 4.10).

6. Why we have Implicit Threading? And its types?

Answer:

5. Implicit Threading

- With the continued growth of multicore processing, applications containing hundreds—or even thousands—of threads are looming on the horizon.
- Designing such applications is not a trivial undertaking:
  - programmers must address not only the challenges outlined in Section 4.2 but additional difficulties as well.
  - These difficulties, which relate to program correctness, are covered in Chapter 6 and Chapter 8.
- One way to address these difficulties and better support the design of concurrent and parallel applications is to transfer the creation and management of threading from application developers to compilers and run-time libraries **(system to take care of the detail, not the user).**
- This strategy, termed **implicit threading**, is an increasingly popular trend

- Growing in popularity as numbers of threads increase, program correctness more difficult with explicit threads
- Creation and management of threads done by compilers and run-time libraries rather than programmers
- Five methods explored
  - Thread Pools
  - Fork-Join
  - OpenMP
  - Grand Central Dispatch
  - Intel Threading Building Blocks

6. What are Thread Pools (resource pool) and its benefit?

Answer:

5.1 Thread Pools (resource pool)

- The general idea behind a thread pool is to create a number of threads at start-up and place them into a pool, where they sit and wait for work.
- When a server receives a request, rather than creating a thread, it instead submits the request to the thread pool and resumes waiting for additional requests.

- If there is an available thread in the pool, it is awakened, and the request is serviced immediately.
- If the pool contains no available thread, the task is queued until one becomes free.
- Once a thread completes its service, it returns to the pool and awaits more work.

- Create a number of threads in a pool where they await work
- Advantages:
  - Usually slightly faster to service a request with an existing thread than create a new thread(create real time take time)
  - Allows the number of threads in the application(s) to be bound to the size of the pool
  - Separating task to be performed from mechanics of creating task allows different strategies for running task??
    - i.e.,Tasks could be scheduled to run periodically??
- Windows API supports thread pools:

```
DWORD WINAPI PoolFunction(AVOID Param) {
    /*
    * this function runs as a separate thread.
    */
}
```

1a)Preemptive

used when a process switches from running state to ready state or from the waiting state(wait for I/O) to ready state

1b)Non preemptive Scheduling

Is used when a process terminates, or a process switches from running to the waiting state(wait for I/O)

2)Comparison of Preemptive and Nonpreemptive Scheduling

Comparison Chart:

Parameter	PREEMPTIVE SCHEDULING	NON-PREEMPTIVE SCHEDULING
Basic	In this resources(CPU Cycle) are allocated to a process for a limited time.	Once resources(CPU Cycle) are allocated to a process, the process holds it till it completes its burst time or switches to waiting state.
Interrupt	Process can be interrupted in between.	Process can not be interrupted until it terminates itself or its time is up.
Starvation	If a process having high priority frequently arrives in the ready queue, a low priority process may starve.	If a process with a long burst time is running CPU, then later coming process with less CPU burst time may starve.
Overhead	It has overheads of scheduling the processes.	It does not have overheads.
Parameter	PREEMPTIVE SCHEDULING	NON-PREEMPTIVE SCHEDULING
Flexibility	flexible	rigid
Cost	cost associated	no cost associated
CPU Utilization	In preemptive scheduling, CPU utilization is high.	It is low in non preemptive scheduling.
Examples	Examples of preemptive scheduling are Round Robin and Shortest Remaining Time First.	Examples of non-preemptive scheduling are First Come First Serve and Shortest Job First.

3)Race Conditions and when does it happen?

They occur when two computer program processes, or threads, attempt to access the same resource at the same time and cause problems in the system. Race conditions are considered a common issue for multithreaded applications.

4)Why Preemptive scheduling can result in race conditions?

- Preemptive scheduling can result in race conditions when data are shared among several processes.
- Consider the case of two processes that share data.
- While one process is updating the data, it is preempted so that the second process can run.

The second process then tries to read the data, which are in an inconsistent state.

5)Scheduling Criteria

- **CPU utilization**. We want to keep the CPU as busy as possible. Conceptually, CPU utilization can range from 0 to 100 percent. In a real system, it should range from 40 percent (for a lightly loaded system) to 90 percent (for a heavily loaded system). (CPU utilization can be obtained by using the `top` command on Linux, macOS, and UNIX systems.)
- **Throughput**. If the CPU is busy executing processes, then work is being done. One measure of work is the number of processes that are completed per time unit, called **throughput**. For long processes, this rate may be one process over several seconds; for short transactions, it may be tens of processes per second.
- **Turnaround time**. From the point of view of a particular process, the important criterion is how long it takes to execute that process. The interval from the time of submission of a process to the time of completion is the turnaround time. Turnaround time is the sum of the periods spent waiting in the ready queue, executing on the CPU, and doing I/O.
- **Waiting time**. The CPU-scheduling algorithm does not affect the amount of time during which a process executes or does I/O. It affects only the amount of time that a process spends waiting in the ready queue. Waiting time is the sum of the periods spent waiting in the ready queue.
- **Response time**. In an interactive system, turnaround time may not be the best criterion. Often, a process can produce some output fairly early and can continue computing new results while previous results are being output to the user. Thus, another measure is the time from the submission of a request until the first response is produced. This measure, called response time, is the time it takes to start responding, not the time it takes to output the response.

6)Scheduling Algorithm Optimization Criteria

- Max CPU utilization
- Max throughput
- Min turnaround time
- Min waiting time
- Min response time

7)Scheduling Algorithms and their app

FCFS
SJF
RR

Priority Scheduling

Multi level queue scheduling

Multi level feedback queue

8)First- Come, First-Served (FCFS) Scheduling

First Come First Serve (FCFS) is an operating system scheduling algorithm that automatically executes queued requests and processes in order of their arrival

9)Shortest-Job-First (SJF) Scheduling

Shortest Job First (SJF) is an algorithm in which the process having the smallest execution time is chosen for the next execution. This scheduling method can be preemptive or non-preemptive.

10)Shortest-remaining-time-first preemptive

The shortest remaining time First (SRTF) algorithm is **preemptive version of SJF**. In this algorithm, the scheduler always chooses the processes that have the shortest expected remaining processing time. When a new process joins the ready queue it may in fact have a shorter remaining time than the currently running process.

11)Round Robin (RR)

In Round-robin scheduling, each ready task runs turn by turn only in a cyclic queue for a limited time slice. This algorithm also offers starvation free execution of processes

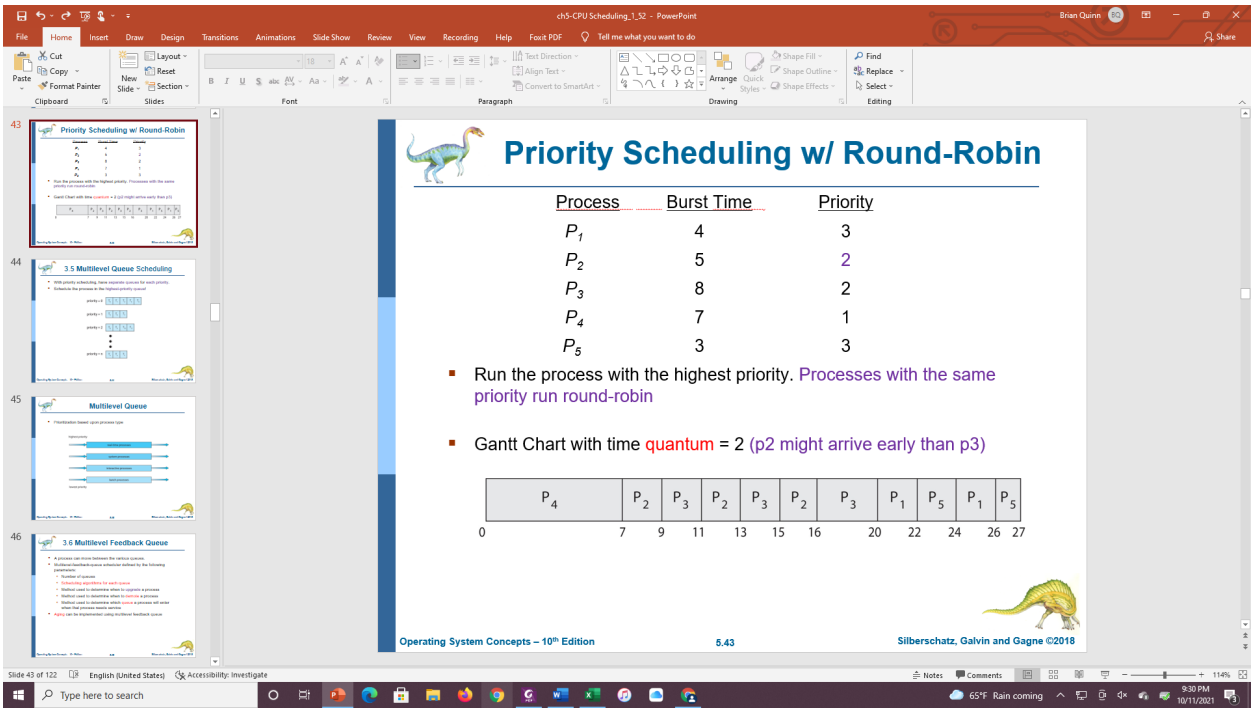
12)Priority Scheduling(no-preemptive)

In this type of scheduling method, the CPU has been allocated to a specific process. The process that keeps the CPU busy, will release the CPU either by switching context or terminating. It is the only method that can be used for various hardware platforms. That's because it doesn't need special hardware (for example, a timer) like preemptive scheduling.

