Resource Sharing

CPEN 432 Real-Time System Design

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Terminology

- Task set $\tau = \{\tau_1, \tau_2, \ldots, \tau_n\}$ consists of n periodic tasks

- Each task is characterized by a period T_i and worst-case completion time C_i

- The tasks cooperate through m shared resources $R_1, R_2, \ldots, R_m$

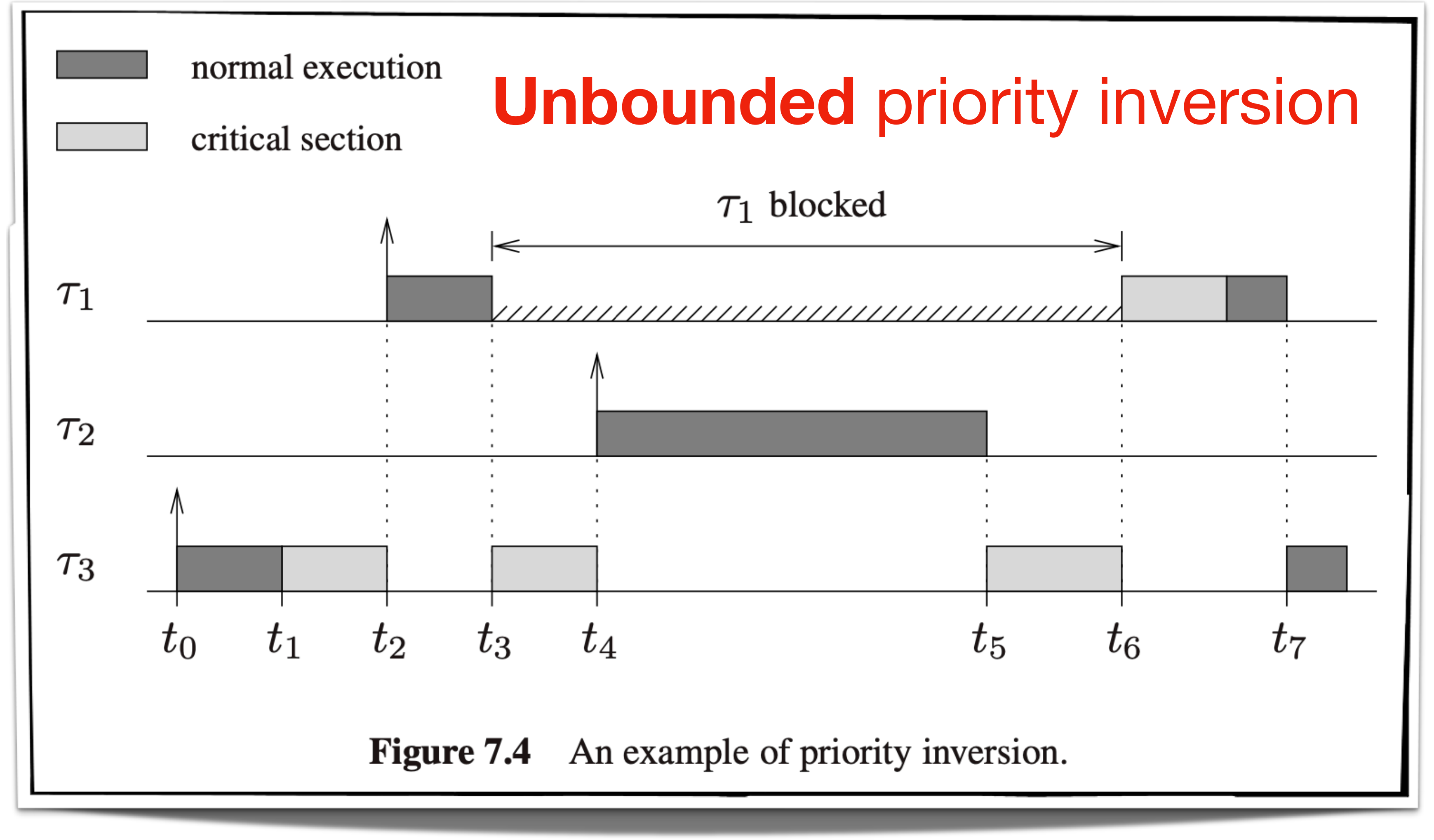
- Each resource R_k is guarded by a distinct **binary semaphore** S_k
  - All critical sections using R_k start and end with operations $wait(S_k)$ and $signal(S_k)$

- Each task is assigned a fixed **base priority** P_i (e.g., using RM)
  - Assumption: priorities are unique and $P_1 > P_2 > \ldots > P_n$

- Each task also has an **effective priority** p_i $(\geq P_i)$
  - It is initially set to P_i and can be **dynamically updated**

