

**Real-Time Systems**  
**Prof. Dr. Rajib Mall**  
**Department of Computer Science and Engineering**  
**Indian Institute of Technology, Kharagpur**

**Module No. # 01**  
**Lecture No. # 13**  
**Resource Sharing among Real-Time Tasks**

Good morning, let us get started. Today, we will discuss about resource sharing among real-time tasks because we have considered the situation where tasks share no resource, but that was unrealistic. In practical situation tasks will be sharing some resources. We will just discuss about the issues that arise, the difficulties, and how these are addressed in the commercial operating systems and real-time operating systems.

(Refer Slide Time: 01:01)

## Introduction

- So far, the only resource that we considered is CPU.
  - CPU is serially reusable
  - Can be used by one task at a time
  - The task can be preempted at any time without affecting correctness.

2/7/2010      267

We considered only CPU as the shared resource among tasks. CPU is a serially reusable resource. It is used by only one task at a time, like the other resources memory, devices, etc.

(Refer Slide Time: 01:42)

**Critical Section**

- Tasks in reality need to share many types of resources:
  - Files, data structures, devices.
  - These are nonpreemptable resources
- A piece of code in which a shared nonpreemptable resource is accessed:
  - Called a **critical section** in the operating systems literature.

2/7/2019 268

The tasks need to share many other types of resources other than the CPU. For example, files, data structures, devices etc. Many of these resources are not used in a preemptable mode.

The part of the code in which a non preemptable resource is accessed is called critical section in the operating system literature. It is the part of the code where once the control is entered the execution starts and it should complete without releasing the resource. Sometimes we loosely talk of critical section as a resource, but it is actually a piece of code.

(Refer Slide Time: 02:45)

**Critical Section Execution**

- Traditional operating system solution to execute critical sections:
  - **Semaphores.**
- However, in real-time systems this solution does not work well --- results in:
  - **Priority inversion**
  - **Unbounded priority inversion**

2/7/2010 269

In the traditional operating systems, the typical solution is to use semaphores. But in case of real-time tasks semaphores are not the solution and it will create problems. The problems are known as priority inversion and unbounded priority inversion.

(Refer Slide Time: 03:36)

**Priority Inversion**

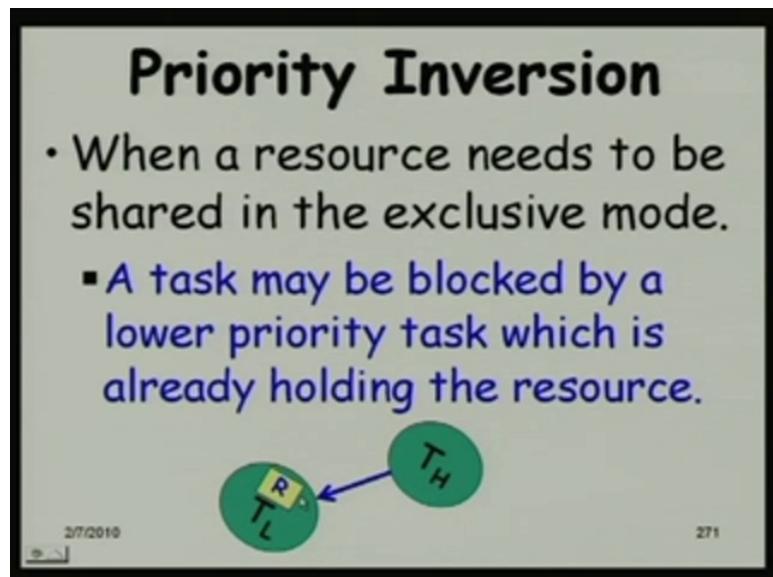
- A task instance executing a critical section:
  - Cannot be preempted.
- Consequence: A higher priority task keeps waiting:
  - While the lower priority task progresses with its computations.

2/7/2010 270

In priority inversion, when a task is executing in its critical section, it should not be preempted from resource uses because it will make the resource inconsistent. These things we know from the first course on operating system.

The consequence in a real-time application is that if a task cannot be preempted (a lower priority task), then higher priority task will keep on waiting. It will create a situation when the real lower priority task is making progress with its computation, and higher priority task is waiting. It is against the basic assumption that we had in the scheduling algorithms.

(Refer Slide Time: 04:59)



When a task is executing and accessed the resource in the exclusive mode, then it can block a higher priority task. For example, a lower priority task  $T_L$ , which has acquired the resource R, and after sometime, the high priority task was released, and it waits for the resource R. Until the lower priority task completes its execution, the resource will not be available to higher priority task.

(Refer Slide Time: 05:51)

## Unbounded Priority Inversion

- Consider the following situation:
  - A low priority task is holding a resource.
  - A high priority task is waiting
  - An intermediate priority task which does not need resource preempts the low priority task.

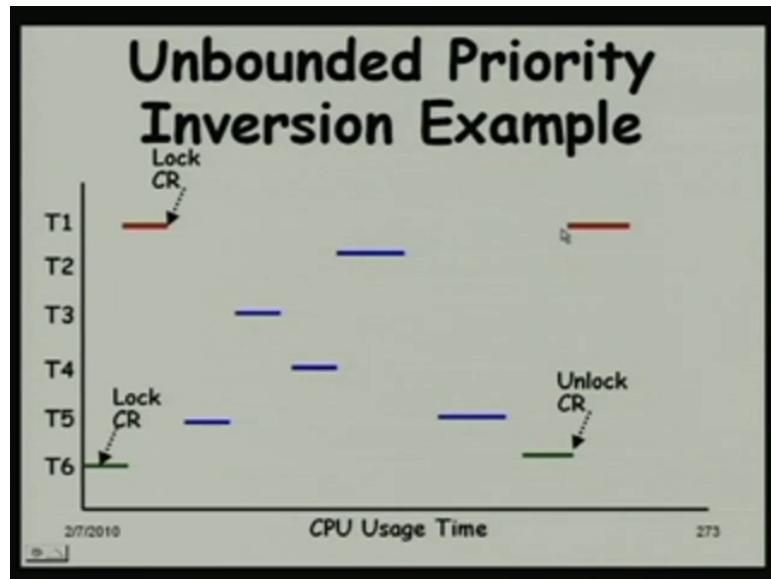
27/2/10 272

A simple priority inversion can be handled. But the one that is very difficult to handle is unbounded priority inversion.