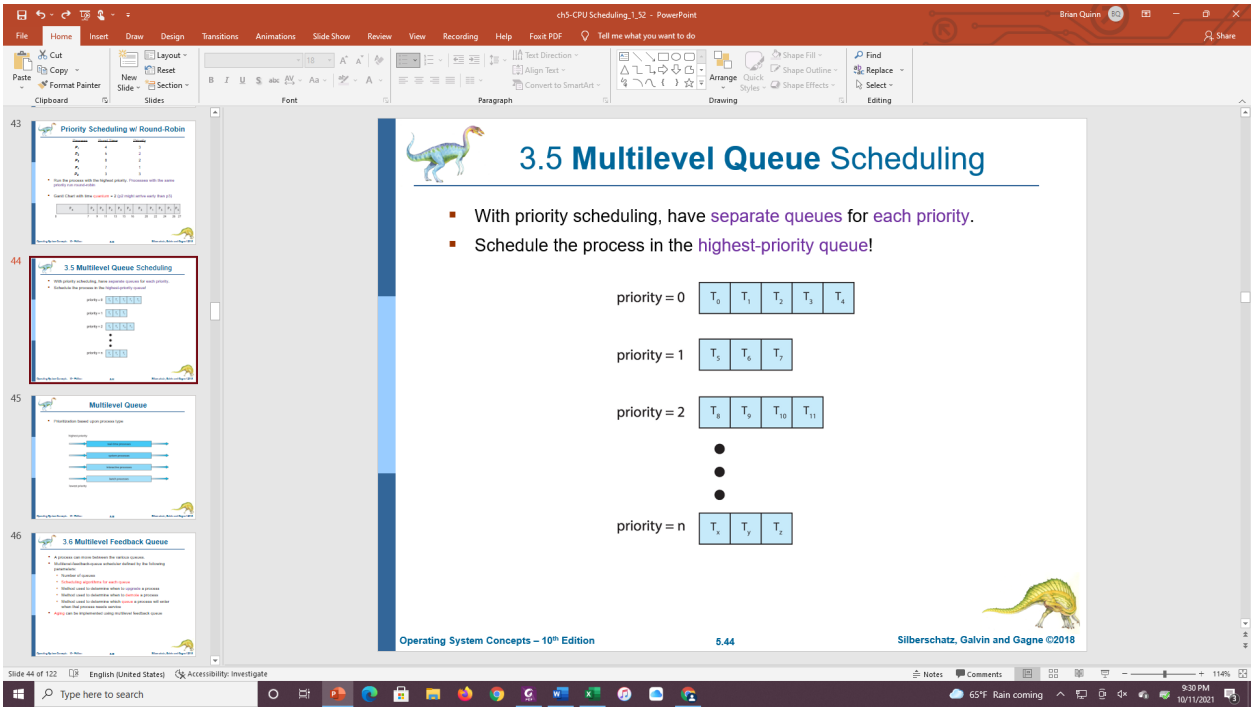
13)Priority Scheduling(preemptive)

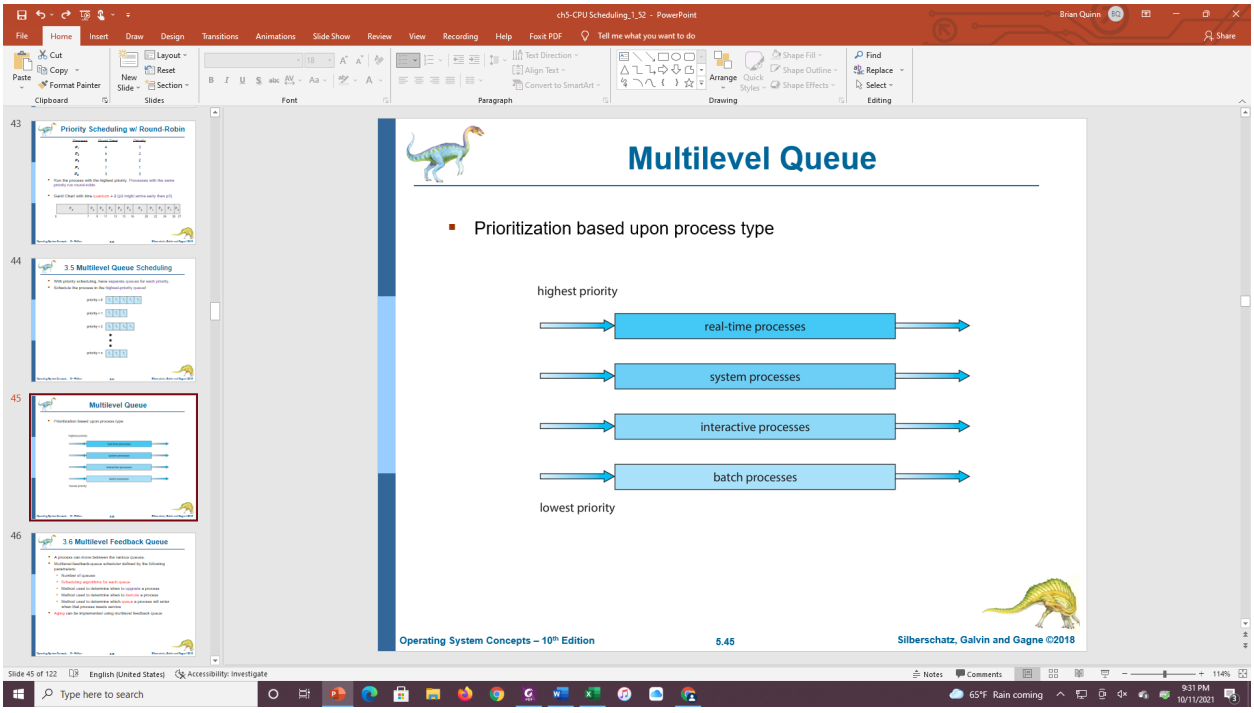
In priority Preemptive Scheduling, the tasks are mostly assigned with their priorities. Sometimes it is important to run a task with a higher priority before another lower priority task, even if the lower priority task is still running. The lower priority task holds for some time and resumes when the higher priority task finishes its execution.

14)Priority Scheduling w/ Round-Robin



15)Multilevel Queue Scheduling



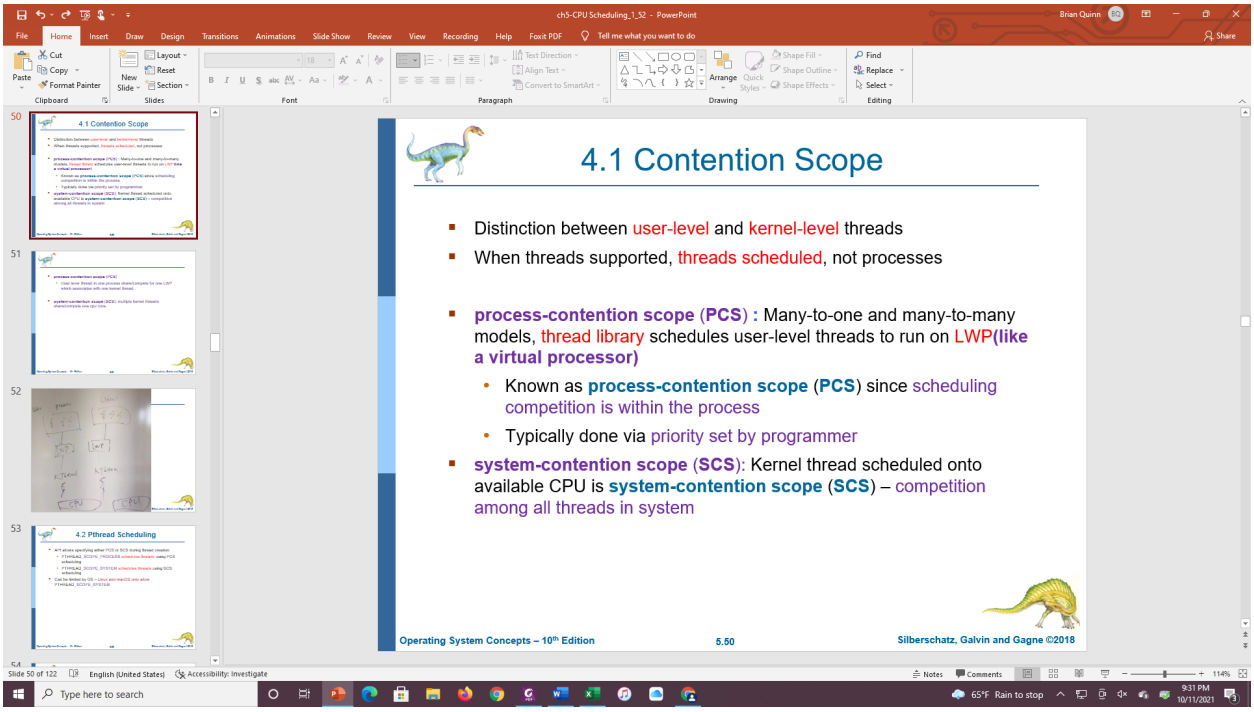


16)Multilevel Feedback Queue

- A process can move between the various queues.

- Multilevel-feedback-queue scheduler defined by the following parameters:
  - Number of queues
  - Scheduling algorithms for each queue
  - Method used to determine when to upgrade a process
  - Method used to determine when to demote a process
  - Method used to determine which queue a process will enter when that process needs service
- Aging can be implemented using multilevel feedback queue

17)Thread Scheduling: Contention Scope



18)process-contention scope (PCS)

process-contention scope (PCS) : Many-to-one and many-to-many models, thread library schedules user-level threads to run on LWP(like a virtual processor)

Known as process-contention scope (PCS) since scheduling competition is within the process.