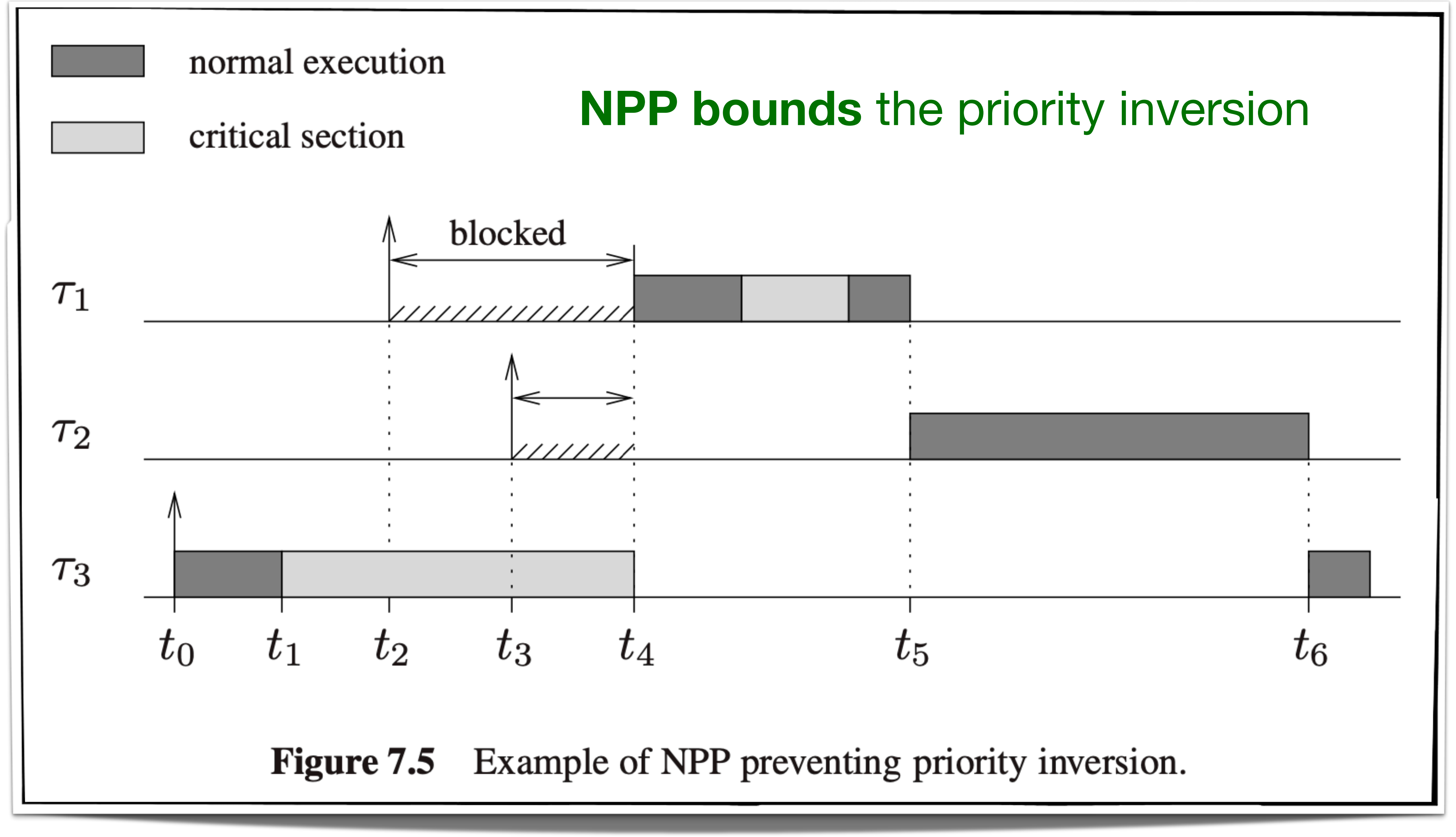
- B_i denotes the maximum blocking time task τ_i can experience
  - B_i goes into the fixed-priority response-time analysis (recall from previous lectures)

- $z_{i,k}$ denotes any arbitrary critical section of τ_i guarded by semaphore S_k
  - $Z_{i,k}$ denotes the longest among all these critical sections
  - $\delta_{i,k}$ denotes the length of this longest critical section $Z_{i,k}$



