Real Time Systems1

lecture 9

Priority Inheritance Protocol

Priority Inheritance Protocol

- The *Priority Inheritance Protocol* (PIP), proposed by Sha, Rajkumar and Lehoczky [SRL90], avoids unbounded priority inversion by modifying the priority of those tasks that cause blocking.

- In particular, when a task *τi* blocks one or more higher-priority tasks, it temporarily assumes (*inherits*) the highest priority of the blocked tasks.

Priority Inheritance Protocol

- This prevents medium-priority tasks from preempting $\tau\ i$ and prolonging the blocking duration experienced by the higher-priority tasks.

- The Priority Inheritance Protocol can be defined as follows:
- 1. Tasks are scheduled based on their active priorities. Tasks with the same priority are executed in a First Come First Served discipline.

Priority Inheritance Protocol

- 2. When task τ_i tries to enter a critical section $z_{i,k}$ and resource R_k is already held by a lower-priority task τ_j , then τ_i is blocked. τ_i is said to be blocked by the task τ_j that holds the resource. Otherwise, τ_i enters the critical section $z_{i,k}$.

- 3. When a task τ_i is blocked on a semaphore, it transmits its active priority to the task, say τ_j , that holds that semaphore.

Priority Inheritance Protocol

- Hence, τ_j resumes and executes the rest of its critical section with a priority $p_j = p_i$. Task τ_j is said to *inherit* the priority of τ_i. In general, a task inherits the highest priority of the tasks it blocks. That is, at every instant, $p_j(R_k) = \max\{P_j, \max_h \{P_h \mid \tau_h$ is blocked on $R_k\}\}$.

- 4. When τ_j exits a critical section, it unlocks the semaphore, and the highest-priority task blocked on that semaphore, if any, is awakened.

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- The active priority of τ_j is updated as follows: if no other tasks are blocked by τ_j , p_j is set to its nominal priority P_j ; otherwise it is set to the highest priority of the tasks blocked by τ_j , according to Equation (7.8).

- 5. Priority inheritance is transitive; that is, if a task τ_3 blocks a task τ_2, and τ_2 blocks a task τ_1, then τ_3 inherits the priority of τ_1 via τ_2.