Consider the situation, that there is a resource and a task was executing. After sometime, the task acquired the resource, and meanwhile, a higher priority task was released. The higher priority task is waiting for the resource. This is the simple priority inversion situation. But if some tasks, which do not need the resource, that are of higher priority than T1, but lower priority than T2, also get ready and start executing, because they do not need the resource, they will preempt; they will not wait for T1.

We have a task T3, which does not need the resource and it preempts T1. T2 will wait for T3 to complete, and then T1 to complete but they may not be one intermediate priority task, there might be multiple of them, and as a result, T2 keeps waiting for all these intermediate priority tasks to complete, so that T1 will finally execute, and release the resource, and then T2 will proceed; but that may be too late.

(Refer Time Slide: 07:45)



This is an example of unbounded priority inversion. We have six tasks and T1 has the highest priority and T6 has lowest priority.

T6 is the lowest priority task and executing at some instant. It locked a critical resource and after sometime, a high priority task has become ready and immediately preempts the lower priority task T 6 and starts executing, but after sometime, it needs the resource CR and whenever, it is use a lock CR call it gets blocked.

T6 will execute, but in meanwhile other tasks have become ready and we are just waiting. Therefore, T6 does not get the CPU but T5 get it and executes for some time. Meanwhile T6 is waiting is executing, then, T4 is executing, T2 executes for some time, T5 again gets back the CPU, starts executing, and after all this, T6 gets to use the CPU and completes resource usage, unlocks the resource, and then only, the task T1 can start executing.

(Refer Slide Time: 09:56)

## Unbounded Priority Inversion

- Number of priority inversions suffered by a high priority task :
  - Can be too many causing it to miss its deadline.
- Most celebrated example:
  - Mars path finder

2/7/2010 274

The number of priority inversion suffered by a high priority task can be too many and is likely to miss deadline, whenever unbounded priority situations occur. There are many situations where systems have malfunctioned, because of the priority inversion problem. The most celebrated example is the Mars Pathfinder.

(Refer Slide Time: 10:32)

## Mars Pathfinder

- Landed on the Mars surface on July 4th, 1997.
  - Bounced onto the Martian surface surrounded by airbags.
  - Deployed the Sojourner rover.
  - Gathered and transmitted voluminous data back to Earth:
    - Included the panoramic pictures now available on the Web.

2/7/2010 275

The pathfinder was sent to the Mars, and it landed on 4th July 1997, and it bounced onto the Mars surface by airbags, so that, it will not get damaged. It had a vehicle which will roam around the Mars surface called as the Sojourner.

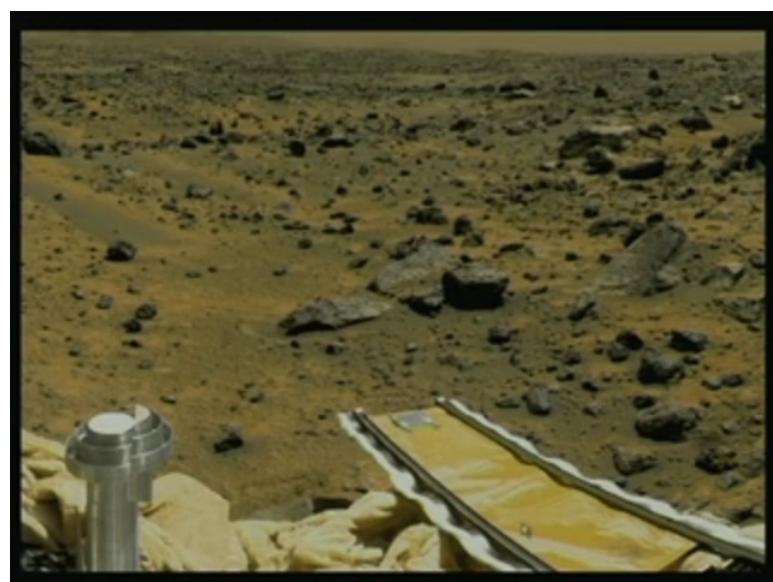
The Sojourner rover is the one, which was released to roam around the moon surface. The Sojourner roamed around and gathered data and starts transmitting the voluminous data to the Earth.

(Refer Slide Time: 11:35)



This is one of the pictures. It contains the rover vehicle, the Sojourner etc

(Refer Slide Time: 11:55)



(Refer Slide Time: 12:06)

## Mars Pathfinder Bug

- Pathfinder began experiencing total system resets:
  - Each resulting in loss of data.
- The newspapers reported these failures using terms such as:
  - Software glitches
  - The computer was trying to do too many things at once, etc.

2/7/2010 278

But soon, it started experiencing total system resets. Each time the system reset, huge amount of data was lost and it appeared in all newspapers. They wrote like Mars Pathfinder is getting into problem, and; some said software glitches have occurred in the Mars Pathfinder, it is not taking commands, and some papers, they said that the computer was trying to do too many things at once and it was crashing etc.