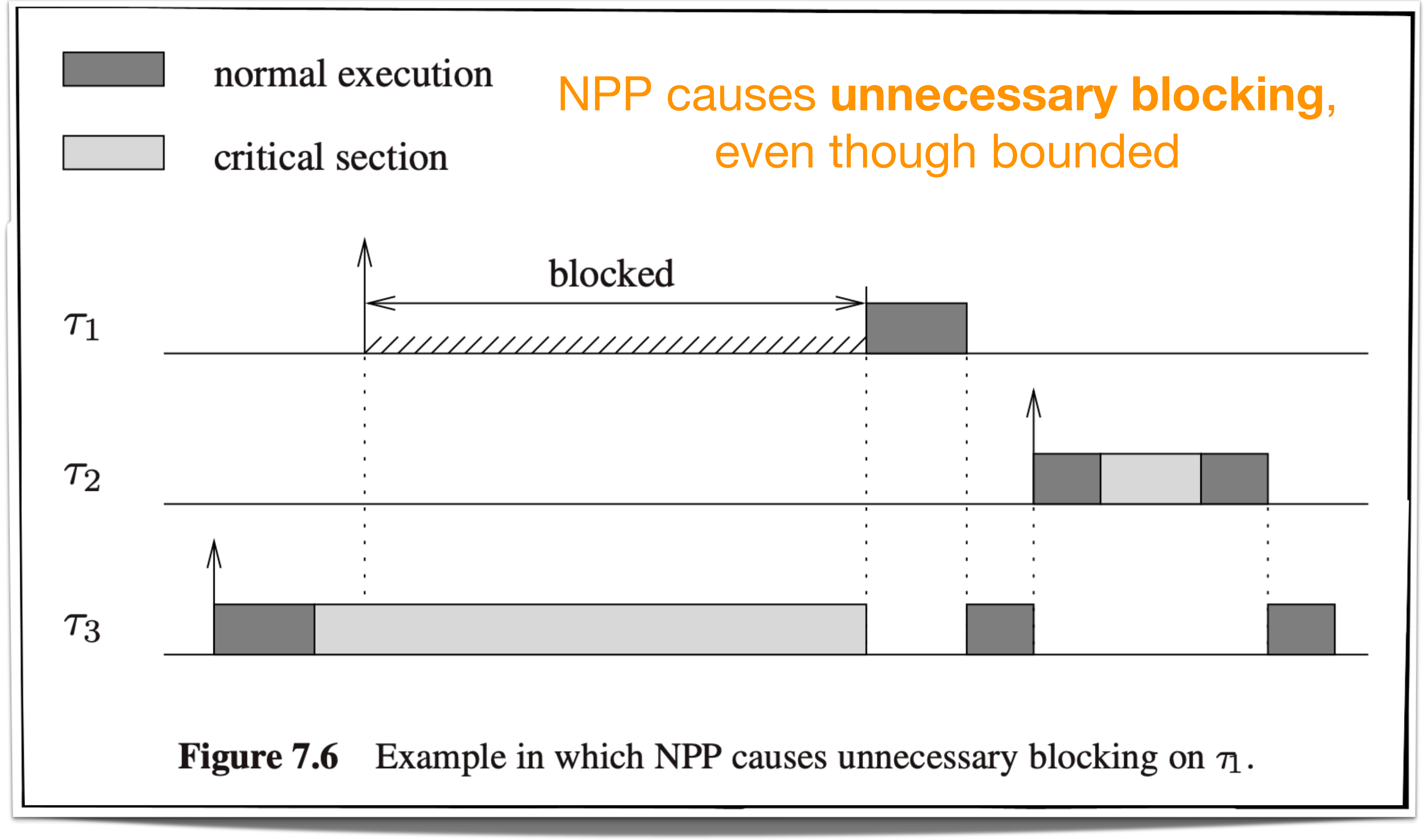
Unbounded priority inversion

Figure 7.4 An example of priority inversion.



NPP bounds the priority inversion

Figure 7.5 Example of NPP preventing priority inversion.



NPP causes **unnecessary blocking**, even though bounded

Figure 7.6 Example in which NPP causes unnecessary blocking on τ_1.

What’s next?

Protocol Definition

- Unlike NPP, resource holding jobs remain **fully preemptive**

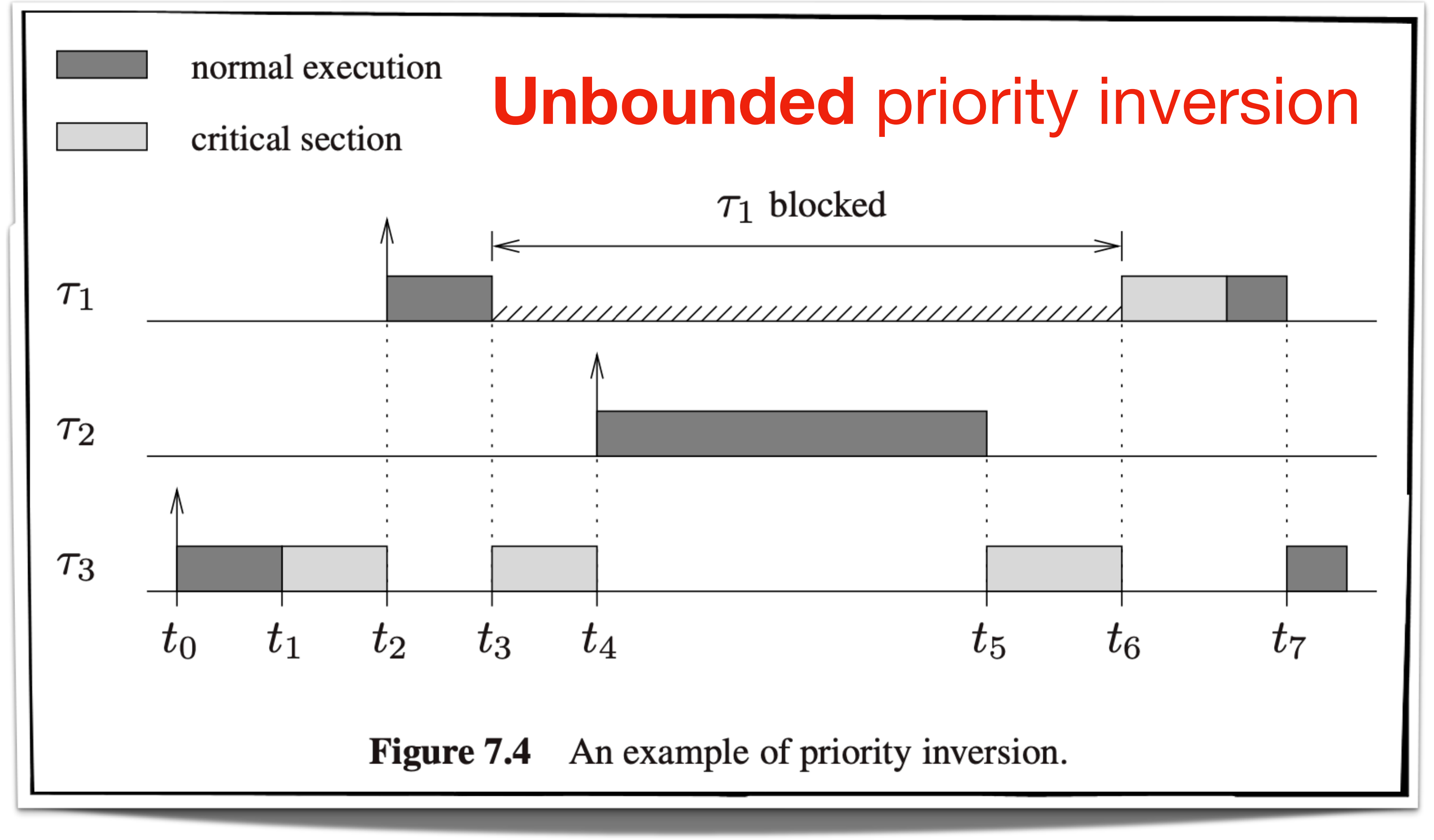
- Tasks are scheduled based on their effective priorities
  - For scheduling purposes, τ_i's priority is considered to be p_i and not P_i