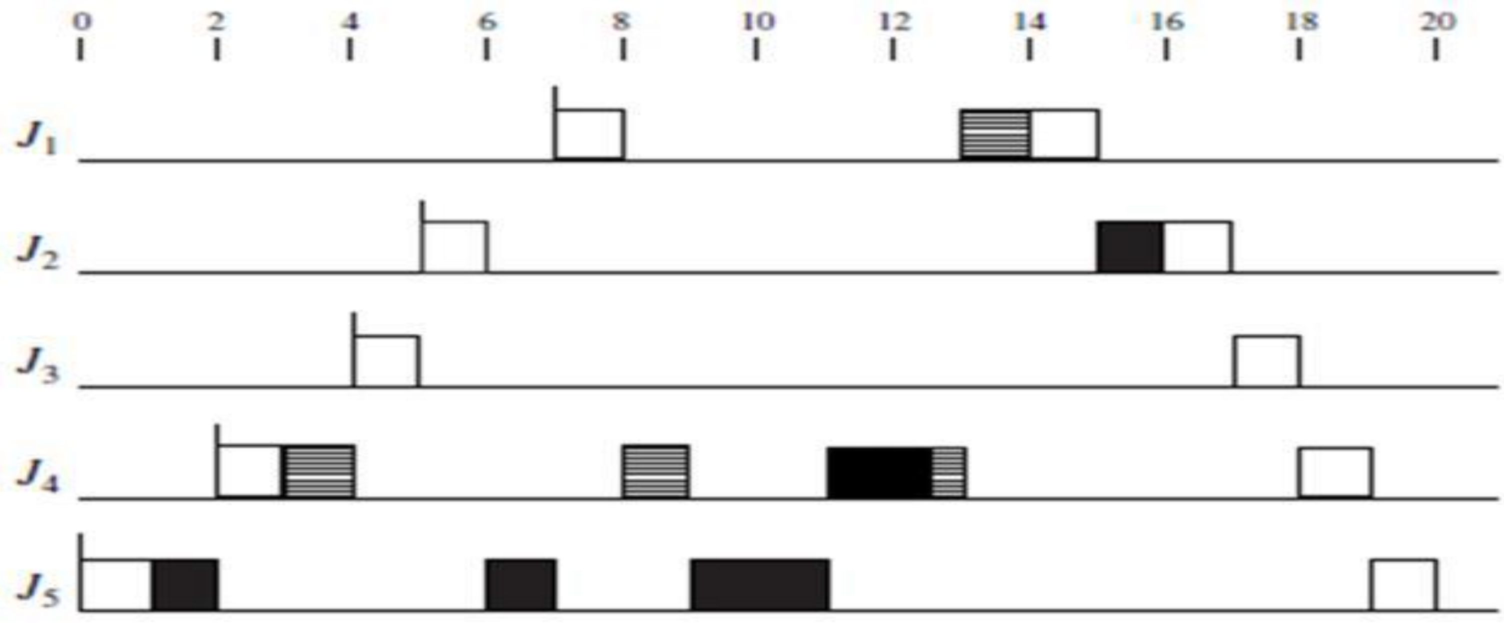
Priority Inheritance Protocol Example

- There are five jobs and two resources *Black* and *Shaded*. The parameters of the jobs and their critical sections are listed in part (a). As usual, jobs are indexed in decreasing order of their priorities:
- The priority π_i of J_i is i , and the smaller the integer, the higher the priority. In the schedule in part (b) of this figure, black boxes show the critical sections when the jobs are holding *Black*.
- Shaded boxes show the critical sections when the jobs are holding *Shaded*

Priority Inheritance Protocol Example

Job	r_i	e_i	π_i	Critical Sections
J_1	7	3	1	[*Shaded*; 1]
J_2	5	3	2	[*Black*; 1]
J_3	4	2	3	
J_4	2	6	4	[*Shaded*; 4 [*Black*; 1.5]]
J_5	0	6	5	[*Black*; 4]

(a)



(b)

FIGURE 8–8 Example illustrating transitive inheritance of priority inheritance. (a) Parameters of jobs. (b) Schedule under priority inheritance.

Priority Inheritance Protocol

- 1. At time 0, job *J*5 becomes ready and executes at its assigned priority 5. At time 1, it is granted the resource *Black*.

- **2.** At time 2, *J*4 is released. It preempts *J*5 and starts to execute.

- **3.** At time 3, *J*4 requests *Shaded*. *Shaded*, being free, is granted to the job. The job continues to execute.

- **4.** At time 4, *J*3 is released and preempts *J*4. At time 5, *J*2 is released and preempts *J*3.

Priority Inheritance Protocol

- **5.** At time 6, *J2* executes *L(Black)* to request *Black*; *L(Black)* fails because *black* is in use by *J5*. *J2* is now directly blocked by *J5*.
- According to rule 3, *J5* inherits the priority 2 of *J2*.
- Because *J5*'s priority is now the highest among all ready jobs, *J5* starts to execute
- *6. J1* is released at time 7. Having the highest priority 1, it preempts *J5* and starts to execute.

Priority Inheritance Protocol

- **7.** At time 8, *J1* executes *L(Shaded)*, which fails, and becomes blocked. Since *J4* has *Shaded* at the time, it directly blocks *J1* and, consequently, inherits *J1*'s priority 1.
- *J4* now has the highest priority among the ready jobs *J3*, *J4*, and *J5*. Therefore, it starts to execute.
- **8.** At time 9, *J4* requests the resource *Black* and becomes directly blocked by *J5*.
- At this time the current priority of *J4* is 1, the priority it has inherited from *J1* since time 8.

