**Lecture 1: Intro**

OS is second most imp subject in CS after DSA.

Mainly it is used when we need to directly interact with the hardware/machine.

Topics like process synchronization and memory management are useful for software development.

OS is a software which takes control of the computer after machine is turned on power on tests are completed. It becomes the incharge of the machine.

Applications don’t directly interact with the machine. The interact with OS and OS with hardware.

Why do we need manager/incharge?

Abstraction: Without the OS we will have to write code for basic functionalities such as displaying text on screen, moving mouse cursor etc. OS contains the necessary codes for the basic functionalities and makes things easier. This also keeps the hardware abstract.

Resource Management: We have limited resources in our machine and using them effectively is difficult. OS manages the resources.

Protection: It also protects the hardware from applications and applications from each other.

Do we always need a manager?

Let us say we want to operate hardware like lifts and ovens. In such cases the chips are simple and only one or few simple tasks are to be done in such cases we don’t need OS.

Desktop OS: Windows, Linux, MacOS.

Mobile OS: Android, iOS.

There are more OS for printers, routers etc.

Three main services that OS provide:

Abstraction.

Resource Management.

Protection.

**Lec 02: Types of OS**

There can be many basis of classification.

Based on functionality provided by OS.

1. Single Tasking: MS-DOS, Only one process other than OS can exist in memory.
2. Multi Programming and Multi Tasking: Having multiple processes in RAM and assign them in smartly to CPU. Multiprogramming is general idea of managing multiple processes and multitasking is an extended version of multi-programming.
3. Multithreading:
4. Multiprocessing: For a system with multiple processors.

Thread: A thread is the smallest unit of execution/process that can be assigned to CPU. A process can be composed of single or multiple threads. Every OS uses concept of multi-threading nowadays.

Multi-user operating systems: Multiple users can use the same machine as different unique users.

**Lec 03: Thread vs Process**

Program gets loaded in RAM and then it is called a Process. A process is program in execution.

Pictorial representation of process with single thread. These are segments of a process.

|  |
| --- |
| Stack ↓ (Stack grows downwards) |
|  |
|  |
|  |
| Heap ↑ (Heap grows upward) |
| Text/Code |
| Data |

If a process is single threaded then it will have only one stack. For multi-threaded processes we have multiple stacks.

Pictorial representation of process with multiple threads.

|  |  |  |
| --- | --- | --- |
| Stack ↓ | Stack ↓ | Stack ↓ |
|  | | |
|  | | |
|  | | |
| Heap ↑ (Heap grows upward) | | |
| Text/Code | | |
| Data | | |

Multiple threads have multiple stacks but same Heap, data and code.

Concurrent and parallel have different meanings with reference to process execution.

More about threads:

1. Faster to create and terminate.
2. Share same address space.
3. Easier to communicate.
4. Context switching is easier.
5. Lightweight.

**Lec 04: Multithreading Intro**

* Multithreading vs Multitasking
* Some real world examples
* Advantages and Disadvantages

Multitasking: Listening to music and browsing. (Multiple tasks are being done)

Multithreading: Downloading and browsing. (Multiple things are begin done within a process)

Real world examples of multithreading:

MS Word: Typing, saving, formatting is done together using multithreading.

IDEs: Error checking is done while the text is formatted.

Advantages of multithreading:

1. Parallelism and improved performance
2. More responsiveness
3. Better resource utilization

Threads are also called light weight processes.

Disadvantages of Multithreading:

1. Difficulty in writing, testing and debugging code.
2. Can lead to deadlock and race conditions. (mainly when variables are shared, like in language JAVA)

R2

R1

Deadlock

The above diagram is technically called **The Resource Allocation Graph**.

Deadlock: T1 thread holds R1 resource and is waiting for R2. Meanwhile T2 holds R2 and is waiting for R1. Until T1 releases R1, T2 cannot be finished and similarly for T1.

**Lec 05: User Threads vs Kernel Threads**

User managed threads: The threads created by a process and the kernel is not aware about the threads and the process manages the threads.