(Refer Slide Time: 12:48)

## Debugging Mars Pathfinder

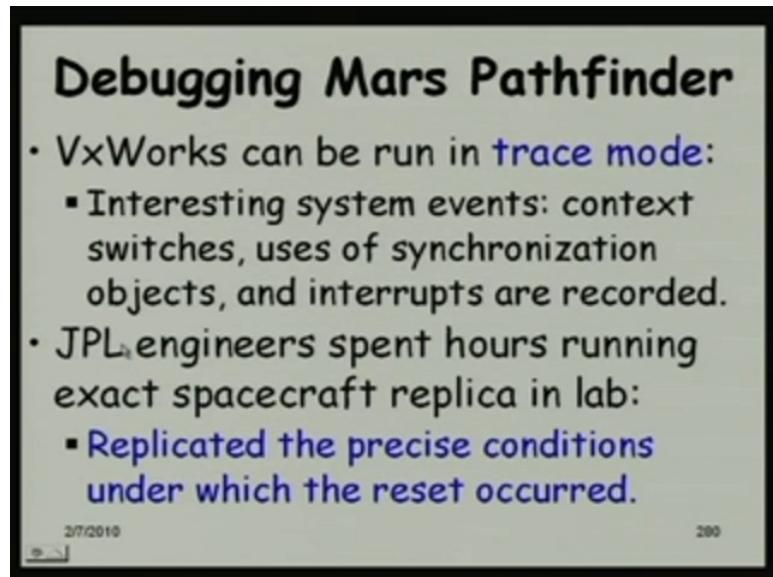
- The real-time kernel used was VxWorks (Wind River Systems Ltd.)
  - RMA scheduling of threads was used
- Pathfinder contained:
  - A information bus -- a shared memory
  - Used for passing information between different spacecraft components.

2/7/2010 279

The pathfinder was using a real-time kernel - the VxWorks - the vendor is Wind River Systems, and RMA scheduling of the threads was used. The pathfinder contained an

information bus, a communication channel, which was a shared memory to communicate among various tasks that execute on the Pathfinder and the rover.

(Refer Slide Time: 13:34)



Once it started resetting itself, the VxWorks provides a facility to run it in the trace mode. In the trace mode, the important system events like when context switches occur, when synchronization primitives are used, when interrupts occur, the different events are recorded. The Jet Propulsion Laboratory engineers spent hours trying on a replica of the space craft that they had in the lab, and where they had set the trace mode on, and they were trying to replicate the precise conditions under which the reset was occurring.

(Refer Slide Time: 14:37)

## Debugging Mars Pathfinder

- VxWorks mutex object:
  - Accepts a boolean parameter indicating whether priority inheritance should be performed.
- It was clear to the JPL engineers:
  - Turning ON priority inheritance would prevent the resets.
  - Initialization parameters were stored in global variables.
  - A short C program was uploaded to the spacecraft.

2/7/2010

201

After spending lots of hours, they came to the following conclusion: that the VxWorks uses as a mutex object, which we will call as the technique to handle priority inversions, and it accepts a boolean parameter, indicating priority inheritance would be enabled or not. After spending many hours, it was clear to the JPL engineers, that if the priority inheritance is turned on, then this kind of situation would not occur.

The initialization parameters, that is including whether the inheritance is set on or not, priority inheritance is set on or not, these are stored as global variables, and this header part of the C program, where the variable is set on, was uploaded to the space craft, and then, the system started working.

(Refer Slide Time: 15:49)

## Solution for Simple Priority Inversion

- Longest duration for which a simple priority inversion can occur:
  - Bounded by the duration for which a lower priority task needs the resource in exclusive mode.

2/7/2010

282

When a simple priority inversion occurs and the high priority task is waiting then what can be done? The longest duration for which a simple priority inversion can occur, when a high priority task is waiting for a low priority task, it is basically, how long the low priority task will use the resource in the exclusive mode.

The maximum duration for which the low priority task will need the critical resource, is the duration for which a simple priority inversion will occur.

(Refer Slide Time: 17:16)

## Solution to Simple Priority Inversion

- A simple priority inversion can be tolerated:
  - Limit the time for which a task executes its critical section.
  - A simple priority inversion can be limited to tolerable levels by careful programming.

2/7/2010

283

If simple priority inversions were to be handled then we have to reduce the maximum duration for which a task will need a critical resource.

How to do that? Limit the time for which a task executes in critical section, by careful programming or by splitting its access to a critical resource across multiple instances, do part of it, release it, and then, acquire it. How unbounded priority inversion can be handled?

(Refer Slide Time: 18:10)

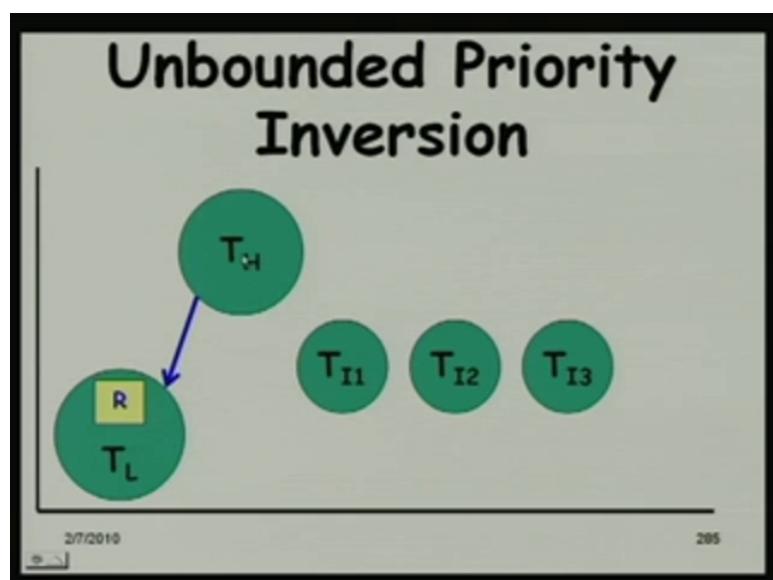
### Unbounded Priority Inversion

- Consider the following situation:
  - A low priority task is holding a resource:
    - A high priority task is waiting.
  - An intermediate priority task which does not need resource:
    - Preempts the low priority task.
  - There can be an unlimited number of such intermediate tasks.

2/7/2010 204

A low priority task is holding a resource and a high priority task is waiting and an intermediate priority task has come in, preempted T1, started executing and T2 is waiting all through.

(Refer Slide Time: 18:37)



And there are many instances of those intermediate priority tasks, which are keeping on coming and preventing the high priority task from acquiring the resource, because low priority task is not able to complete its resource uses.