Typically done via priority set by programmer.

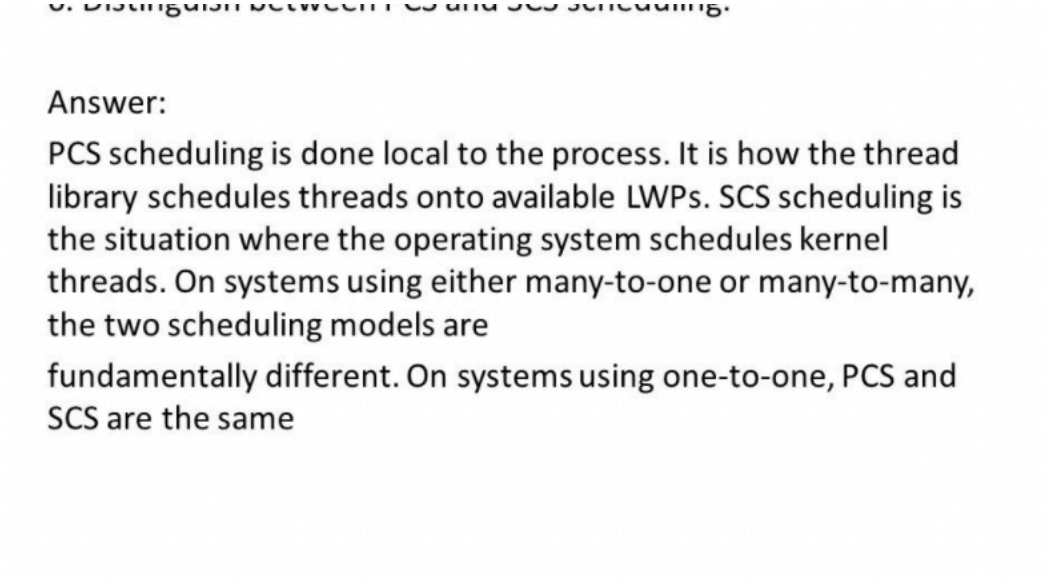
User lever thread in one process share/compete for one LWP which associates with one kernel thread.

19)system-contention scope (SCS)

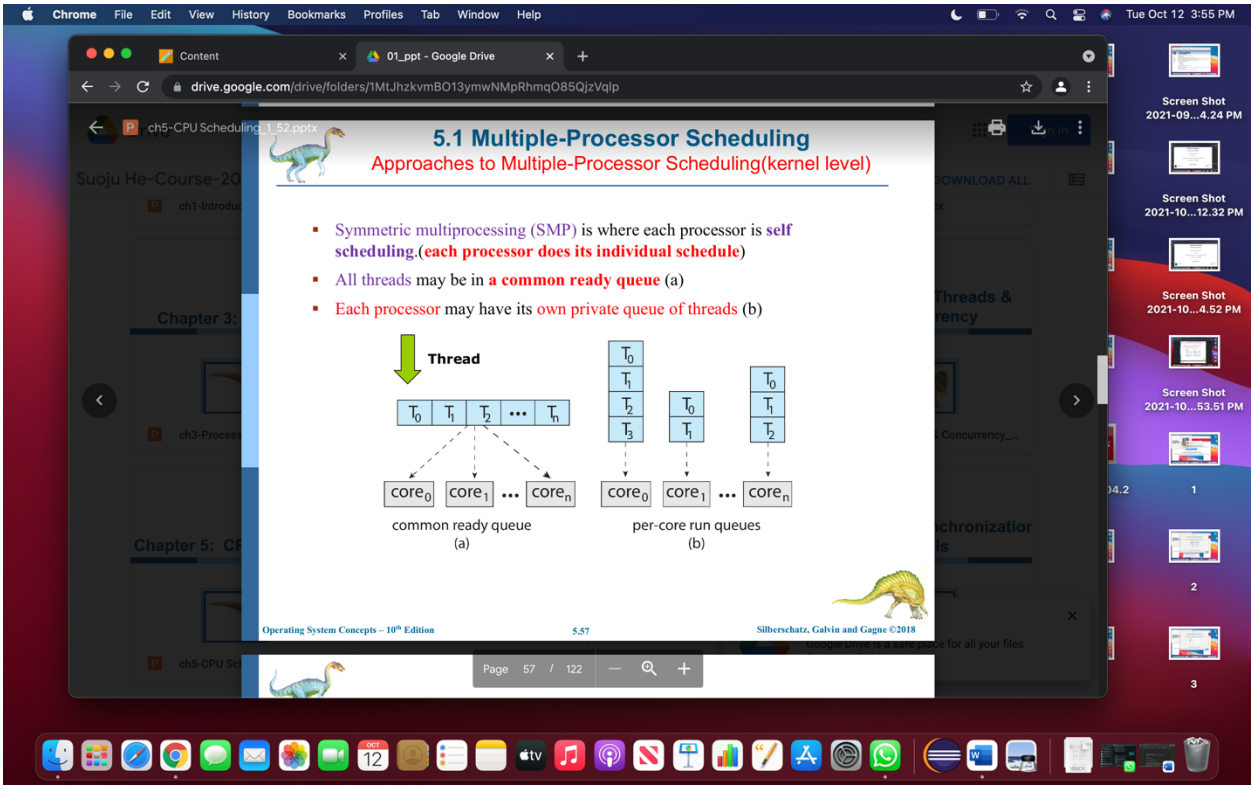
system-contention scope (SCS): Kernel thread scheduled onto available CPU is system-contention scope (SCS) – competition among all threads in system.

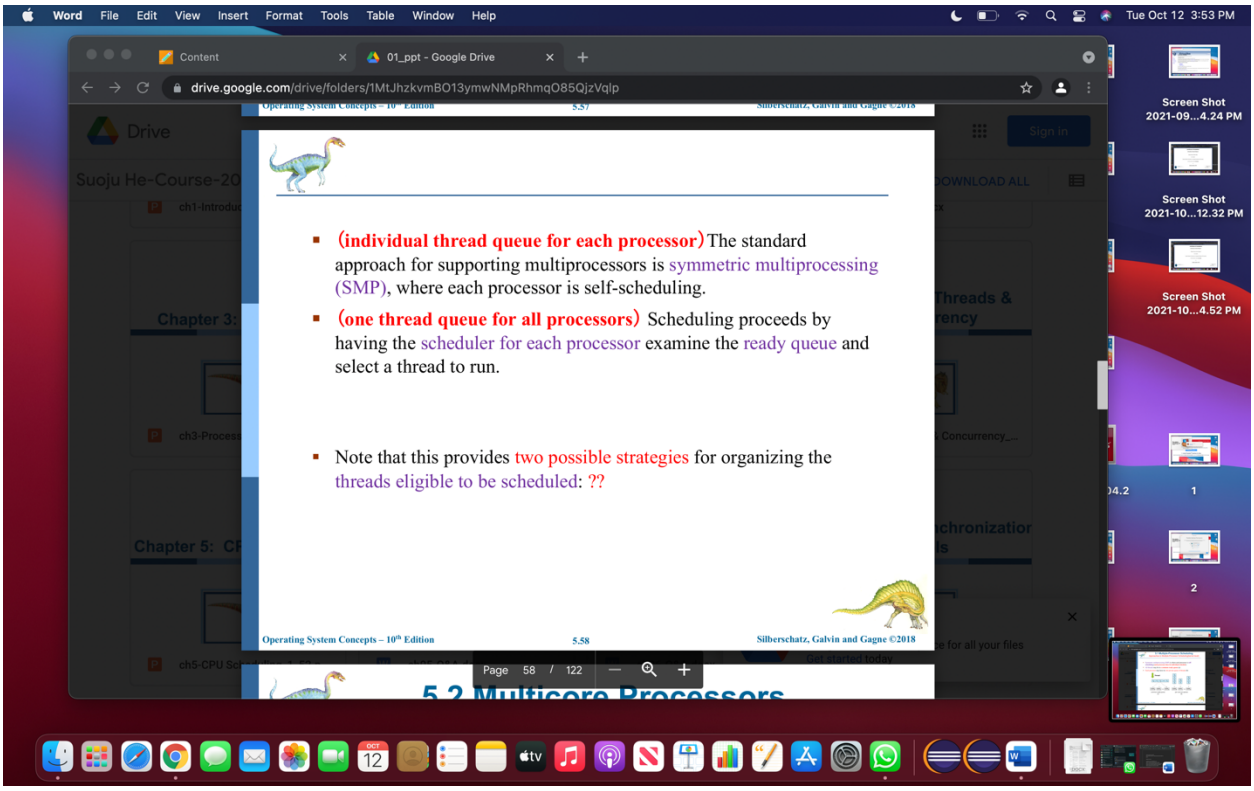
system-contention scope (SCS): multiple kernel threads share/compete one cpu core.