- Suppose task τ_i tries to enter a critical section by acquiring resource R_k
  - Case 1: R_k is already held by a lower-priority task $\tau_j \implies \tau_i$ is **blocked** by τ_j
  - Case 2: R_k is already held by a higher-priority task $\tau_j \implies \tau_i$ is **interfered** by τ_k
  - Case 3: R_k is not held by any task $\implies \tau_i$ **enters** the critical section

- For Case 1,τ_j **inherits** τ_i's effective priority
  - τ_j's dynamic priority is updated as $p_j = p_i$

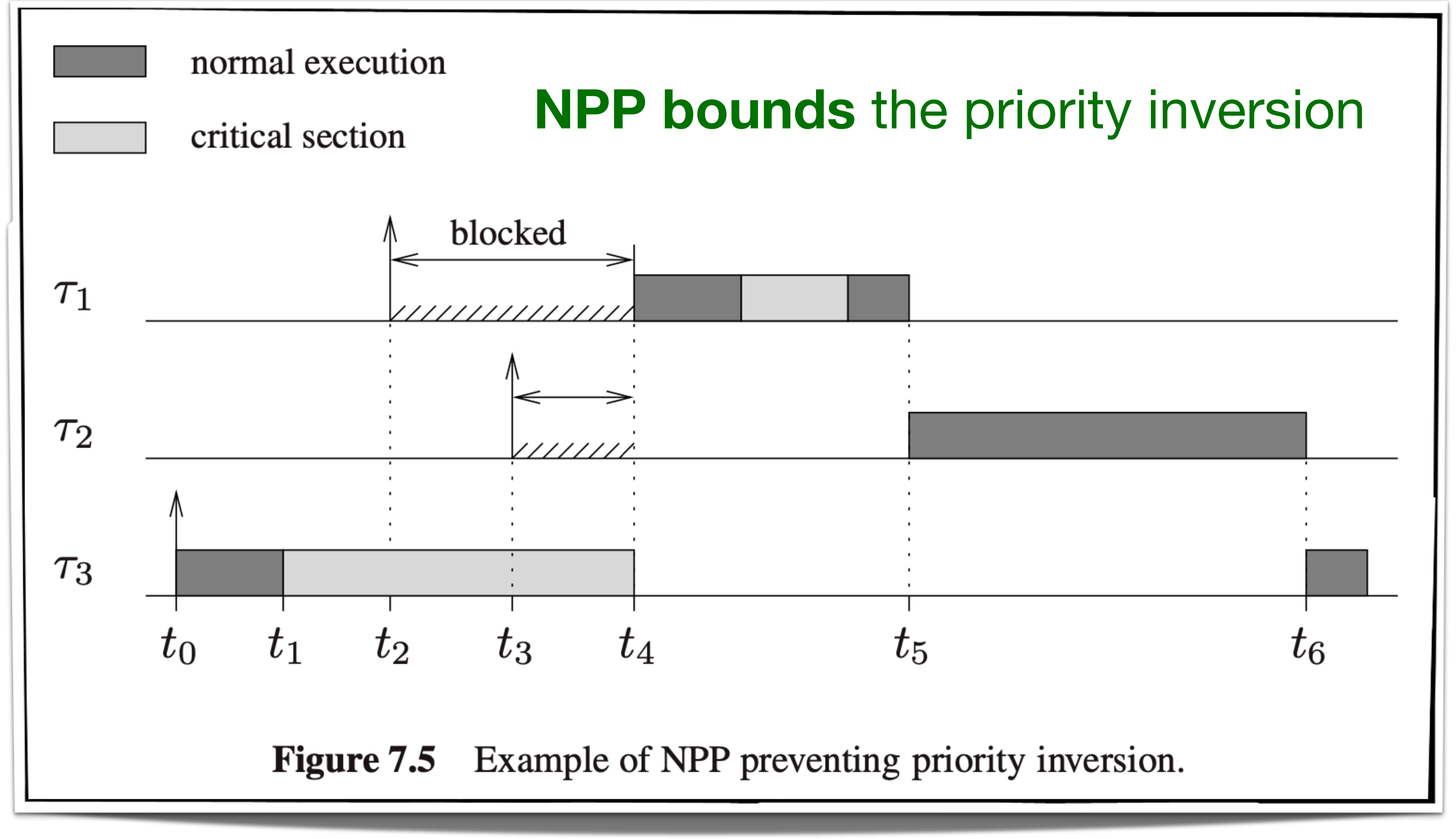
- In general, τ_j inherits the **highest priority of among all tasks that it blocks**
  - At any point of time, $p_j(R_k) = \max\{P_j, \max\limits_{\forall h}\{p_h \mid \tau_h \text{ is blocked on } R_k\}\}$

Example



Unbounded priority inversion

Figure 7.4 An example of priority inversion.



NPP bounds the priority inversion

Figure 7.5 Example of NPP preventing priority inversion.