(Refer Slide Time: 19:35)

## Unbounded Priority Inversion

- Number of priority inversions suffered by a high priority task can be unbounded:
  - Can cause the task to miss its deadline.
  - In the worst case:
    - The high priority task might have to wait indefinitely.

27/2010 206

The high priority task that is waiting for all these unbounded priority inversions is likely to miss its deadline.

(Refer Slide Time: 19:48)

## Priority Inheritance Protocol

Sha and Rajkumar

- The main idea behind this scheme:
- A task in critical section cannot be preempted:
  - It should be allowed to complete as early as possible.

27/2010 207

A simple solution was proposed in the form of a priority inheritance protocol by Sha and Rajkumar. The main idea is that, a task in its critical section cannot be preempted from resource uses.

Sha and Rajkumar said that a low priority task once it has acquired a resource cannot be preempted only thing that can be done is that to allow it to complete as early as possible because the simple priority inversion is not a problem; the problem is that if unbounded priority inversions occur.

(Refer Slide Time: 22:52)

**Priority Inheritance Protocol**

- How do you make a task complete as early as possible?
  - Raise its priority, so that low priority tasks are not able to preempt it.
- By how much should its priority be raised?
  - Make its priority as much as that of the task it is blocking.

27/2010 208

How do you make a task that is holding the resource to complete as quickly as possible?

We can raise its priority so that the low priority task is not able to preempt it. The priority of the task should be raised to a priority, which is as much as the priority of the task that is waiting for the resource because if we raise it to anywhere lower than that, then we will have intermediate priority tasks which will preempt it.

(Refer Slide Time: 24:50)

## Priority Inheritance Protocol

- How do you make a task complete as early as possible?
  - Raise its priority, so that low priority tasks are not able to preempt it.
- By how much should its priority be raised?
  - Make its priority as much as that of the task it is blocking.

2/7/2010 288

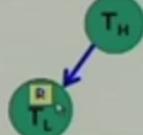
The priority should be raised to as much as that of the task that is blocking it. The priority of the task that is holding the resource should be raised by as much as the task that is waiting for the resource (the highest priority task).

(Refer Slide Time: 25:11)

## Priority Inheritance Protocol

Sha and Rajkumar

- When a resource is busy:
  - Requests to lock the resource are queued in FIFO order.
  - Then apply the inheritance clause after a higher priority task blocks.



2/7/2010 289

When a resource is busy, then the requests to lock the resource are queued in FIFO order. Multiple tasks might come in and wait for the resource, right we just shown it just one task has waiting, but it is likely that multiple tasks might be waiting for the resource.

May be a low priority task  $T_L$  was using the resource R, and meanwhile, some other task  $T_i$  requested the resource.  $T_i$  started executing, and then requested, and it blocked. Then,  $T_L$  was executing again, and  $T_H$  a higher priority task started executing, because that time it did not need resource, and it continued up till the point it started, requesting for the resource R, then that time it blocked, and there will be two tasks waiting for the resource R. We will have to find the highest priority task that is waiting for the resource, and then, we have to raise the priority of the task holding the resource by that much. As soon as the task releases the resource, it should get back its old priority.

(Refer Slide Time: 26:37)

## Inheritance Clause

- The priority of the task in the critical section:
  - Raised to equal the highest priority task in the queue.

The diagram illustrates the inheritance clause. A green circle labeled  $T_H$  is positioned above a green circle labeled  $T_L$ . Inside the  $T_L$  circle, there is a yellow square containing the letter 'R', representing a resource. A blue arrow points from  $T_H$  down towards  $T_L$ , indicating that  $T_H$ 's priority has been raised to match  $T_L$ 's priority while it holds resource R.

Many operating systems for simplicity let task wait in a queue, and then, use a round robin scheduling among them.

(Refer Slide Time: 28:42)

**Priority Inheritance Protocol (PIP)**  
Sha and Rajkumar

- As soon as the task releases the resource,
  - It gets back its original priority value if it is holding no other critical resource.
- In case it is holding other critical resources:
  - It inherits priority of the highest priority task waiting for resource.

Once the low priority task has completed its resource uses, then it gets back its old priority. Also, if it is holding some other resource, then it releases that.

(Refer Slide Time: 29:28)

**PIP: Pseudocode**

```
if the required resource is free,
    then grant it
if the required resource is being held by a higher
    priority task,
    then wait for the resource
if the required resource is held by a lower
    priority task, then
{
    Wait for the resource
    The low priority task holding the resource
    acquires the priority of highest priority task
    waiting for the resource.
```

The basic pseudo code of priority inversion protocol is given. Whenever, there is a resource is available and the request is there, grant it, you do not check the priority whether it is a low priority or high priority. As long as the resource is available, it is granted. If the required resource is held by a higher priority task, then it should wait for the resource and nothing needs to be done, because this not a priority inversion situation.

Because already higher priority task is using the resource and naturally a low priority task will wait for it.

But if the resource is held by a lower priority task, then we will have to apply the inheritance clause. Not only the high priority tasks wait for the resource, but the low priority task has to inherit the highest priority task in the queue.