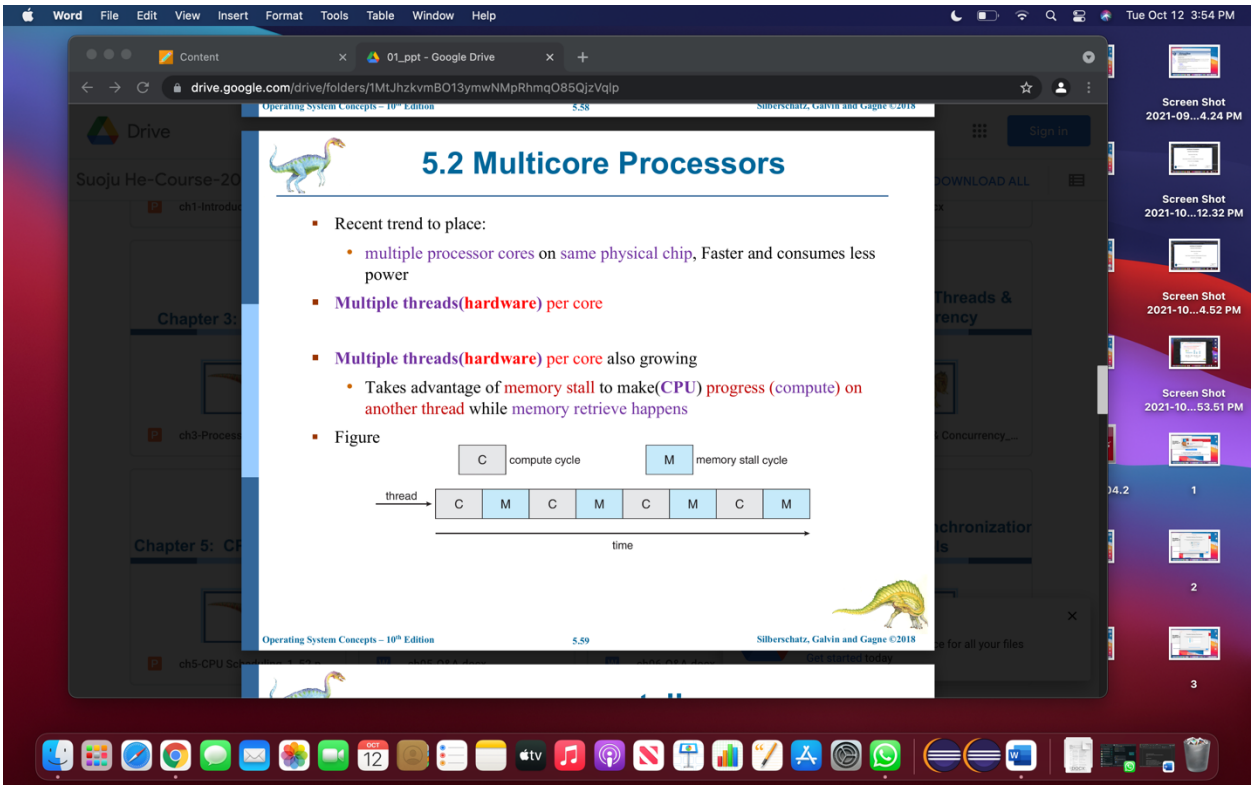
20)Differ PCS & SCS?



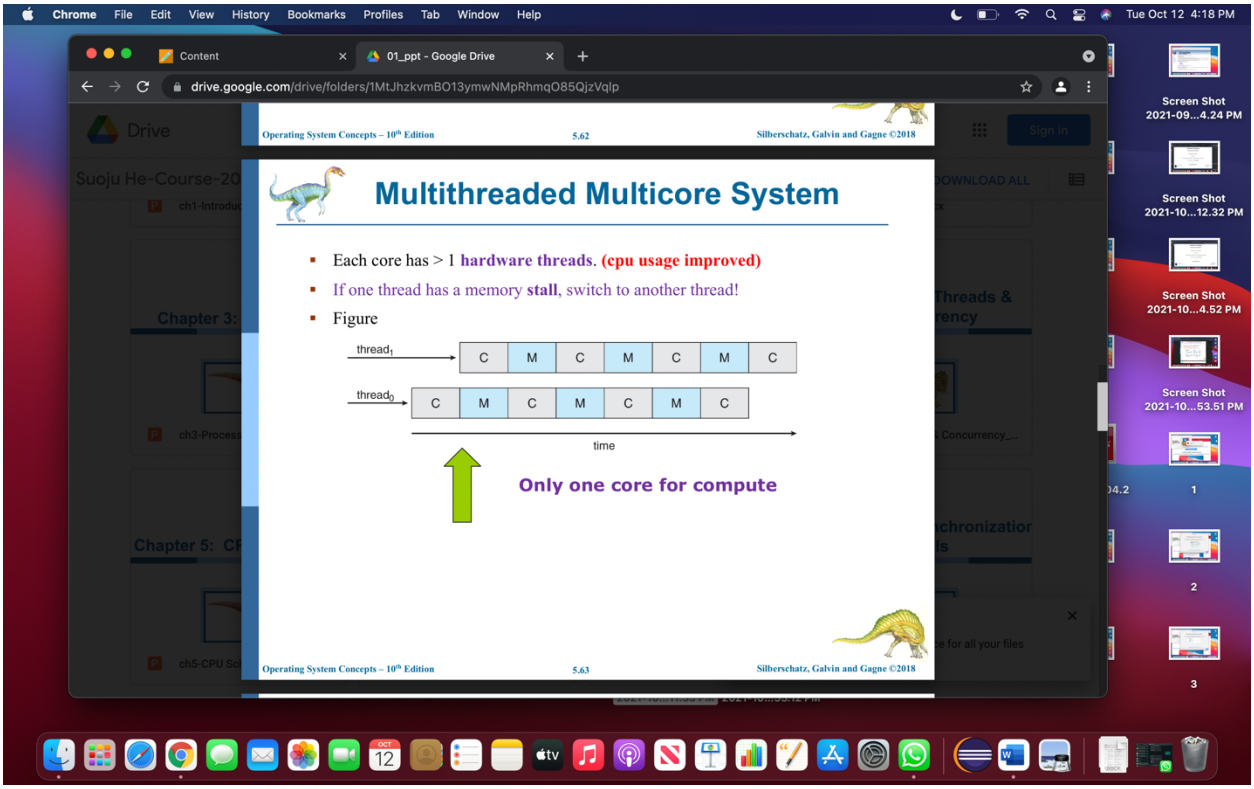
21)Multiple-Processor Scheduling(multi-core)

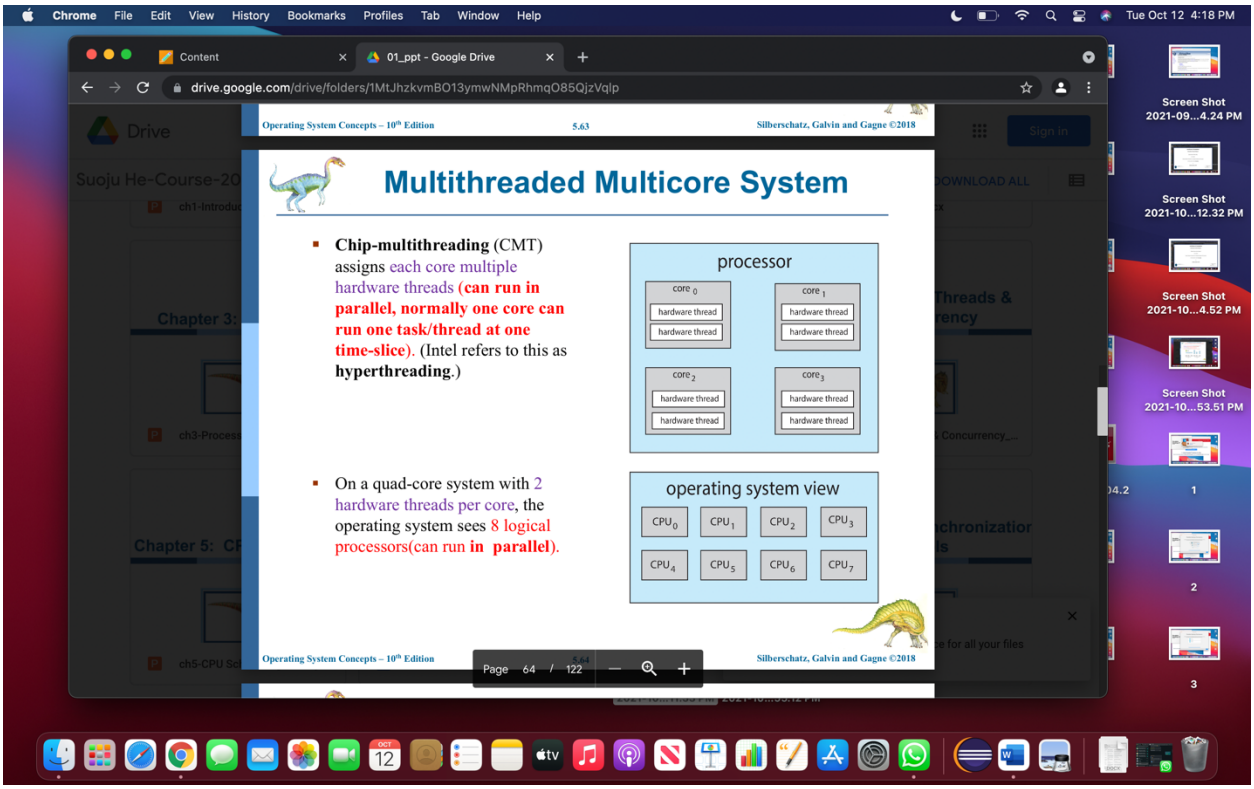






22)Why we should have Multithreaded Multicore System?