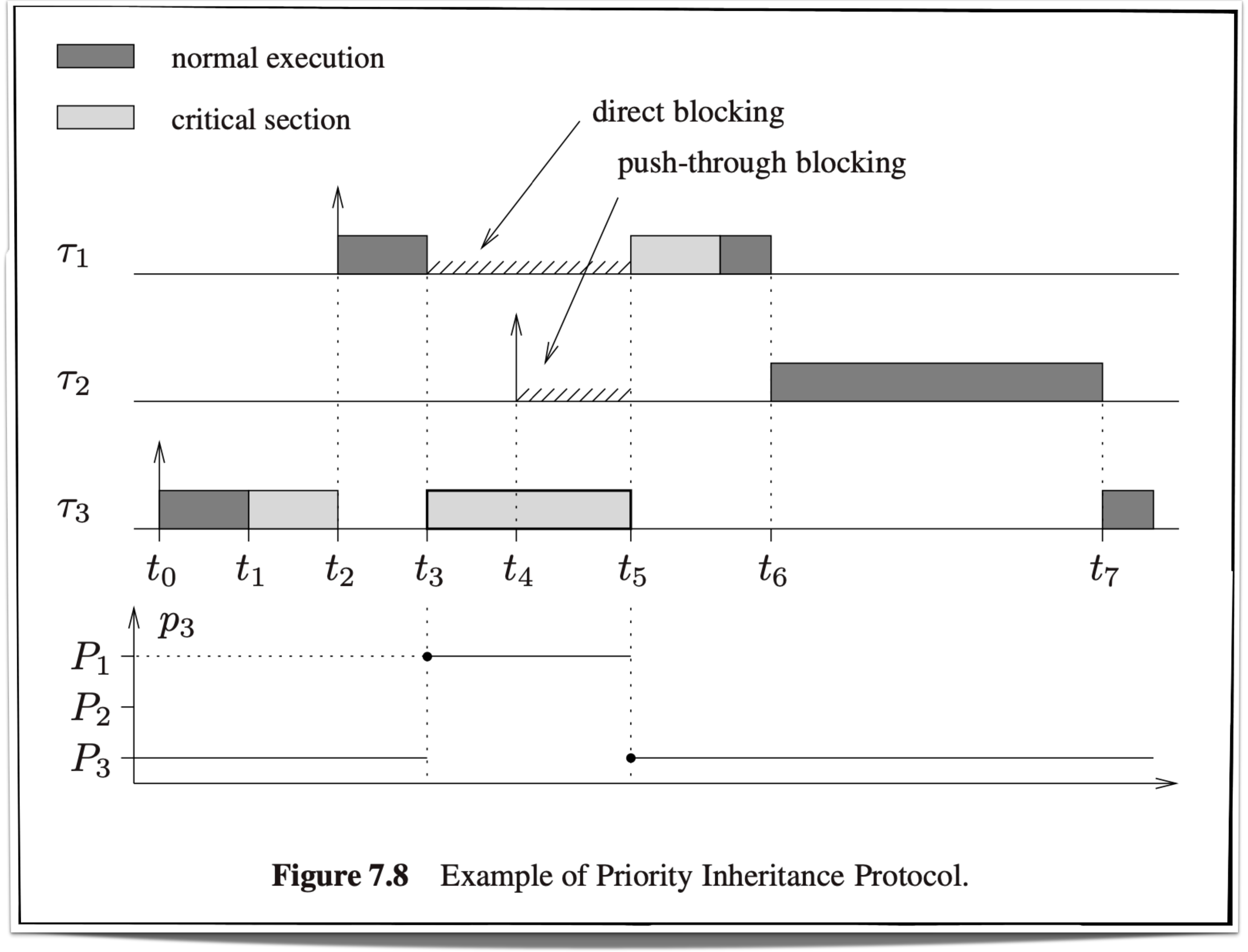


Figure 7.8 Example of Priority Inheritance Protocol.

Properties of PIP [1/5]

A semaphore S_k can cause push-through blocking to task T_i, only if S_k is accessed both by a task with priority lower than P_i and by a task with priority higher than P_i.