Kernel managed threads: Managed by kernel and kernel is aware of everything going on.

|  |  |  |
| --- | --- | --- |
|  | User Managed Threads | Kernel Managed Threads |
| Management | In user space | In kernel space |
| Context Switching | Fast | Slow |
| Blocking | One thread can block all other threads | A thread can block itself only. |
| Multicore or Multiprocessor | Cannot take advantage of multicore systems. Only concurrent execution on single processor. | Takes full advantage of multicore systems. |
| Creation/Termination | Fast | Slow |

Usually every process have both kind of threads.

One to one: One user thread is mapped to only one kernel thread. On other user thread is mapped to this kernel thread. This is most common. This resembles with purely kernel managed threading system.

Many to one: Multiple user threads are mapped to one kernel thread. This resembles with purely user managed threading system.

Many to many: Multiple user threads are connected to multiple kernel threads. Very uncommon.

**Lec 06: Intro to process**

Program: File that resides on hard disk which can be executed.

Process: A program in execution.

The binary file (.exe) is loaded into RAM and then run. While it runs it is called a process.

|  |
| --- |
| Stack ↓ (Stack grows downwards) (for function calls, local variables) |
|  |
|  |
|  |
| Heap ↑ (Heap grows upward) (head for dynamically allocated memory) |
| Text/Code (Instructions to be executed) |
| Data (static and global variables) |

**Lec 07: Process States**

Single tasking systems (MS – DOS)

New Process-> Goes in Memory -> Finished/Terminated

In such systems processor remains idle for long.

Multiprogramming System: Systems which can have multiple processes in RAM other than OS simultaneously. They have 5 state model.

Running

New

(

Finished

Ready

Waiting

New State: We just double clicked an exe file. Process control info is created. But the exe file is not yet loaded in RAM, it is still in HD. It is also said that process is not created yet.

Ready State: exe file is partially or completely in RAM. Now it is said that process has been created and ready to be picked by the processor.

When the required part in in RAM. The dispatcher takes it to CPU and the process is said to be dispatched.

If a higher priority process comes or time-out happens the process is sent back to ready state.

If the process requests I/O word it is sent to waiting state from running state.

Once the I/O is done, the process is again sent to ready state and then dispatched.

If the process gets finished or aborted, it is sent to finished state.

The seven-state model:

Two more states come out of waiting state.

New

(

Ready

Running

Finished

Waiting

Suspend

Resume

Suspend/Ready

Suspend/Block

Suspend

Resume

When all the current processes are in waiting state, CPU is idle. In such cases, one of the processes is sent back to HD to pick a new process from HD.

While waiting the process is in RAM but on suspending the process is in HD.

Process can be directed to suspended state while waiting or while in ready state.

While in any suspended state the process is in HD but suspended state means that process has been through ready state for at least once and has not completed yet.

There is a dedicated place for suspended processes. Swap partition/space is available in Linux for these. In windows, a folder, page file stores these processes. (Things might have changed over time.)

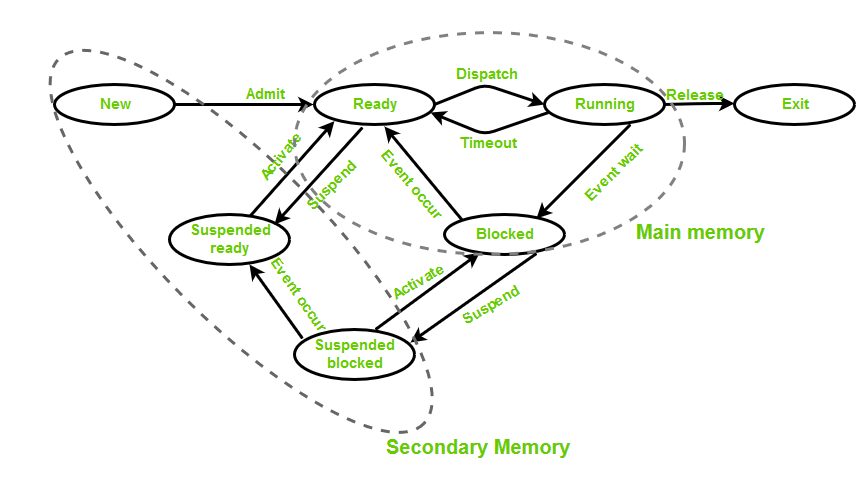


Diagram from GeeksForGeeks

Note: CPU interacts with RAM only. It doesn’t interact with HD. CPU doesn’t pick up processes. It is responsibility of OS to assign process to CPU.