(Refer Slide Time: 30:54)

**Understanding PIP**

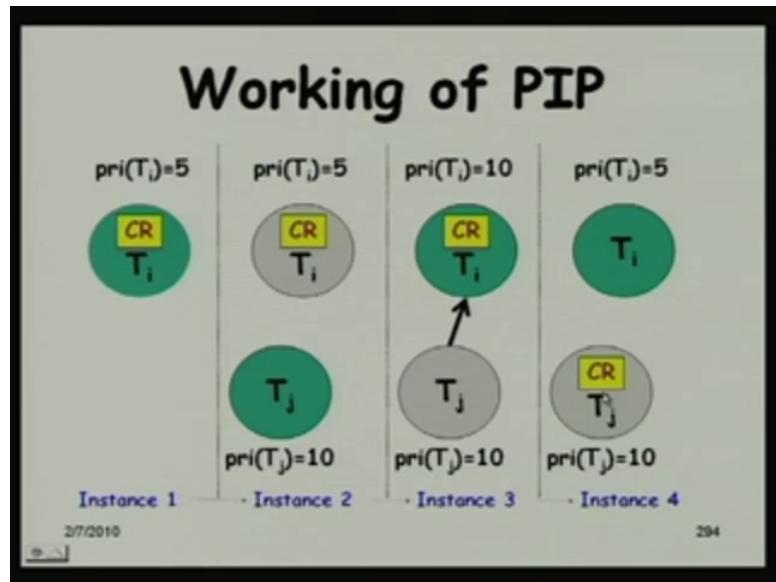
- How does PIP prevent unbounded priority inversions?
- The priority of low priority task holding resource is raised to that of the waiting high priority task:
  - Intermediate priority tasks can not preempt it.

2/7/2010 293

How does priority inheritance protocol prevent unbounded inversions?

The task cannot preempt now because the priority of the task is raised to that of the highest waiting task, there is no intermediate priority tasks, which can preempt the task from CPU usage.

(Refer Slide Time: 31:21)



This is an example of the working of priority inheritance protocol. A task  $T_i$  with priority 5 was using the resource CR, and in the next instance, a task with priority 10 started using the CPU. Then this was preempted, because  $T_j$  did not require the resource and it started executing. But after sometime, it needed the resource, and it started waiting for the resource to be released by  $T_i$ , and  $T_i$  got execution on the CPU.

Due to the inheritance protocol, the priority of  $T_i$  is raised to 10, because  $T_j$  is 10. The inheritance clause by that priority is raised, and after it completed the resource usage, its priority was changed to 5, and then,  $T_j$  has got hold of the resource and it will start executing now.

(Refer Slide Time: 32:43)

**Shortcomings of the Basic Priority Inheritance Scheme**

- PIP suffers from two important drawbacks:
  - Deadlocks
  - Chain blocking
- PIP is susceptible to chain blocking:
  - Also does nothing to prevent deadlocks

2/7/2010 295

The protocol is very simple basic priority inheritance scheme, but there are problems with this protocol. Two main problems are deadlocks and chain blocking.

(Refer Slide Time: 33:08)

**Deadlocks**

- Consider two tasks  $T_1$  and  $T_2$  accessing critical resources  $CR_1$  and  $CR_2$ .
- Assume:
  - $T_1$  has a higher priority than  $T_2$
  - $T_2$  starts running first
- $T_1$ : Lock  $R_1$ , Lock  $R_2$ , Unlock  $R_2$ , Unlock  $R_1$
- $T_2$ : Lock  $R_2$ , Lock  $R_1$ , Unlock  $R_1$ , Unlock  $R_2$

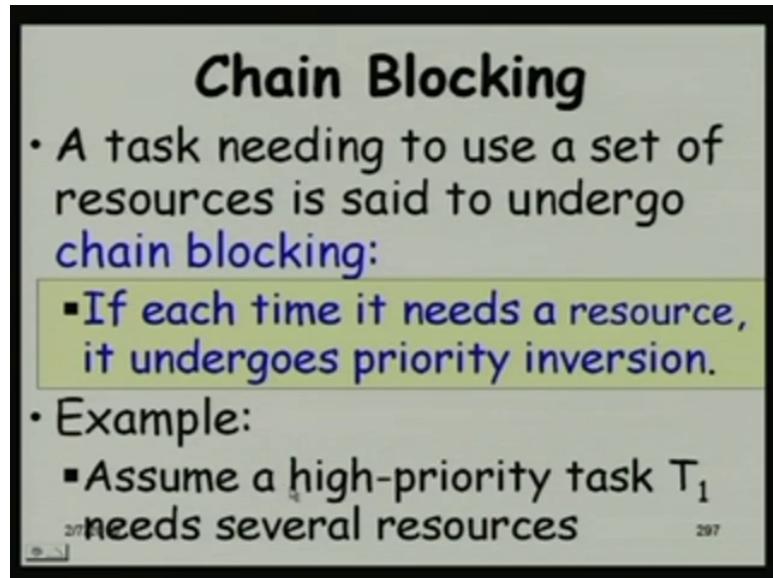
2/7/2010 296

Assume that, we have two tasks  $T_1$  and  $T_2$  and they are accessing the resource  $CR_1$  and  $CR_2$ . Also assume that  $T_1$  has higher priority than  $T_2$ , and  $T_2$  starts running first.

$T_2$  is the lower priority and  $T_1$  is the higher priority,  $T_2$  locks resource  $R_2$ , and started executing. At that time  $T_1$  started executing, preempted  $T_2$  from CPU users, and locked

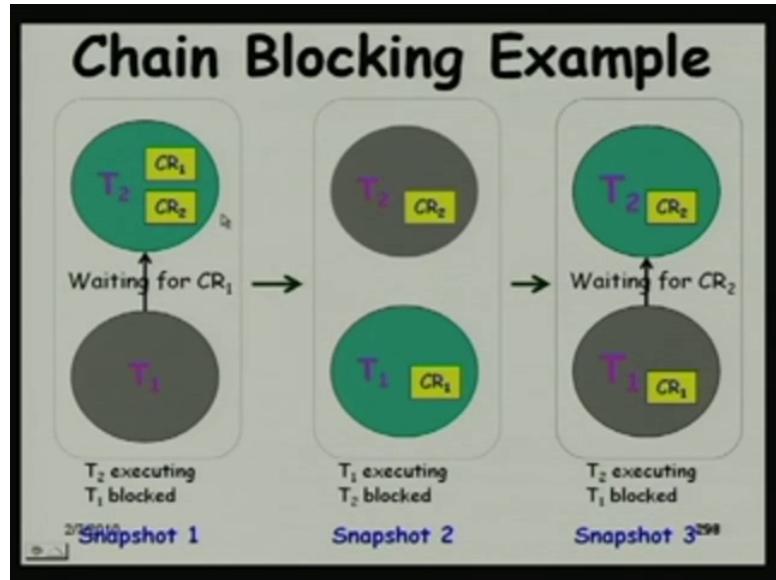
$R_1$ . After some computation, it tries to lock  $R_2$ , but  $R_2$  is the lock being held by  $T_2$  and it will block for  $T_2$ . And,  $T_2$ 's priority will be raised to that of  $T_1$  through the inheritance clause, but  $T_2$  has already got into deadlock even if priority is raised.