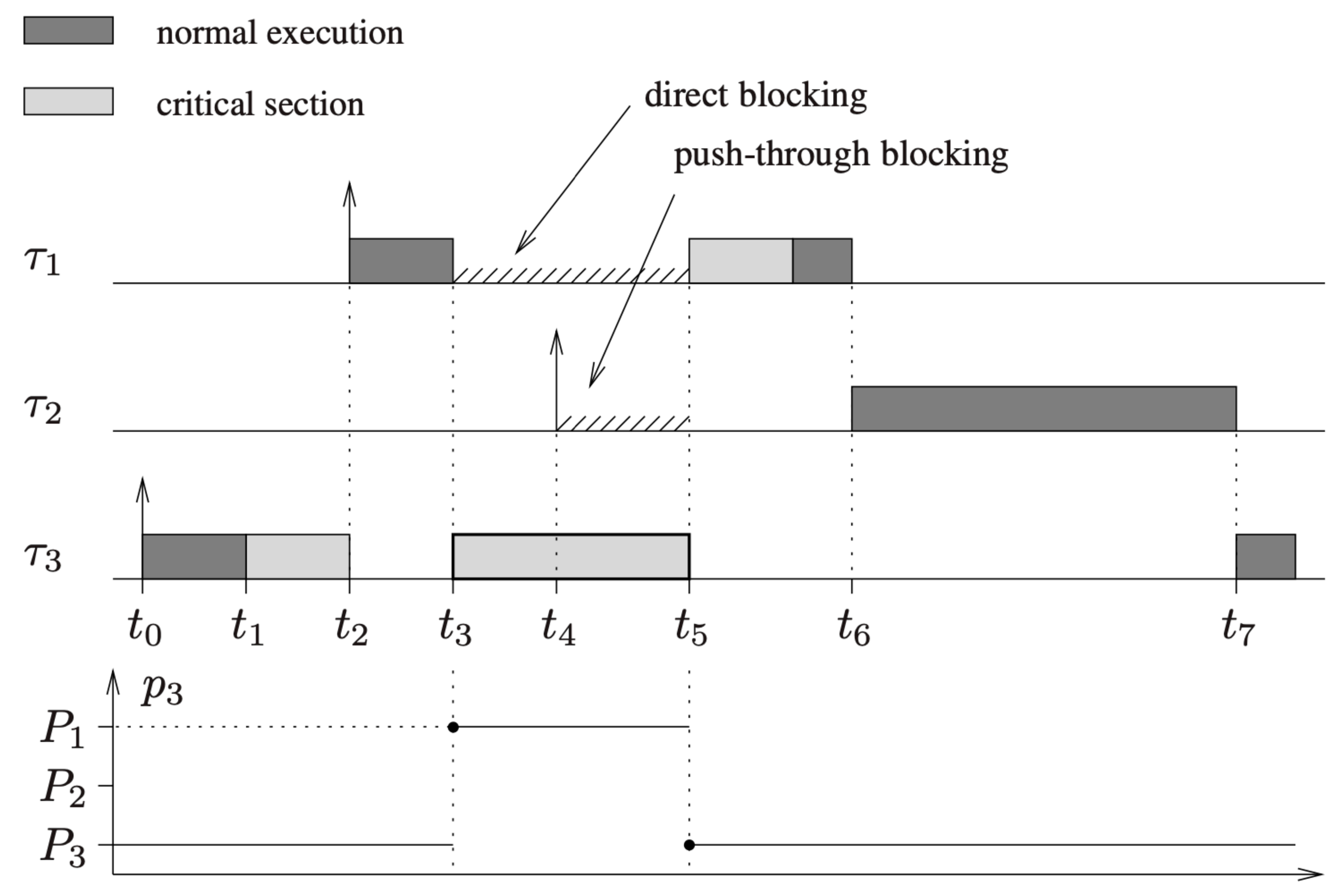


Figure 7.8 Example of Priority Inheritance Protocol.

Properties of PIP [2/5]

Transitive priority inheritance can occur only in the presence of nested critical sections.

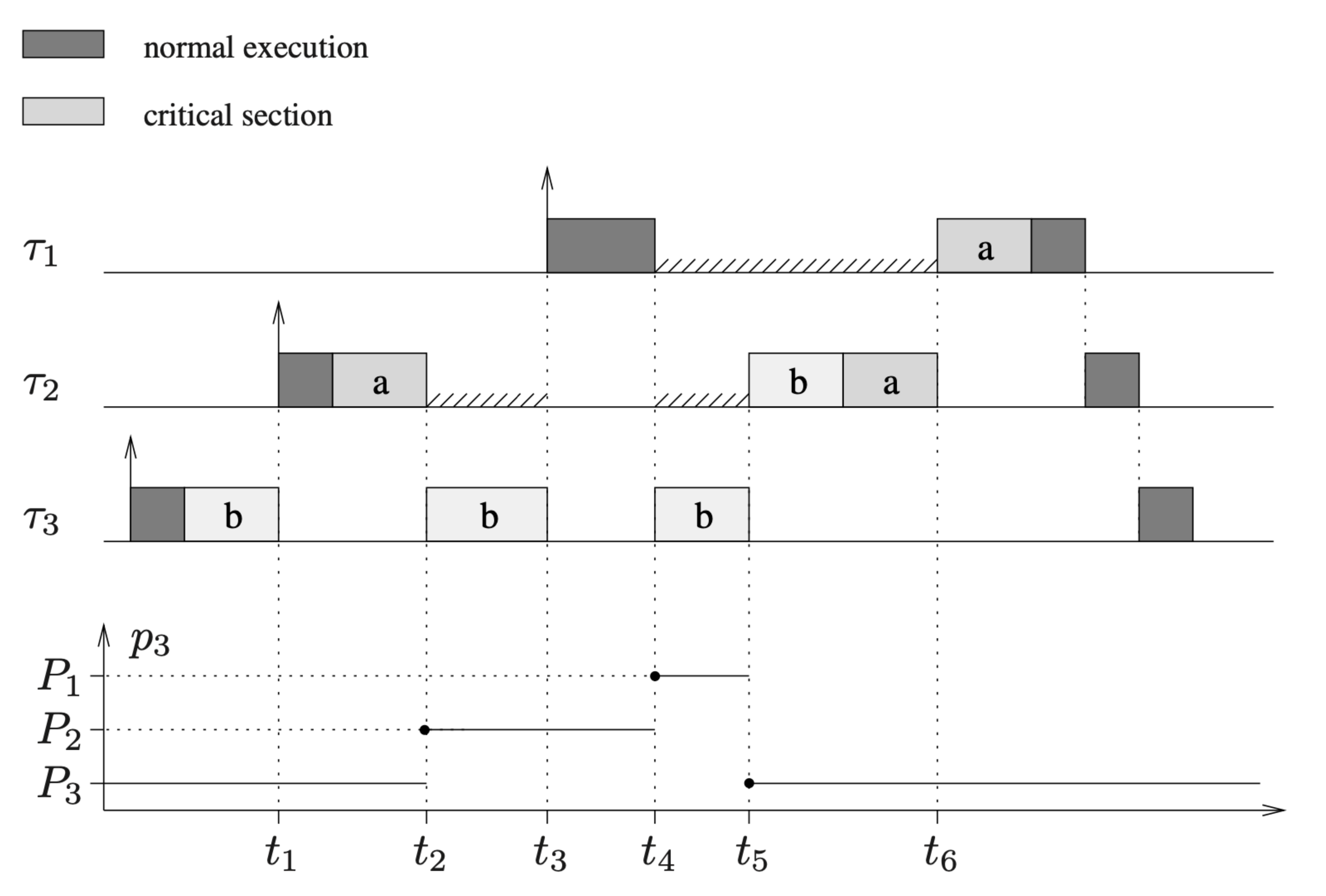


Figure 7.10 Example of transitive priority inheritance.