**Lec 08: Process State Block**

PCB is a data structure. It is the most central data structure of OS. It is the most secure DS so that id doesn’t get corrupted.

It stores info regarding process state. Some of the imp info is:

1. Process Id (Integer)
2. Process state
3. CPU Register
4. Accounts info (how much CPU time has been consumed etc.)
5. I/O Info
6. CPU scheduling info
7. Memory Info (memory blocks allocated to process etc.)

One imp CPU register is program counter which tells the next instruction to be executed.

**Lec 09: Process Schedulers**

I/O Bound Processes:

CPU Bound Processes:

1. Long Term Scheduler: Brings process from HD to RAM. Controls the degree of multi programming. Ideally it should bring a good mix of I/O bound and CPU bound processes. Decisions made by it occur on large gap that is why it is named so.
2. Short Term Scheduler: Moves the process from ready to running state. It assigns processor one of the picked processes. It has to make frequent decisions that is why it is named so. It also calls dispatcher. Dispatcher does the process control switch.
3. Medium Term Scheduler: It manages the suspending, blocking and resuming of process. It can be said that it moves processes from HD to RAM and vice versa.

**Lec 10: Background for Scheduling Algos**

The most crucial part is which process should be picked from ready state.

Most of the algos we study are for short term scheduler or for the jobs in ready Q.

* Different Queues: Ready Q, Job Q, I/O Q (each I/O device has its own Q).
* Short Term Scheduler and Dispatcher: STS picks one of the processes from ready Q and dispatcher comes into light. Once a process is picked, Dispatcher does the context switch, mode switch and tells from where a program should begin (a program might come from suspended state so it should not run from beginning).

When does STS picks a process?

1. When some process moves from running to waiting state.
2. When some other process moves from running to ready state.

Pre-emptive cases

1. When a new/existing process moves to ready state.
2. When a process is aborted or terminated.

Time related terms in Scheduling Algos:

1. Arrival Time (Point):
2. Completion Time (Point):
3. Burst Time (Period):
4. Turn Around Time (Period):
5. Waiting Time (Period):
6. Response Time (Period):­

Goals of Scheduling Algos:

1. Max CPU utilization
2. Max throughput (throughput is number of jobs finished in unit time.)
3. Min Turn Around Time
4. Min Waiting Time
5. Min Response Time
6. Fair CPU Allocation (No Starvation)

Starvation: If a process has been waiting for a long time to get picked and executed then it is said to be starving.

Almost every time we care much about averages of the time.

GANTT Chart: Representation of CPU utilization by process with time stamps.

**Lec 11: FCFS Scheduling**

First Come First Serve. It is non pre-emptive. It is not batch processing.

The process which comes first gets executed first.

Advantages:

1. Simple and easy to implement.

Disadvantages:

1. Non-pre-emptive.
2. Convoy effect.
3. Average waiting time is not optimal.

**Lec 12: SJF (Non Pre-Emptive)**

Considers the jobs in increasing order of their Burst time.

**Lec 13: SJF (Pre-Emptive)**

Also called shortest remaining time first algo.

At every second, the process which has shortest remaining time is picked and executed.

Advantages:

1. Min average waiting time among all scheduling algos.

Disadvantages:

1. May cause high waiting time and response time for CPU bound processes.
2. Impractical, because the burst time can only be known after a process is aborted or terminated. However, there are ways to guess the CPU time of the process but still they would be guesses.

**Lec 14: Priority Scheduling**

It can be pre-emptive or non pre-emptive.

Every process has a priority and the process which has highest priority is picked.

It is very common.

Average times depend on arrival time and priorities of process.

Advantages:

Disadvantages:

1. Starvation of low priority processes. Starvation of processes can be handled with a technique called aging. Aging means priority of process increases with time.

How can we manually assign priorities?