(Refer Slide Time: 34:32)



Deadlock occurs using the simple priority inheritance scheme. The other problem is chain blocking. The definition of chain blocking is whenever a task needs a set of resources, and it has to wait and undergo priority inversion, then it for set of 5 resources, it has to separately wait five times to get the resource, and we will say that it has undergone chain blocking.

(Refer Slide Time: 35:15)



Assume that a task  $T_1$  needs several resources say,  $CR_1$  and  $CR_2$ , two resources. After some computation, it blocks for  $T_2$ , and then,  $T_2$  release  $CR_1$  after executing for some time, and  $T_1$  could execute with  $CR_1$ , but after sometime, it needed  $CR_2$ , and then, it started blocking again. This is example of a chain blocking.

We can also have a situation where multiple tasks are holding different resource and it is waiting for  $T_2$  for getting  $CR_1$ , it is waiting for  $T_3$  to get  $CR_3$  and so on. So, chain blocking is the situation where a task to get the set of resources it needs, each time needs to block for one resource.

Each time it waited for some microseconds to get  $CR_1$ , then it will wait again to get  $CR_2$ , it will like wait again, just see the problem a multiple equation of the delay for each individual resource, undesirable situation; this can cause problem; chain blocking can cause problem. Deadlock is definitely unacceptable, but chain blocking also can cause problem, if the tasks have tight deadlines.

This principle just converts the unbounded priority inversion to a normal priority inversion.

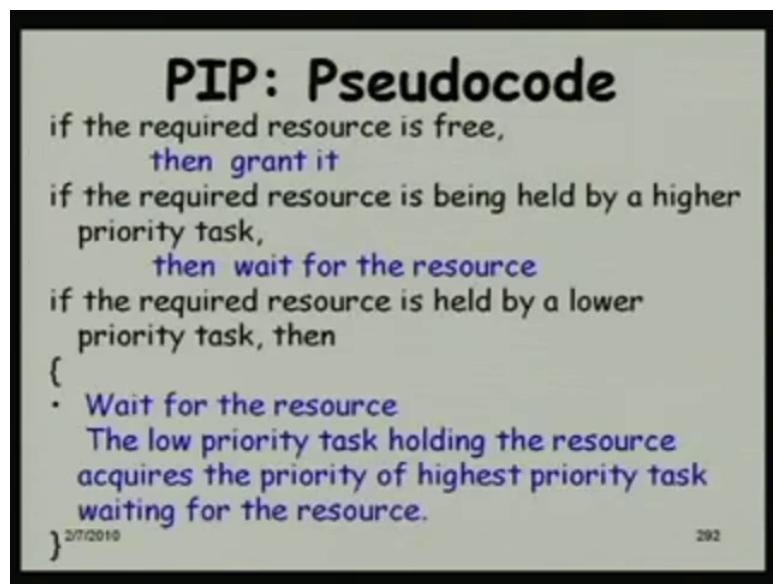
We have not eliminated a simple priority inversion; a simple priority inversion can never be eliminated, but what we have said is that a simple priority inversion can be tolerated by careful programming, by splitting the access to a critical resource of a low priority

task into small chunks. So, simple priority inversion, we will see all these protocols, which are refinement of the basic inheritance scheme and which are used in the commercial operating systems. They cannot eliminate a simple priority inversion, but what they are targeted is to eliminate unbounded priority inversions.

When a process does have blocked for some resource and another higher priority process comes and it also blocks for the same resource. So, the priority inheritance takes place during the suspended state or when one of the lower priority task is executing; at what time does the priority inheritance takes place?

The question is that when the priority inheritance takes place? The basic pseudo code is given in the slide.

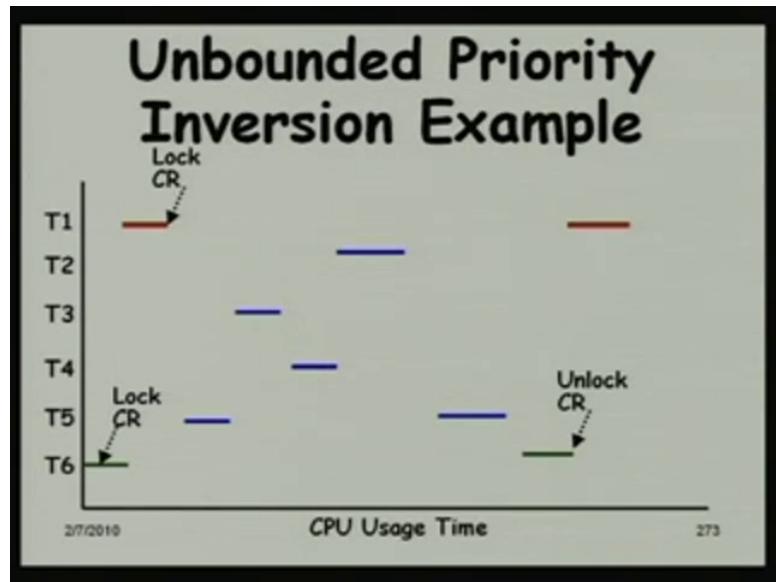
(Refer Slide Time: 38:59)



Whenever there is a request for a resource, this pseudo code is applied. Any task is requesting for a resource and if it is resource is free then grant it. If the resource is held by a higher priority task, then wait. And keep on waiting for the resource.