Priority Inheritance Protocol

- Therefore, *J*5 inherits priority 1 and begins to execute.
- **9.** At time 11, *J*5 releases the resource *Black*. Its priority returns to 5, which was its priority when it acquired *Black*.
- The job with the highest priority among all unblocked jobs is *J*4.
- Consequently, *J*4 enters its inner critical section and proceeds to complete this and the outer critical section.

Priority Inheritance Protocol

- **10.** At time 13, *J4* releases *Shaded*. The job no longer holds any resource; its priority returns to 4, its assigned priority.
- *J1* becomes unblocked, acquires *Shaded*, and begins to execute.
- **11.** At time 15, *J1* completes. *J2* is granted the resource *Black* and is now the job with the highest priority. Consequently, it begins to execute.
- **12.** At time 17, *J2* completes. Afterwards, jobs *J3*, *J4*, and *J5* execute in turn to completion

Priority Inheritance Protocol

- From this example, we notice that a high-priority task can experience two kinds of blocking:
- **Direct blocking.** It occurs when a higher-priority task tries to acquire a resource already held by a lower-priority task. Direct blocking is necessary to ensure the consistency of the shared resources.
- **Push-through blocking**. It occurs when a medium-priority task is blocked by a low-priority task that has inherited a higher priority from a task it directly blocks. Push-through blocking is necessary to avoid unbounded priority inversion.

Priority Inheritance Protocol

- Note that in most situations when a task exits a critical section, it resumes the priority it had when it entered. This, however, is not always true.
- Consider the example illustrated in Figure 7.9. Here, task $\tau 1$ uses a resource *Ra* guarded by a semaphore *Sa*, task $\tau 2$ uses a resource *Rb* guarded by a semaphore *Sb*, and task $\tau 3$ uses both resources in a nested fashion (*Sa* is locked first).
- At time $t1$, $\tau 2$ preempts $\tau 3$ within its nested critical section; hence, at time $t2$, when $\tau 2$ attempts to lock *Sb*, $\tau 3$ inherits its priority, $P2$.

Priority Inheritance Protocol

- Similarly, at time $t3$, $\tau 1$ preempts $\tau 3$ within the same critical section, and at time $t4$, when $\tau 1$ attempts to lock *Sa*, $\tau 3$ inherits the priority $P1$.
- At time $t5$, when $\tau 3$ unlocks semaphore *Sb*, task $\tau 2$ is awakened but $\tau 1$ is still blocked; hence, $\tau 3$ continues its execution at the priority of $\tau 1$.
- At time $t6$, $\tau 3$ unlocks *Sa* and, since no other tasks are blocked, $\tau 3$ resumes its original priority $P3$