One simple way: Earlier is the deadline, more should be the priority. This is static way of assigning priority. There are more and better ways of assigning priorities.

Aging is a dynamically priority assigning technique.

FCFS and SJF both are priority scheduling algos. In FCFS, processes are prioritized on the basis of arrival time. In SJF, remaining time is considered for priority.

**Lec 15: Round Robin Scheduling Algo**

One of the most asked and popular scheduling algo.

Terminologies:

1. Time Quantum: Max time for which a process can be executed.

Idea: We maintain a circular ready queue. Pick the process from the front. Execute it not more than for the fixed time. If it does not finish in fixed time, push it back with its remaining time. Move to next process.

Average waiting time can be high.

Response time is generally good.

Deciding time quantum is difficult. Small time quantum will lead to too many context switches. Large time quantum will make it FCFS.

**Lec 16: Multilevel Queue Scheduling**

Concept: Divide the ready queue into multiple queues, use different scheduling algo for different queues. Put different processes in different queues. Then we have to arrange queues as well on the basis of some scheduling algo.

Commonly the queues are arranged on the basis of priorities or round robin algo.

Another way of running multiple queues is using two queues, one for foreground processes and on for background. Background queue is generally for lower priority processes.

The multi-level queue scheduling is used with feedback in Windows and Mac OS. Linux has improved itself and uses better scheduling algo.

In multilevel queue scheduling with feedback, process can be moved from one queue to another. It is one of the hardest, most useful and most flexible algos to implement.

**Lec 17: Deadlocks**

When a process runs it uses resources. Process runs in its own address space. Processes request the OS to get the resources and it is the responsibility of OS to manage the resources. The resources might be sharable or non-sharable.

Deadlock has been discussed earlier with diagram.

Four **necessary** conditions for deadlock:

1. Mutual Exclusion: Deadlocks are possible only if the resources cannot be shared among the processes.
2. Hold and Wait: Processes must be holding some resources and must be waiting for some resources.
3. No pre-emption: This pre-emption is different from process pre-emption. It means that an assigned resource cannot be taken until the process is finished/aborted.
4. Circular Wait: In circular wait, processes wait in circle for each other to finish.

All these 4 conditions are together responsible for deadlock.

Real world example of deadlock: Trains coming towards each other.

The Resource Allocation Graph is used in DBMS.

In Resource Allocation Graph:

1. Process is represented in circle.
2. Resource is represented in rectangle.
3. There might be multiple instances of a resource. Multiple instances are shown by using dots in graph.

Resource

. . .

This means that resource has three instances.

1. Arrow from process to resource means that process is waiting for the resource.
2. Arrow from resource to process means that the resource is allocated to process.

Two instances of R1 allocated to different processes. Both the instances of R2 allocated to same process.

Resource 1

**. .**

Resource 2

**. .**

**Lec 18: Methods of handling deadlocks**

1. Deadlock Prevention: Making sure that one of the necessary four conditions always fails. This is achieved by setting rules for processes or for resources. Before sending any request to access the resource it is made sure that it must not create deadlock. OS in this case has nothing to do for deadlock.
2. Deadlock avoidance: Processes can send all requests. It is responsibility of OS to check if granting the request will cause deadlock or not. OS can use any algo for the check. Banker’s algo is one such algo.
3. Detection and Recovery: OS periodically checks if deadlock has happened or not. If a deadlock is found, one of the processes is killed to free the processes.
4. Ignore the deadlock: If a type of deadlock is very rare. OS let the deadlock happen and user has to reboot the system. Ignoring deadlock was a method used by windows and Linux earlier but nowadays OS use advanced ways to deal with them.

Deadlock handling techniques might vary from resource to resource.

**Lec 19: Deadlock Prevention**

Prevent/Eliminate any of the necessary conditions for deadlock.

1. Mutual Exclusion: It cannot be completely eliminated practically. It is done by a method called Spooling.

For example: the printers have their own job queue and each print request is added to that queue.

Spooling is not a full proof solution because the job queue might get full.