Operating System Concepts – 10th Edition 5.63 Silberschatz, Galvin and Gagne ©2018
Multithreaded Multicore System
Chip-multithreading (CMT) assigns each core multiple hardware threads (can run in parallel, normally one core can run one task/thread at one time-slice). (Intel refers to this as hyperthreading.)
processor
core 0
core 1
core 2
core 3
hardware thread
On a quad-core system with 2 hardware threads per core, the operating system sees 8 logical processors(can run in parallel).
operating system view
CPU0 CPU1 CPU2 CPU3 CPU4 CPU5 CPU6 CPU7
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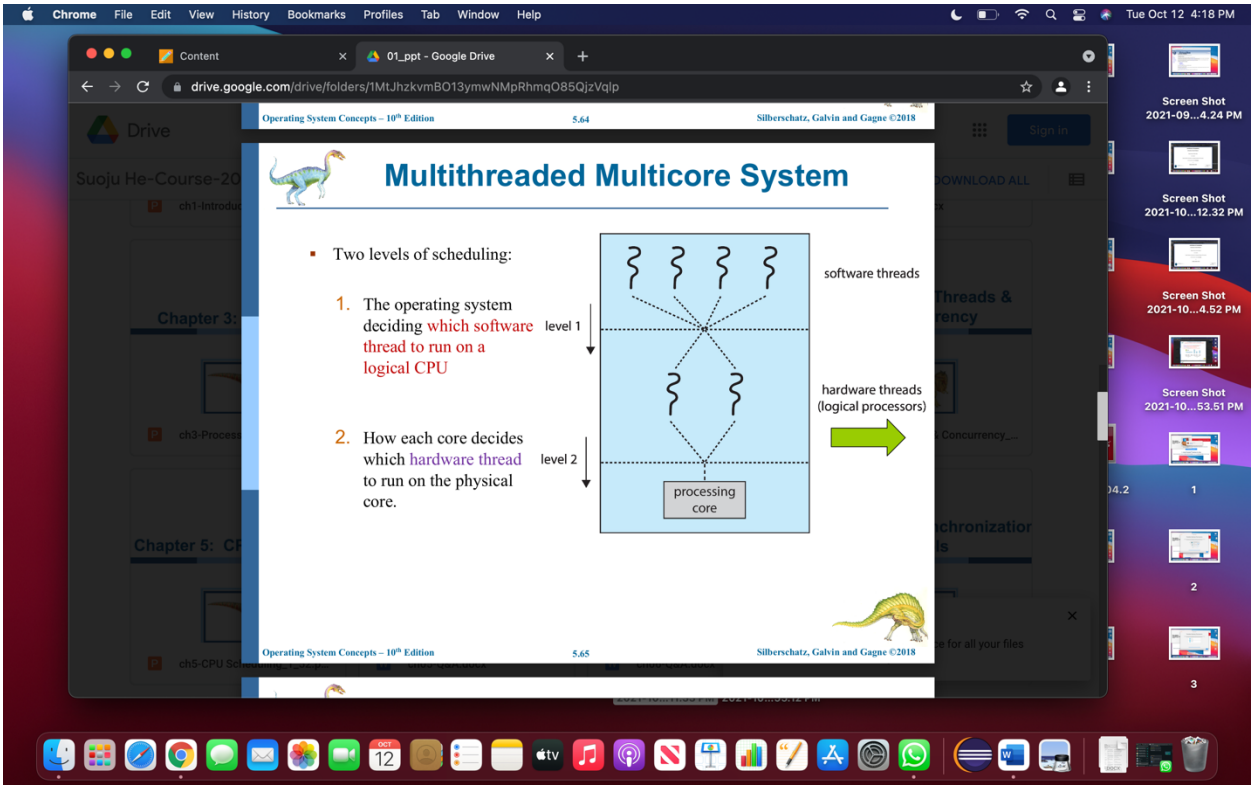
Operating System Concepts – 10th Edition 5.64 Silberschatz, Galvin and Gagne ©2018
Multithreaded Multicore System
Two levels of scheduling:
1. The operating system deciding which software thread to run on a logical CPU
level 1
2. How each core decides which hardware thread to run on the physical core.
level 2
software threads
hardware threads (logical processors)
processing core
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23)Why we need Load Balancing in Multiple-Processor Scheduling?
If SMP（symmetric multiprocessing, each processor has its own scheduler）, need to keep all CPUs loaded for efficiency.

Load balancing attempts to keep workload evenly distributed.

Push migration – periodic task checks load on each processor, and if found pushes task from overloaded CPU to other CPUs.

Pull migration – idle processors pulls waiting task from busy processor.

24)What is Processor Affinity in Multiple Processor Scheduling?
When a thread(task) has been running on one processor, the cache contents of that processor stores the memory accesses by that thread.

We refer to this as a thread having affinity for a processor (i.e., “processor affinity”).

25)Why Load balancing may affect processor affinity?
Load balancing may affect processor affinity as a thread may be moved from one processor to another to balance loads, yet that thread loses the contents of what it had in the cache of the processor it was moved off .

Soft affinity – the operating system attempts to keep a thread running on the same processor, but no guarantees.

Hard affinity – allows a process to specify a set of processors it may run on.

26)Real-Time CPU Scheduling

Can present obvious challenges.

Soft real-time systems – Critical real-time tasks have the highest priority,

but no guarantee as to when tasks will be scheduled.

Hard real-time systems – task must be serviced by its deadline.

27)Soft real-time systems

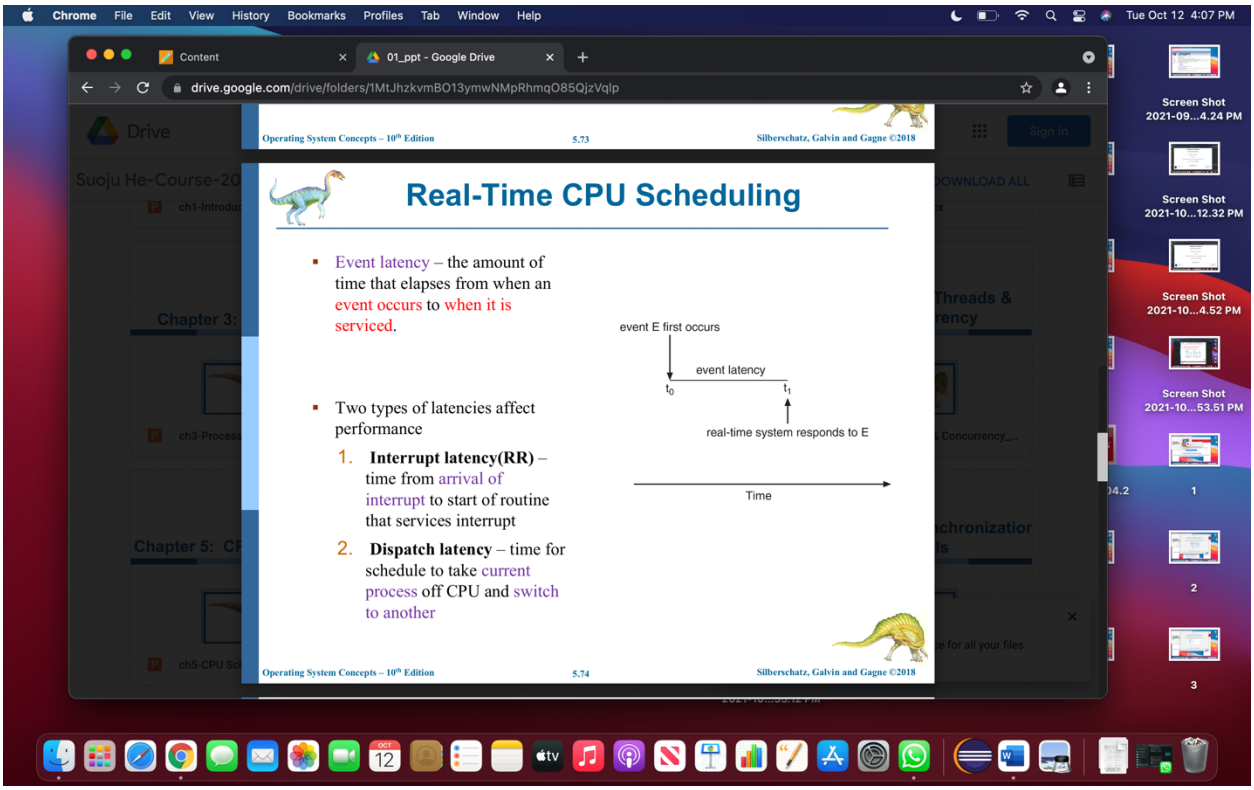
Soft real-time systems – Critical real-time tasks have the highest priority,

but no guarantee as to when tasks will be scheduled.

28)Hard real-time systems

Hard real-time systems – task must be serviced by its deadline.

29)What are two types of latencies that affect real-time systems performance?