Properties of PIP [3/5]

If there are l_i lower-priority tasks that can block a task τ_i, then τ_i can be blocked for at most the duration of l_i critical sections, one for each of the l_i lower- priority tasks, regardless of the number of semaphores used by τ_i.

Properties of PIP [4/5]

If there are s_i *distinct semaphores that can block a task* τ_i*, then* τ_i *can be blocked for at most the duration of* s_i *critical sections, one for each of the* s_i *semaphores, regardless of the number of critical sections used by* τ_i*.*

Properties of PIP [5/5]

Under the Priority Inheritance Protocol, a task τ_i can be blocked for at most the duration of $\alpha_i = min(l_i, s_i)$ critical sections, where l_i is the number of lower-priority tasks that can block τ_i and s_i is the number of distinct semaphores that can block τ_i.

Computing Blocking Time B_i [1/2]

- A precise evaluation of the blocking factor B_i is quite complex because each critical section of the lower-priority tasks may interfere with τ_i via **direct blocking**, **push-through blocking**, or **transitive inheritance**

- Simplified algorithm
    - Assumes **no nested critical sections**, hence **no transitive inheritance**

Computing Blocking Time B_i [2/2]

- Semaphores that can **directly** block τ_i and that are shared by the lower-priority task τ_j are $\sigma_{i,j}^{dir} = \sigma_i \cap \sigma_j$

- Semaphores that can block τ_i by **push-through** and that are shared by the lower-priority task τ_j are $\sigma_{i,j}^{pt} = \cup_{h:P_h>P_i} \sigma_h \cap \sigma_j$

- Semaphores that can block τ_i either **directly or by push-through** and that are shared by the lower-priority task τ_j
  - $\sigma_{i,j} = \sigma_{i,j}^{dir} \cup \sigma_{i,j}^{dir} = \cup_{h:P_h \geq P_i} \sigma_h \cap \sigma_j$

- Longest critical sections used by lower-priority task τ_j that can block τ_i either directly or by push-through is
  - $\gamma_{i,j} = \{Z_{j,k} \,|\, R_k \in \sigma_{i,j}\}$

- Lll critical sections that can block τ_i either directly or by push-through is $\gamma_i = \cup_{j:P_j<P_i} \gamma_{i,j}$

- B_i is given by the largest sum of the lengths of the α_i critical sections in γ_i
  - The sum should contain only terms $\delta_{i,k}$ referring to different tasks and different semaphore

The Priority Ceiling Protocol (PCP)

PCP vs PIP

- The PIP is a **reactive** locking protocol
  - It only kicks in when resource contention already exists

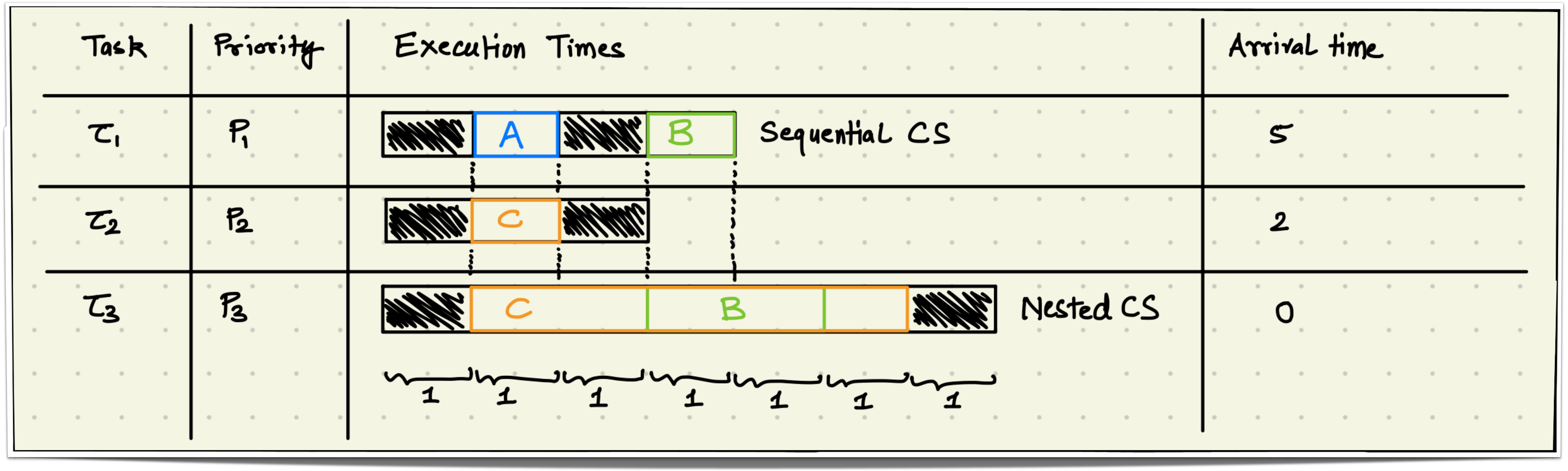
- **Key PCP insight**
  - Better to **prevent** problematic scenarios rather **than resolve** them