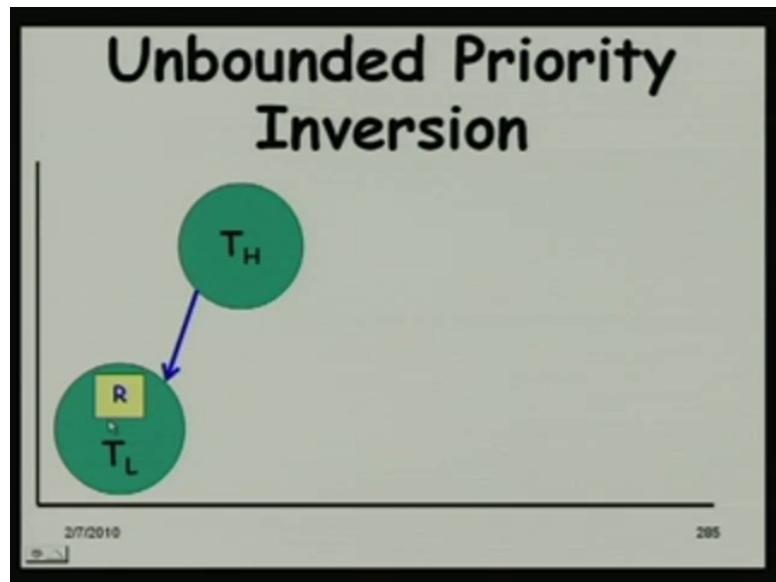
If the lower priority task is itself not running and the higher priority task is waiting for resource, which is held by the lower priority task, which is not running on the CPU. So, in that case, with the lower priority task inherit the priority of the higher priority task.

(Refer Time Slide: 40:56)



This is the example. The lower priority task was running for some time, and then, it was preempted by the higher priority task. While the higher priority task was running, it requested the resource. So, very likely the lower priority task will not be running when the resource is requested.

(Refer Slide Time: 42:18)



A task will get the highest priority of all the tasks that are waiting for various resources, which is being held by it.

(Refer Slide Time: 43:09)

## Practice Questions

- What do you understand by priority inversion?

2/7/2010

299

Question: What is priority inversion?

Actually situation where the higher priority task waits for the lower priority task in case of a resource need lower priority task. Lower priority task keeps on executing and a higher priority task is waiting.

(Refer Slide Time: 43:30)

## Practice Questions

- What do you understand by priority inversion?
- (T/F) When several tasks share a set of critical resources,
  - Is it possible to avoid priority inversion altogether by using a suitable task scheduling algorithm?

2/7/2010

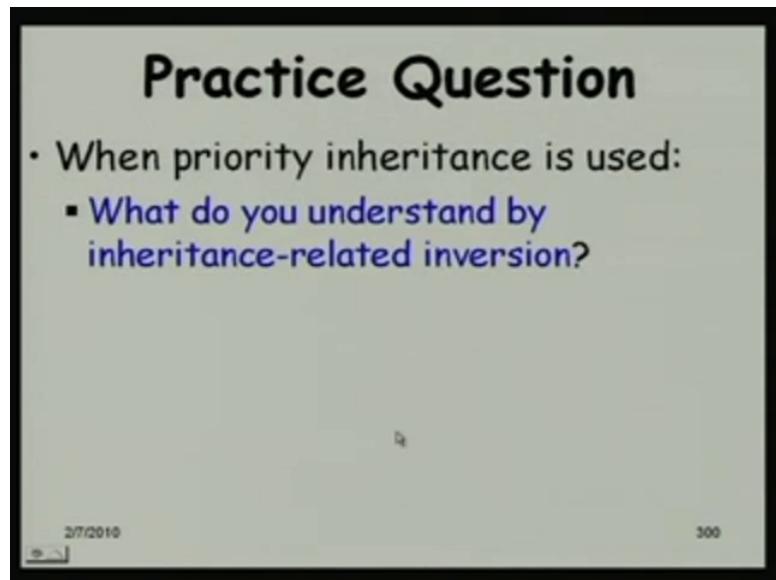
299

Whether this sentence is true or false?

Sentence: When several tasks share a set of critical resources, it is possible to avoid priority inversions altogether using a suitable scheme.

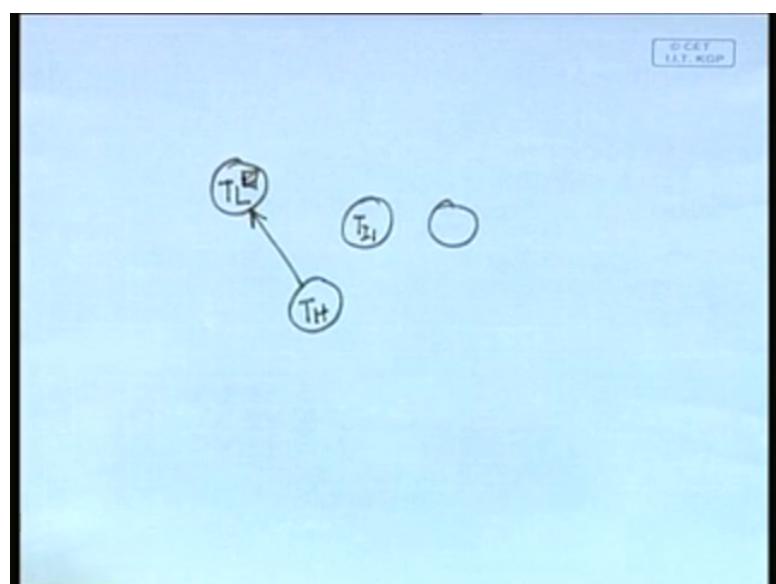
Answer: No, because a simple priority inversion is very difficult to prevent.

(Refer Slide Time: 44:01)



When a priority inheritance is used, what is inheritance- related inversion?

(Refer Slide Time: 44:45)



We had a low priority task  $T_L$ , and a high priority task is waiting for some resource held by it, and as a result the  $T_L$  inherits the priority of the high priority task. But, there may be other tasks intermediate tasks which do not need this resource, but still they cannot proceed with their computation, they are undergoing inversion, they should have

completed, because they do not need this resource. So, that is an inheritance related inversion.