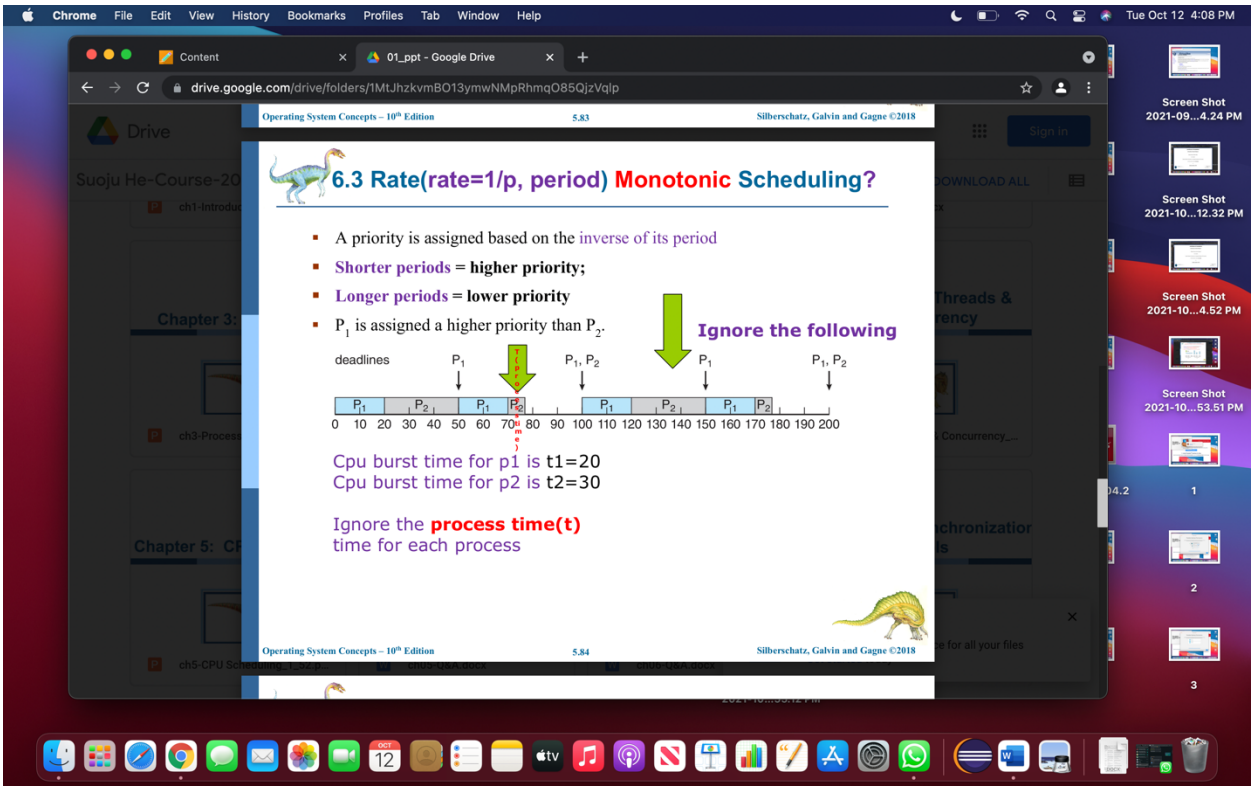


30)Why Real-Time CPU Scheduling is Priority-based Scheduling?

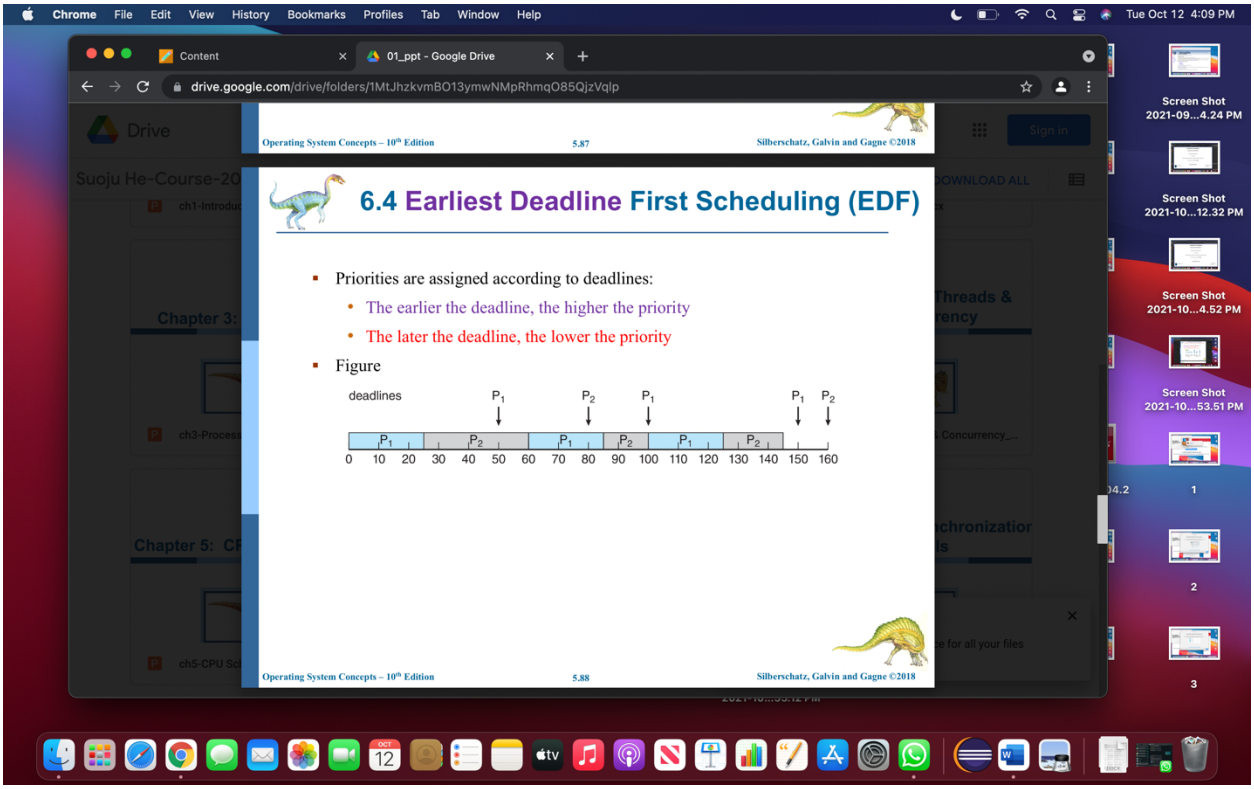
The most important feature of a real-time operating system is to respond immediately to a real-time process as soon as that process requires the CPU.

As a result, the scheduler for a real-time operating system must support a priority-based algorithm with preemption.