Priority Inheritance Protocol

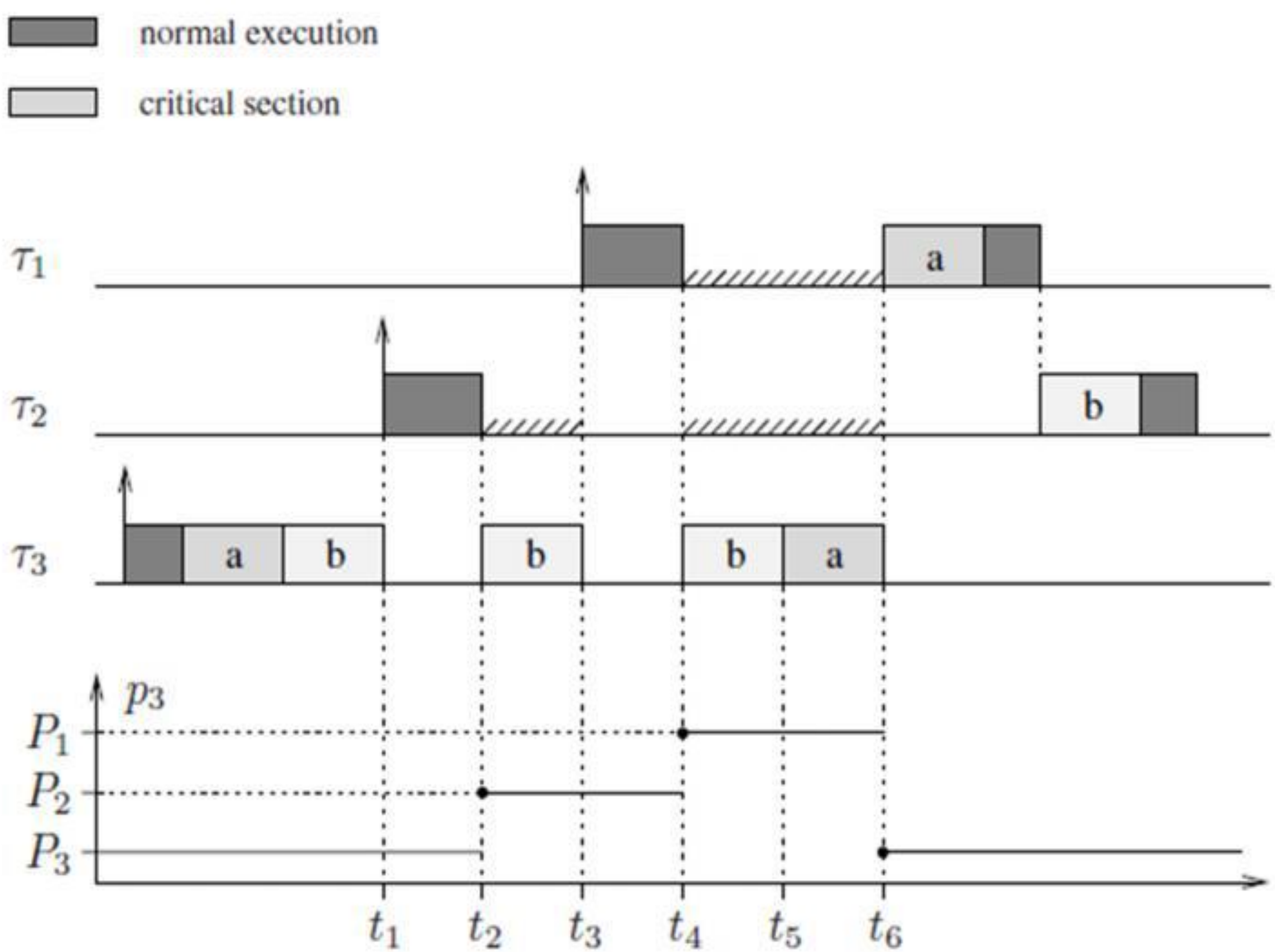


Figure 7.9 Priority inheritance with nested critical sections.

Priority Inheritance Protocol

- An example of transitive priority inheritance is shown in Figure 7.10.
- Here, task $\tau 1$ uses a resource *Ra* guarded by a semaphore *Sa*, task $\tau 3$ uses a resource *Rb* guarded by a semaphore *Sb*, and task $\tau 2$ uses both resources in a nested fashion (*Sa* protects the external critical section and *Sb* the internal one).

- At time $t1$, $\tau 3$ is preempted within its critical section by $\tau 2$, which in turn enters its first critical section (the one guarded by *Sa*), and at time $t2$ it is blocked on semaphore *Sb*. As a consequence, $\tau 3$ resumes and inherits the priority $P2$.

Priority Inheritance Protocol

- At time $t3$, $\tau 3$ is preempted by $\tau 1$, which at time $t4$ tries to acquire Ra. Since Sa is locked by $\tau 2$, $\tau 2$ inherits $P1$. However, $\tau 2$ is blocked by $\tau 3$; hence, for transitivity, $\tau 3$ inherits the priority $P1$ via $\tau 2$.

- When $\tau 3$ exits its critical section, no other tasks are blocked by it; thus it resumes its nominal priority $P3$. Priority $P1$ is now inherited by $\tau 2$, which still blocks $\tau 1$ until time $t6$.