- The PCP is an **anticipatory** locking protocol
  - Exploits the knowledge of resource needs at **design time** to avoids excessive blocking at runtime

PCP Key Concepts

- **Priority ceilings**
  - Each semaphore S_k is **statically** assigned a priority ceiling $C_{static}(S_k)$
    - $C_{static}(S_k) =$ priority of the highest-priority task that **ever** accesses S_k
- **Current system ceiling**
  - At any time t, a global system ceiling $C_{global}(t)$ is dynamically computed
    - $C_{global}(t)$ = highest priority ceiling among all semaphores locked at time t OR
      (if no semaphores are locked) sentinel value P_0 that is **smaller** than all task priorities

- **Protocol**
  - Task τ_i can acquire semaphore S_k at time t only if
    - Its effective priority $p_i > C_{global}(t)$ OR $p_i = C_{global}(t)$ and τ_i "owns" the ceiling resource
    - OTHERWISE, it transmits its priority to the task τ_j that holds semaphore S_k
- **Example**



Task	Priority	Execution Times	Arrival time
τ_1	P_1	A B Sequential CS	5
τ_2	P_2	C	2
τ_3	P_3	C B Nested CS	0

Properties of PCP [1/4]

- PCP prevents transitive blocking

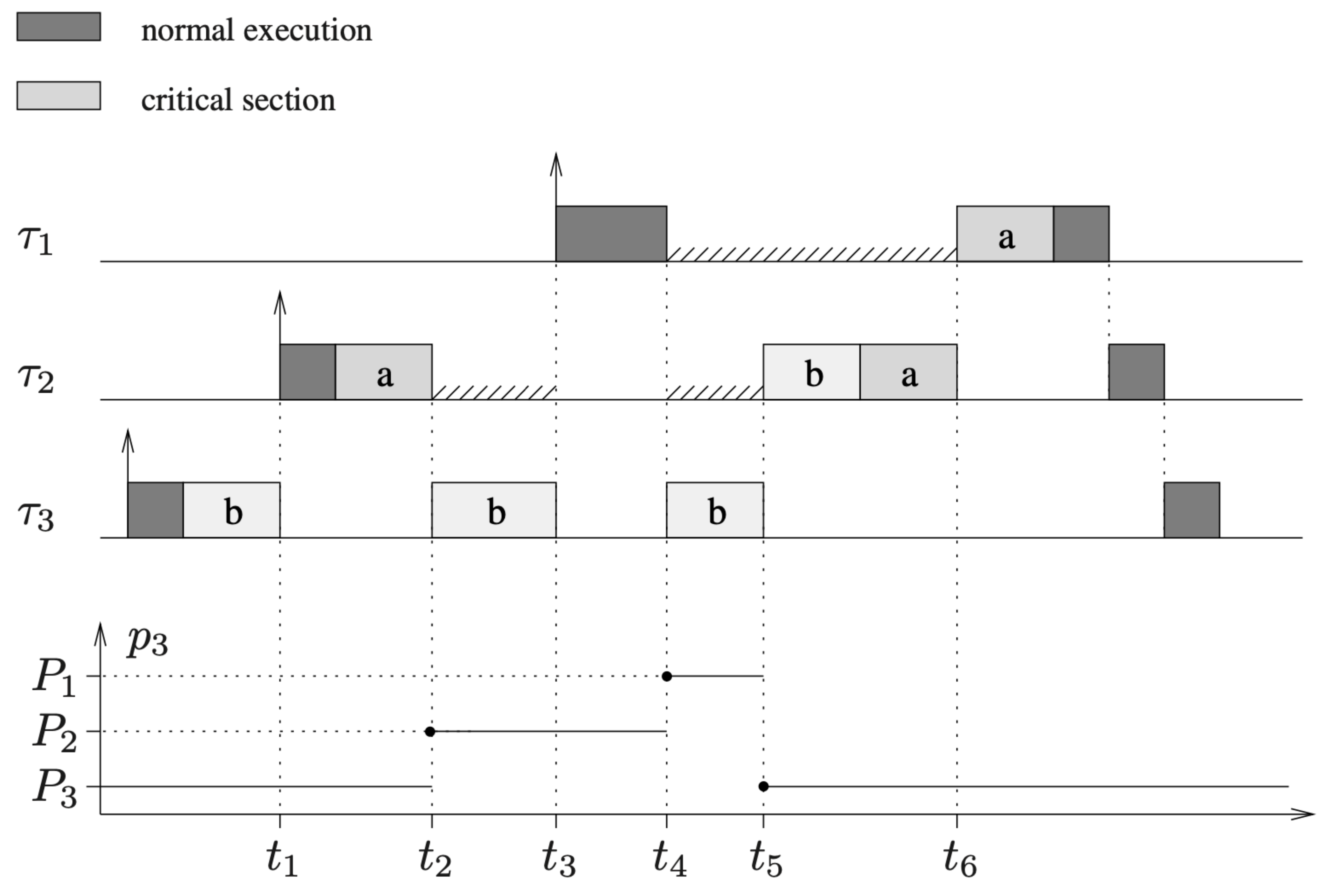


Figure 7.10 Example of transitive priority inheritance.

Properties of PCP [2/4]

- PCP prevents deadlocks

Properties of PCP [3/4]

- A task τ_i can be blocked for **at most** the duration of **one** critical section

Properties of PCP [4/4]

- A critical section $z_{i,k}$ belonging to task τ_j and guarded by semaphore S_k can block a task τ_i only if $P_j < P_i$ and $C_{global}(S_k) \geq P_i$

Computing Blocking Time B_i