1. Hold and Wait: There are two ways to eliminate Hold and Wait.
2. Knowing which resources are going to be used by the process. This way is quite impossible.
3. A process while sending a request for a resource must release all the other resources it is holding. This way is also not very useful because the released resources by this process might be useless for the other processes.
4. No pre-emption: OS takes away the resources allocated to a process. This might be problematic because the process might be in the middle of something.
5. Circular Wait: We number the resources. Then we make a rule to assign the resources to the processes. For example: If a process has taken resource with number n, it cannot acquire any resource which has number lesser than n. This prevents cycle.

**Lec 20: Deadlock Avoidance (Banker’s Algorithm)**

|  |  |  |  |  |
| --- | --- | --- | --- | --- |
|  | Allocated | | Max Required | |
|  | R0 | R1 | R0 | R1 |
| P0 | 0 | 1 | 7 | 5 |
| P1 | 2 | 0 | 3 | 2 |
| P2 | 3 | 0 | 9 | 0 |
| P3 | 1 | 1 | 2 | 2 |
| P4 | 0 | 0 | 4 | 3 |

Total instances of R0 = 10 and R1 = 5

Deadlock avoidance works if the max required for each process is known before. Knowing which resources are required and in what quantity before the execution of process is impossible. But let us work on this.

Let us say P3 requests for <1, 0>. Should the OS grant the request?

Make the resource allocation diagram by assuming that the resources have been allocated to P3.

Now try to generate a safe sequence. If a safe sequence can be generated then it is said that safe state can be achieved after resource allocation and the resources will actually be allocated.

Safe Sequence:

* A permutation of the processes
* in which when the processes are executed one by one in sequence
* and after execution of every process the resources allocated to the process are released
* and can be used by other processes.
* If all the processes can be executed,
* then the sequence is called, Safe Sequence.

Algo to find Safe Sequence:

Create a Need Matrix.

Must remember: For generating safe sequence we must assume that the resources have been allocated.

|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
|  | Allocated | | Max Required | | Need Matrix | |
|  | R0 | R1 | R0 | R1 | R0 | R1 |
| P0 | 0 | 1 | 7 | 5 | 7 | 4 |
| P1 | 2 | 0 | 3 | 2 | 1 | 2 |
| P2 | 3 | 0 | 9 | 0 | 6 | 0 |
| P3 | 1+1 | 1+0 | 2 | 2 | 0 | 1 |
| P4 | 0 | 0 | 4 | 3 | 4 | 3 |

SafeSequence = {} //initialize empty safe sequence

While(all the processes are not added to safe sequence)

{

1. Find Pi such that need(i) <= available
2. If (no such Pi can be found)

Return false;

1. Else

Available+=Allocated //we are updating Available because this process will be finished and resources will be available for all upcoming processes.

Add Pi to the SafeSequence

}

For the above problem, the SafeSequence is P1 P3 P4 P0 P2.

Before jumping to finding safe sequence do some basic checks such as, is the process asking for resources more than available or the resource is asking for more than max.

Banker’s Algo is developed by Djiktra. It is the only algo for Deadlock Avoidance.

Drawbacks:

1. Requires max required resources.
2. Assumes that resources will be released.

Note: Failing to generate SafeSequence does not guarantee that Deadlock will happen, because the processes need lesser than or equal to max (max is the upper limit). Also, there are more things to consider which we did not.

**Lec 21: Deadlock Detection and Recovery**

It has two steps:

1. Detection: All resources involved have only one instance and there is a cycle in resource allocation diagram, then there is a deadlock. If there are multiple instances then cycle does not guarantee deadlock. If there are multiple instances, then we use Modified Banker’s Algo. We don’t consider the resources which do not hold any resources.
2. Recovery:
3. We can pre-empt resources: It might be problematic because the process might be in middle of something. There might chances of starvation too because the resources might be away from the process for too long.
4. Kill one or more processes: Kill a process and check if the resources are enough or not.

**Lec 22: Process Synchronization**

Processes are of two types:

1. Independent: They run independently.
2. Co-operative: They interact with other processes.

OS has to manage the communication between the processes.

Inter-process communication may happen on same device or across multiple devices using computer networks.

Generally, people think that process synchronization happens when we have multiple processors.

In single processor devices concurrent execution may lead to inter-process communication.