Priority Inheritance Protocol

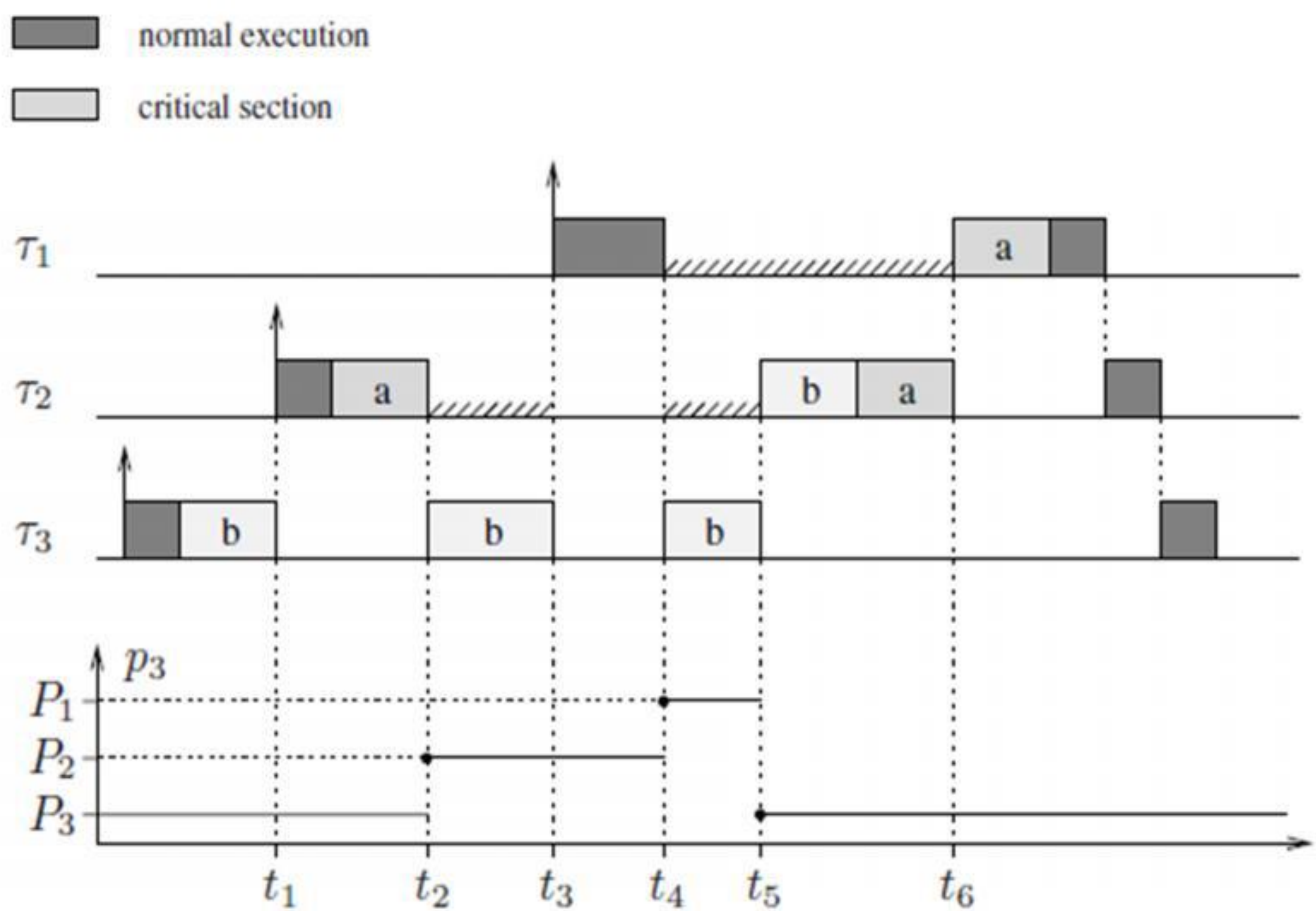


Figure 7.10 Example of transitive priority inheritance.