(Refer Slide Time: 45:19)

## Practice Question

- When priority inheritance is used:
  - What do you understand by inheritance-related inversion?
- When a set of real-time tasks share certain critical resources using the priority inheritance protocol:
  - The highest priority task does not suffer any inversions. (T/F)

2/7/2010 300

Statement: When a set of real-time tasks share critical resources using the priority inheritance protocol, then the highest priority task does not suffer any inversions.

Solution: True, Lower priority task, by its definition itself, it cannot suffer any inversion.

(Refer Slide Time: 46:03)

## Practice Question

- When priority inheritance scheme is used, a task needing a resource undergoes priority inversions due to:
  - A higher priority task holding the resource
  - A lower priority task holding the resource
  - An equal priority task holding the resource
  - Either a higher or a lower priority task holding the resource

2/7/2010 301

When a priority inheritance scheme is used, a task needing a resource undergoes a priority inversion due to:

- 1) Higher priority task holding the resource, 2) A lower priority task holding the resource, 3) An equal priority task holding the resource, 4) Either a higher or a lower priority task holding the resource.

Solution: A lower priority task holding the resource, because when a higher priority task is holding the resource, inversion cannot occur; and a equal priority task holding the resource also, inversion does not occur, because it is at least the same priority; and this also, either a higher or lower is not true, because lower priority task, a higher priority task cannot cause inversion.

(Refer Slide Time: 47:36)

## Practice Question

• Using semaphores of traditional operating systems, what is the maximum duration for which a task may undergo priority inversion:

1. Longest duration for which a higher priority task uses a shared resource.
2. Longest duration for which a lower priority task uses a shared resource.
3. Sum of the durations for which different lower priority tasks may use the shared resource.
4. Greater than the longest duration for which a lower priority task uses a shared resource

2/7/2010

302

Using semaphores of traditional operating system, what is the maximum duration for which a task may undergo priority inversion?

- i) The longest duration for which a higher priority task uses the resource;
- ii) The longest duration, for which a lower priority task uses the resource; s
- iii) Sum of the durations for which different lower priority tasks may use the shared resource

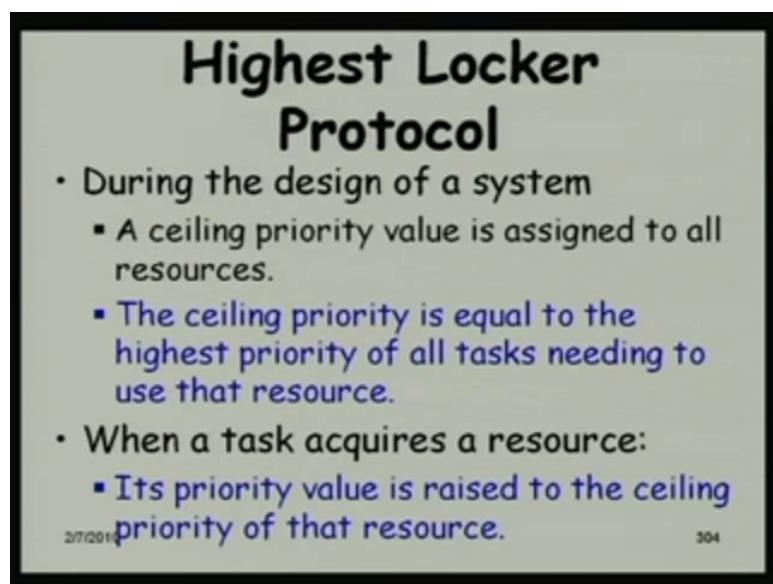
- iv) Greater than the longest duration for which a lower priority task uses the shared resource.

Answer: Greater than the longest duration for which a lower priority task uses the shared resource.

Because even when they are not using the resource only holding the resource, there may be intermediate priority task, which are not requiring the resource and they have preempted it. It is longer than the maximum duration for which a task holds the resource. We cannot say that it is sum of the durations for different tasks need the resource.

We discuss some of the improvements that were proposed to overcome the problems of the basic priority inheritance scheme.

(Refer Slide Time: 49:58)



Highest locker protocol is a straight extension of the inheritance protocol, but itself has problem. It solves the main problems of the basic inheritance scheme, but it creates new problems.

In the highest locker protocol a ceiling priority is assigned to every resource and the ceiling priority is computed as equal to the highest priority of all tasks needing that resource.

Once we have computed the ceiling priority, whenever a task acquires a resource raise its priority to that of the ceiling priority.

(Refer Slide Time: 51:49)

### Highest Locker Protocol (HLP)

- Addresses the shortcomings of PIP:
  - However, introduces new complications.
  - Addressed by Priority Ceiling Protocol (PCP).
  - Easier to first understand working of HLP and then PCP.
- During the design of a system:
  - A ceiling priority value is assigned to all critical resources.
  - The ceiling priority is equal to the highest priority of all tasks using that resource.

It addresses all the shortcomings of the basic inheritance scheme but it introduces new complications, which will be addressed by the ceiling protocol. During the design of the system, a ceiling priority is assigned to all critical resources, that we had seen and the ceiling priority is equal to the highest priority of all tasks using that resource.

(Refer Slide Time: 52:45)

### Ceiling Priority of a Resource

- When a task acquires a resource:
  - Its priority value is raised to the ceiling priority of that resource.

$\text{Ceil}(R) = \max\text{-prio}(T_1, T_2, T_3)$

```
graph TD; T1((T1)) --> R[R]; T2((T2)) --> R; T3((T3)) --> R; R --> T1; R --> T2; R --> T3;
```

For every resource R, we will find out which are the tasks using resource, which data structure, which device, etcetera be used by one task, and based on that we know the priorities of these tasks, and we will set the ceiling priority of the resource R is the maximum priority of all the three tasks.

Let us stop here, we will continue from this point in the next class.