Con-current execution: In round robin, processes get executed one by one. When multiple processes run on intervals, this execution is called con-current execution.

Inter-process communication happens in a device using shared memory. Global Variables are examples of shared memory.

//Global Variables

Int size = 10;

Char buffer[size];

Int in=0, out = 0;

Int count = 0;

//Producer is process 1

Void producer(){

While(true)

{

While(count==Size){

//if no free space is available producer waits

}

Buffer[in]=producerItem();

In = (in+1)%size;

Count++; //IMP LINE

}

}

//Consumer is process 2

Void consumer(){

While(true)

{

While(count==0){//consumer waits infinite if the count is 0 }

consumeItem(buffer[out]);

out = (out+1)%size;

count--; //IMP LINE

}

}

Understanding IMP LINES:

Reg = CPU register

Count++ is interpreted as:

1. Reg = count
2. Reg = reg +1
3. Count = reg

Count-- is interpreted as:

1. Reg = count
2. Reg = reg-1
3. Count = reg

Let us say, count is 8 and count++ was executing in P1 and as soon as statement 2 i.e. Reg = reg +1 executed, P1 was pre-empted. It means that count was not updated.

Now, the CPU is executing P2 and when it comes to count--, it would see that count is 8 because the count has not been updated in P1. Now, P2 makes the count to 7 and CPU goes back to P1.

When P1 resumes, the count sets to 9, because the incremented value was stored in CPU register.

Due to all this, there were inconsistent values of count for both the processes.

Race Condition: When the output depends on the sequence of execution of instructions in a con-current/multi-programming/multi-threading environment, the condition is called Race Condition.

Lec 23: Critical Section

//Global Variable

Int balance = 100;

//Process 1

Void deposit (int x){

Balance = balance + x; //Critical Section

}

//Process 2

Void withDraw (int x)

{

Balance = balance - x; //Critical Section

}

Terminologies:

1. Critical section: The part of code in which we access shared variables is called critical section. The rest of the part is called remainder section or non-critical section.

The inconsistency is due to partial execution of critical section of one process and then execution of another process. We need to put some logic so that only one of the critical section gets executed completely and then only the another critical section gets executed.

The logic has two parts. One has to be before the critical section which allows/denies the process to enter the critical section, this is called entry section. And another has to be after the critical section which controls the exit of process from critical section, this is called exit section.

There might be more than two processes.

**Lec 24: Goals of Synchronization**

1. Mutual Exclusion: Only one process is allowed to enter critical section.
2. Progress: The processes which do not wish to execute their critical section must not block other processes.
3. Bounded Waiting (Fair): It means fairness. Any process should not be waiting for too long to enter the critical section.
4. Performance: The logic must not be slow. There are two ways to lock the processes so that critical section is accessed by one process only.
5. Hardware Locking Mechanism: Better than Software Locking Mechanism.
6. Software Locking Mechanism:

Mutual Exclusion and Progress must be achieved by any synchronization mechanism, others are optional.

**Lec 25: Overview of Synchronization Mechanisms**

1. Disabling Interrupts: The Synchronization problems happen because of race condition. What if a process before entering the critical section declares that it must not be interrupted while it is in critical section. This sounds good. But this works only for single processor devices. There is one more problem that the process might stay in critical section for too long.
2. Locks (Mutex): This mechanism is basic building block for synchronization mechanisms. Locks can be implemented in software and hardware both. A lock is made, process enters critical section, does the work and releases the lock (there might be pre-emption when the process is in critical section). While the lock is on, only the processes which have critical section have to wait until the critical section is executed completely.

Hardware Locks are better than software.

Software locks: Peterson’s Implementation, Bakery Algo.

1. Semaphore: It is higher level mechanism. When a process enters the critical section, it causes wait and when the process exits the critical section it causes signal. Wait and signal must be atomic. Semaphores are built on Locks.
2. Moniters: They are managed in JAVA. They are software mechanisms. The shared variables are put into a class and synchronized methods are implemented to handle the variables. They are built on top of Semaphores.

Applications of Synchronizations:

There are two types of synchronization:

1. Process synchronization
2. Thread synchronization: They are used a lot.