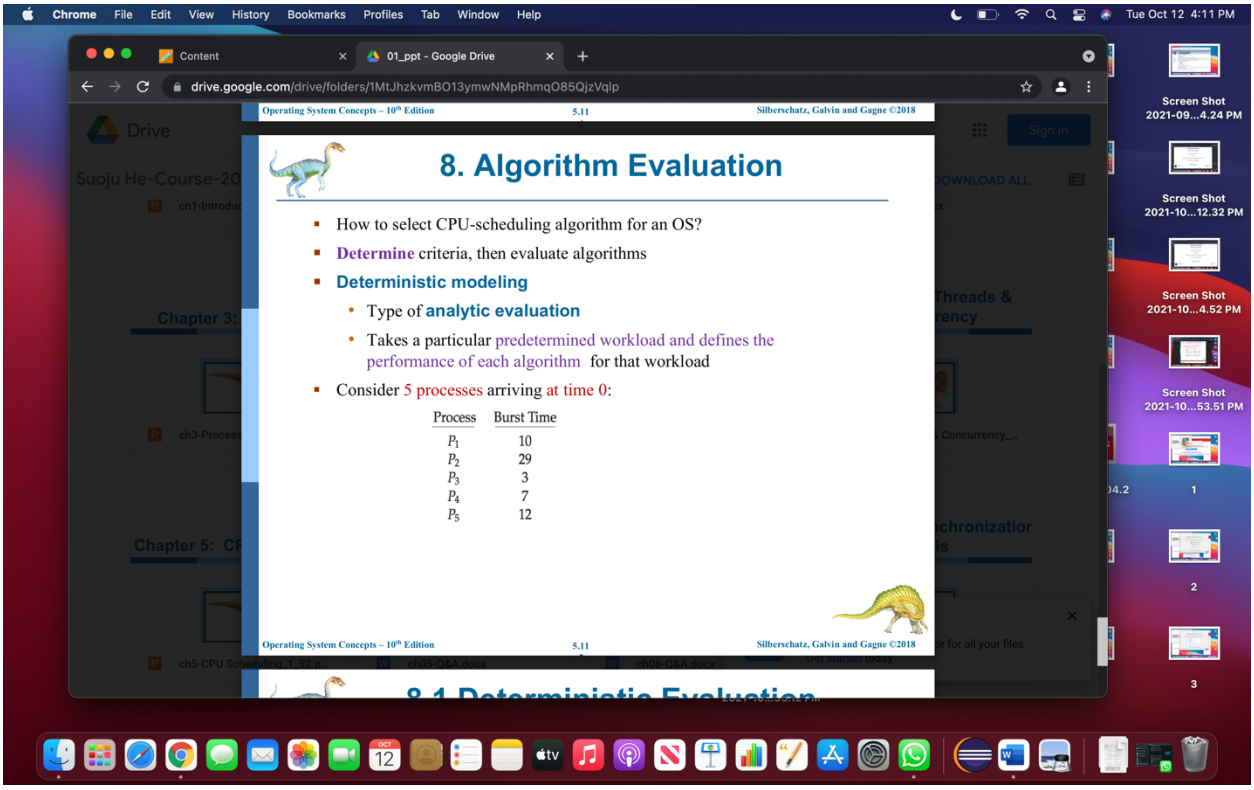
31)Rate Monotonic Scheduling



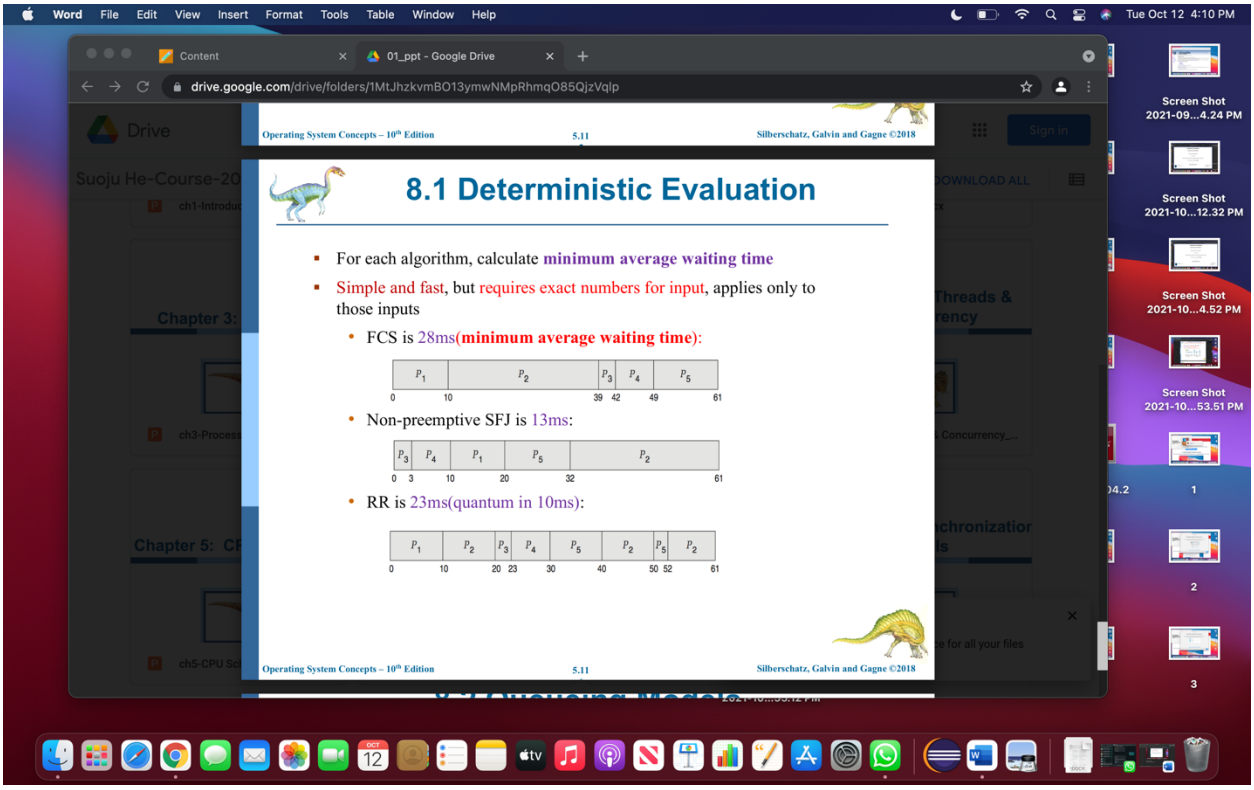
32)Earliest Deadline First Scheduling (EDF)



33)Algorithm Evaluation



34)Deterministic modeling/Evaluation



1Q.What is race condition? Give an example of it?

➔Several processes access and manipulate the same data concurrently and the outcome of the execution depends on the particular order in which the access takes place（read/write for same data）, is called a race condition.

- To guard against the race condition above, we need to ensure that **only one process** at a time can be manipulating the **variable count**.
- To make such a guarantee, we require that the processes be synchronized(scheduled) in some way.

- Ex: Writer process is not finishing writing, when reader starts to read.

2Q.Describe the critical-section problem and illustrate a race condition?

- Consider system of ***n*** processes {$p_0, p_1, \ldots p_{n-1}$}
- Each process has **critical section** segment of code
  - Process may be **changing common variables**, **updating table**, **writing file**, etc.
  - When one process in critical section, no other may be in its critical section
- ***Critical section problem*** is to design protocol to solve this
- Each process must ask permission to enter critical section in **entry section**, may follow critical section with **exit section**, then **remainder section**
  - **entry section(**process must ask permission to enter CS**)**
  - critical section
  - **exit section**

- **remainder section**

Critical Section

- General structure of process P_i

```
while (true) {
        entry section
            critical section
        exit section
            remainder section
}
```

3Q.Requirements for solution to critical-section problem?

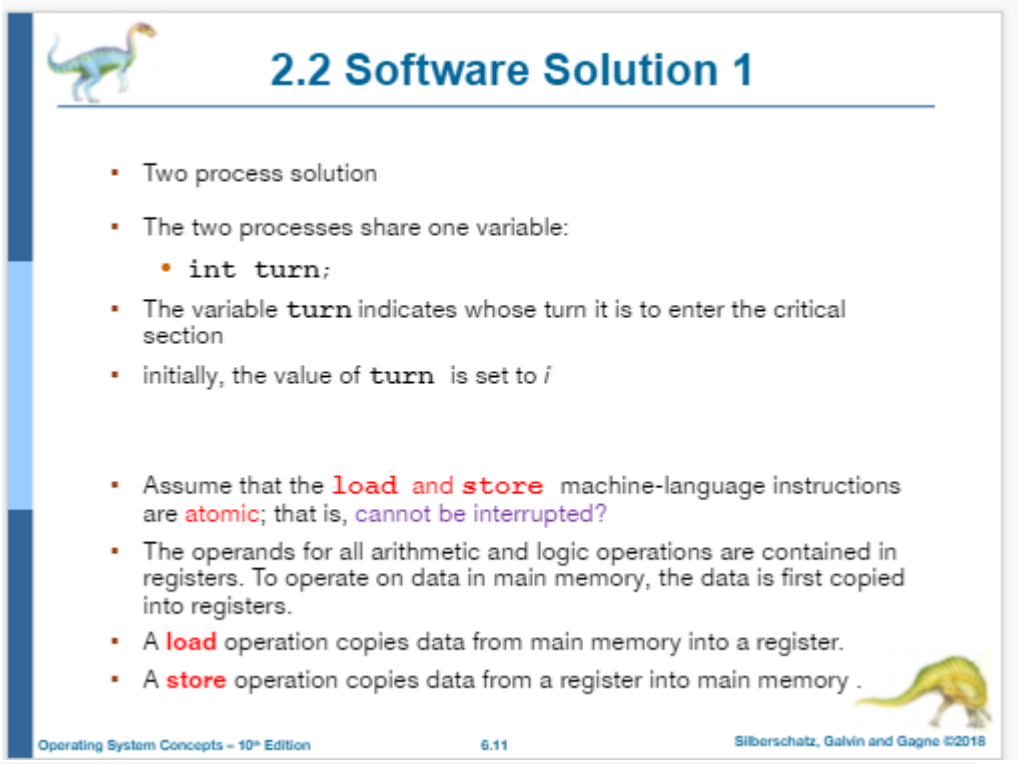
1. **Mutual Exclusion** - If process P_i is executing in its critical section, then no other processes can be executing in their critical sections
2. **Progress** - If no process is executing in its critical section and there exist some processes that wish to enter their critical section, then the selection of the process that will enter the critical section next cannot be postponed indefinitely(each process need to progress)
3. **Bounded Waiting** - A bound must exist on the number of times that other processes are allowed to enter their critical sections

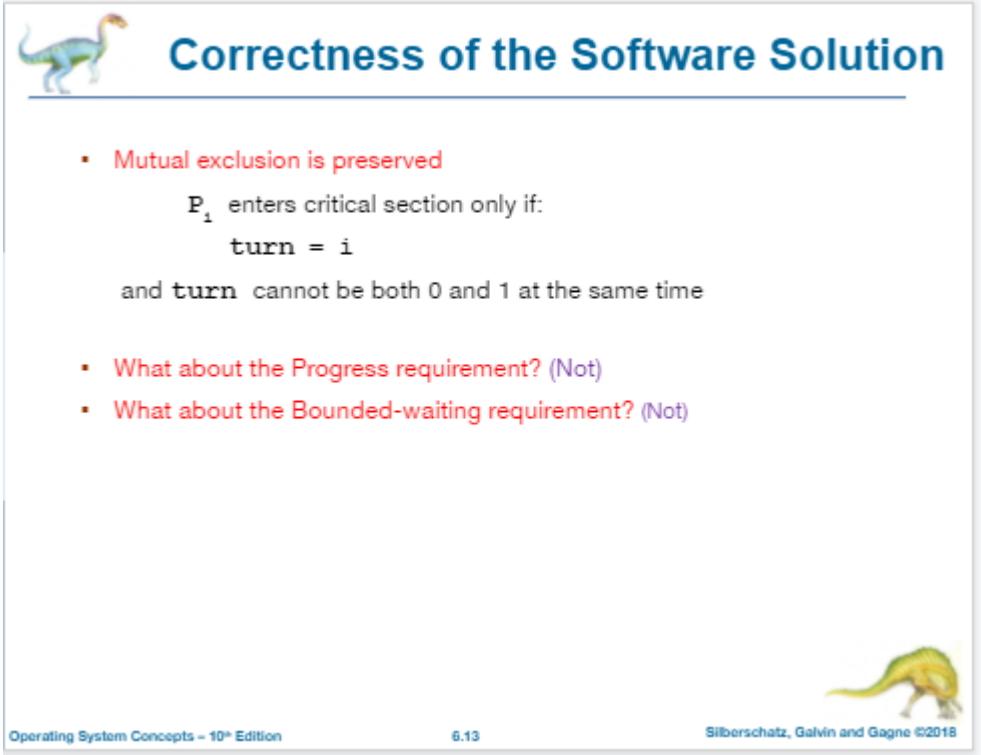
after a process has made a request to enter its critical section and before that request is granted

- Assume that each process executes at a nonzero speed
- No assumption concerning **relative speed** of the ***n*** processes
- Can not wait indefinitely?

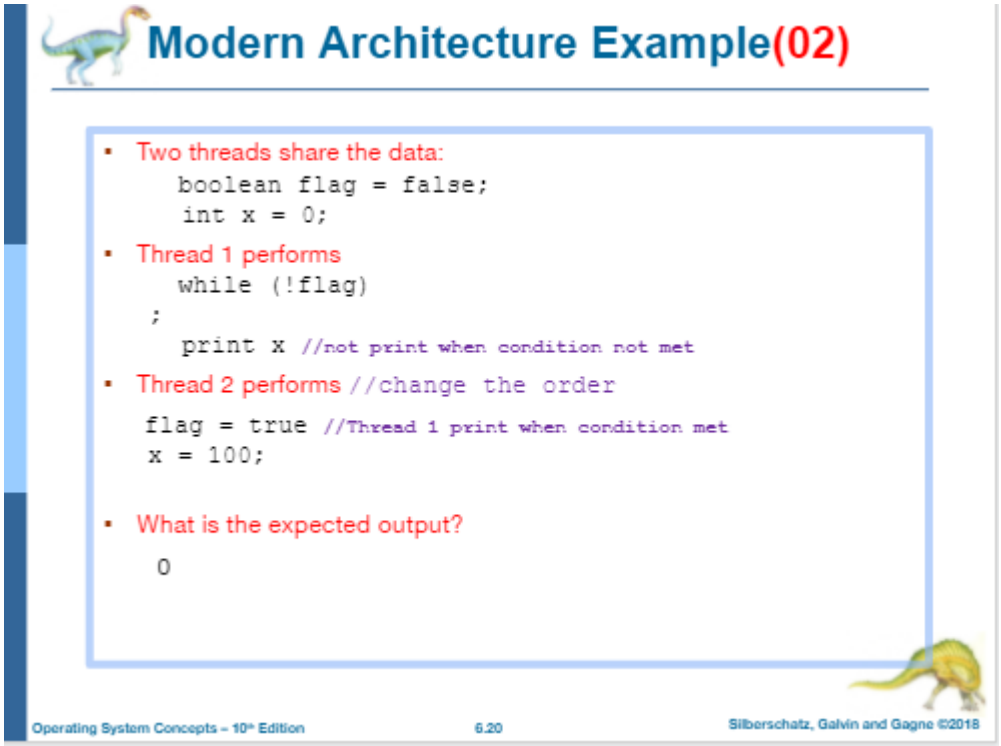
4Q.Can Interrupt-based Solution meet all the requirements for solution to critical-section problem? Why?

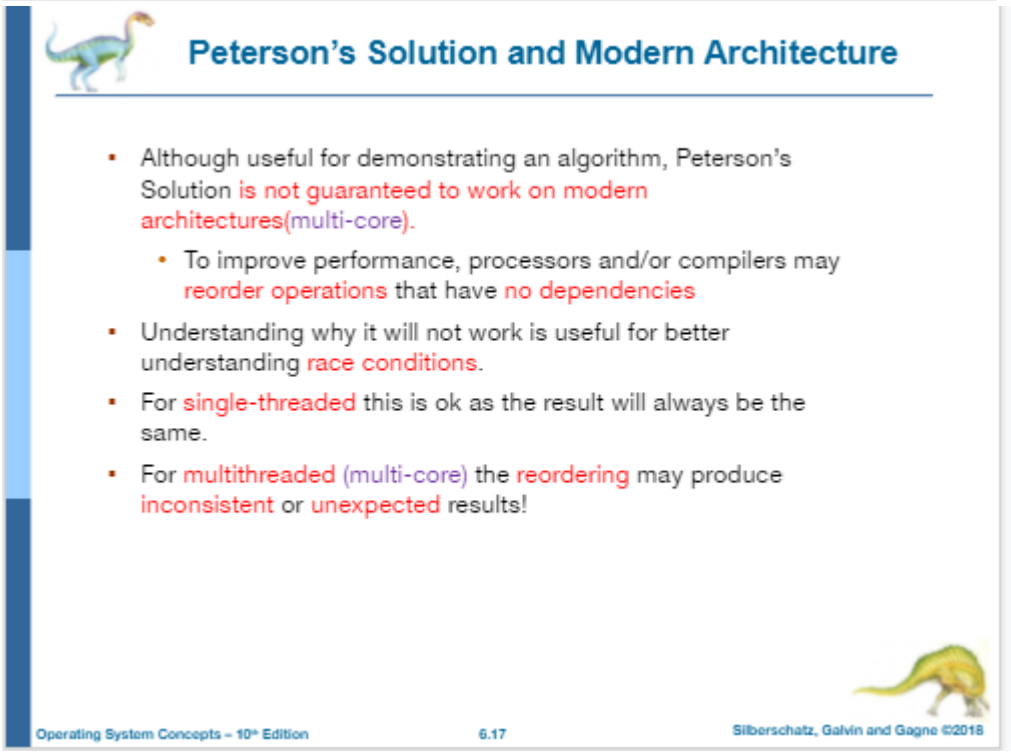
5.What is Software Solution No.1 (instructor names it to differ from Peterson's Solution)? Can this solution meet all the requirements for solution to critical-section problem? Why?





Why Peterson's Solution is not guaranteed to work on modern architectures(multi-core)?





Why software solution cannot eventually solve CS problem on modern architectures?

8.Illustrate hardware solutions to the critical-section problem using memory barriers, Test-and-Set, compare-and-swap operations, and atomic variables

Demonstrate how mutex locks, semaphores can be used to solve the critical section problem

The definition of `acquire()` is as follows:

```
acquire() {
   while (!available)
     ; /* busy wait */
   available = false;
}
```

The definition of `release()` is as follows:

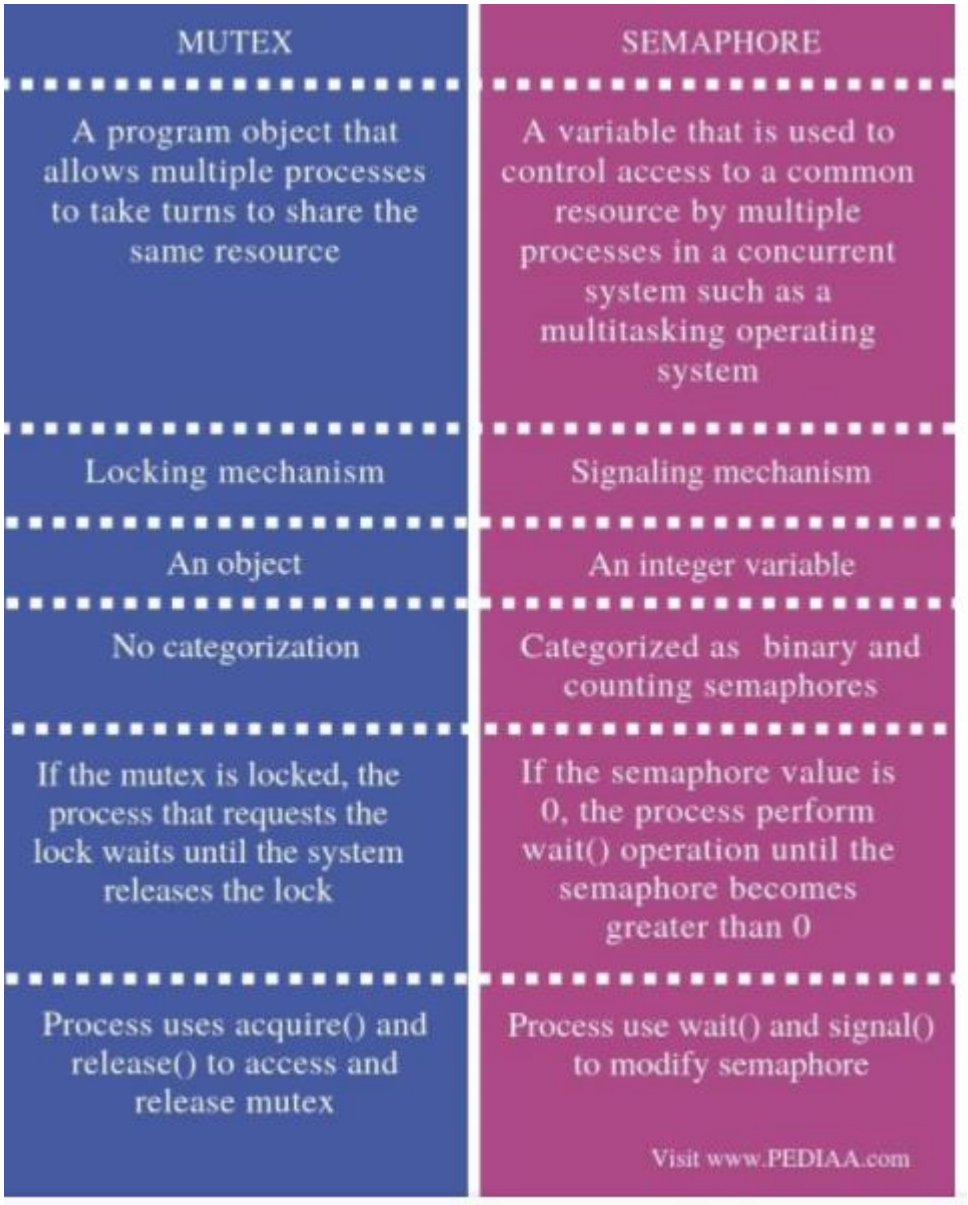
```
release() {
  available = true;
}
```

Solution to CS Problem Using Mutex Locks

```
while (true) {
    acquire lock

       critical section

    release lock

remainder section
}
```

Figure 6.10 Solution to the critical-section problem using mutex locks.

Differ Mutex Locks and Semaphore



What is the relation between mutex locks & semaphores and hardware solutions, such as Test-and-Set & compare-and-swap?

A mutex object allows multiple process threads to access a single shared resource but only one at a time. On the other hand, semaphore **allows multiple process threads to access the finite instance of the resource until available**. In mutex, the lock can be acquired and released by the same process at a time.
Test and set vs Compare and Swap

test-and-set **modifies the contents of a memory location** and returns its old value as a single atomic operation. compare-and-swap atomically compares the contents of a memory location to a given value and, only if they are the same, modifies the contents of that memory location to a given new value.