Real-time Synchronization
(Semaphores, Resources and Blocking)

Priority Inheritance

Priority Ceiling

Slack Resource Policy

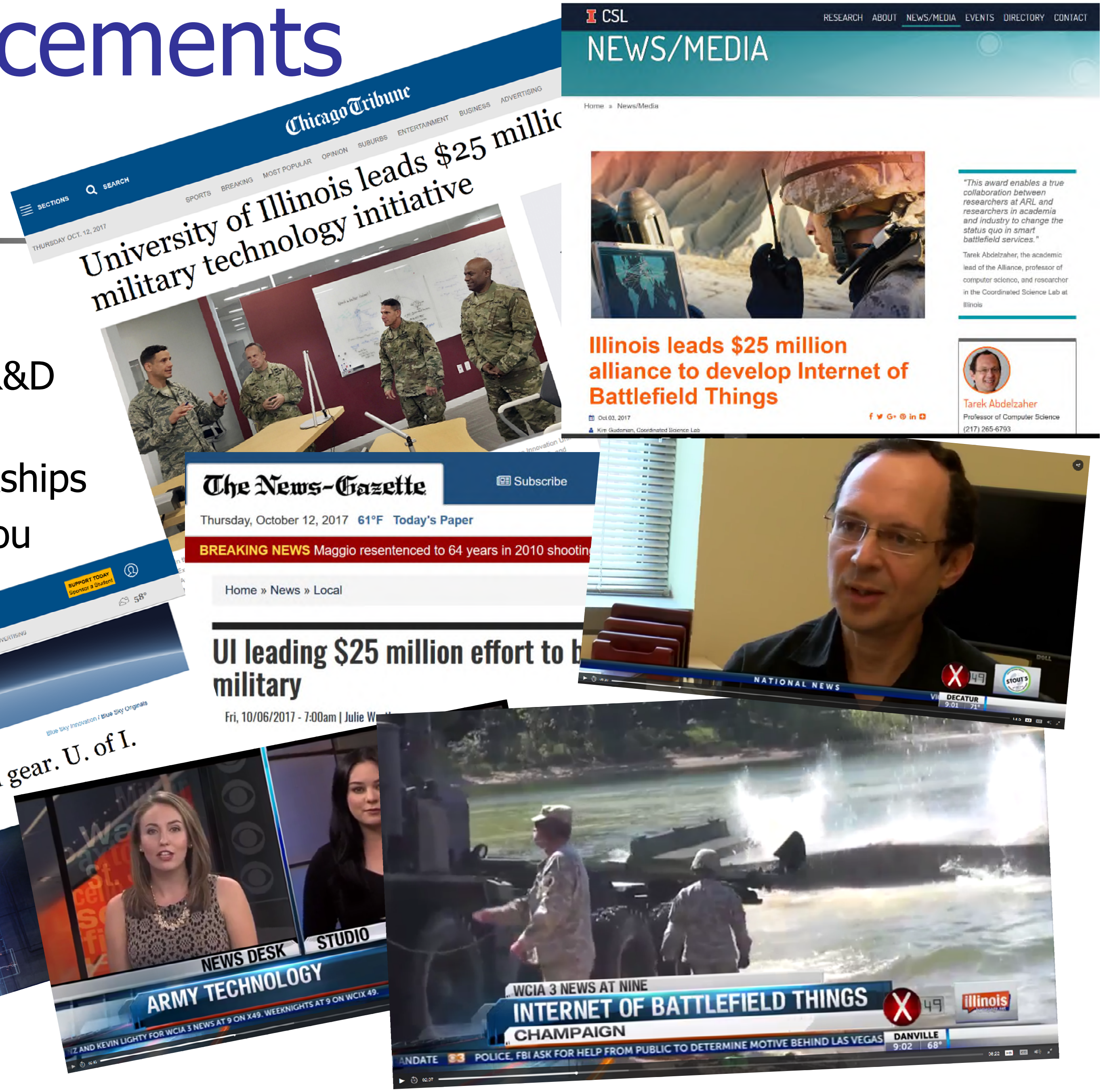
Reminder

- MP1 due soon.

Announcements
R&D

Wanted!!

- Undergraduates for R&D positions
- Masters/MCS: Full RAships
- Professional (when you graduate): Up to $75K/yr

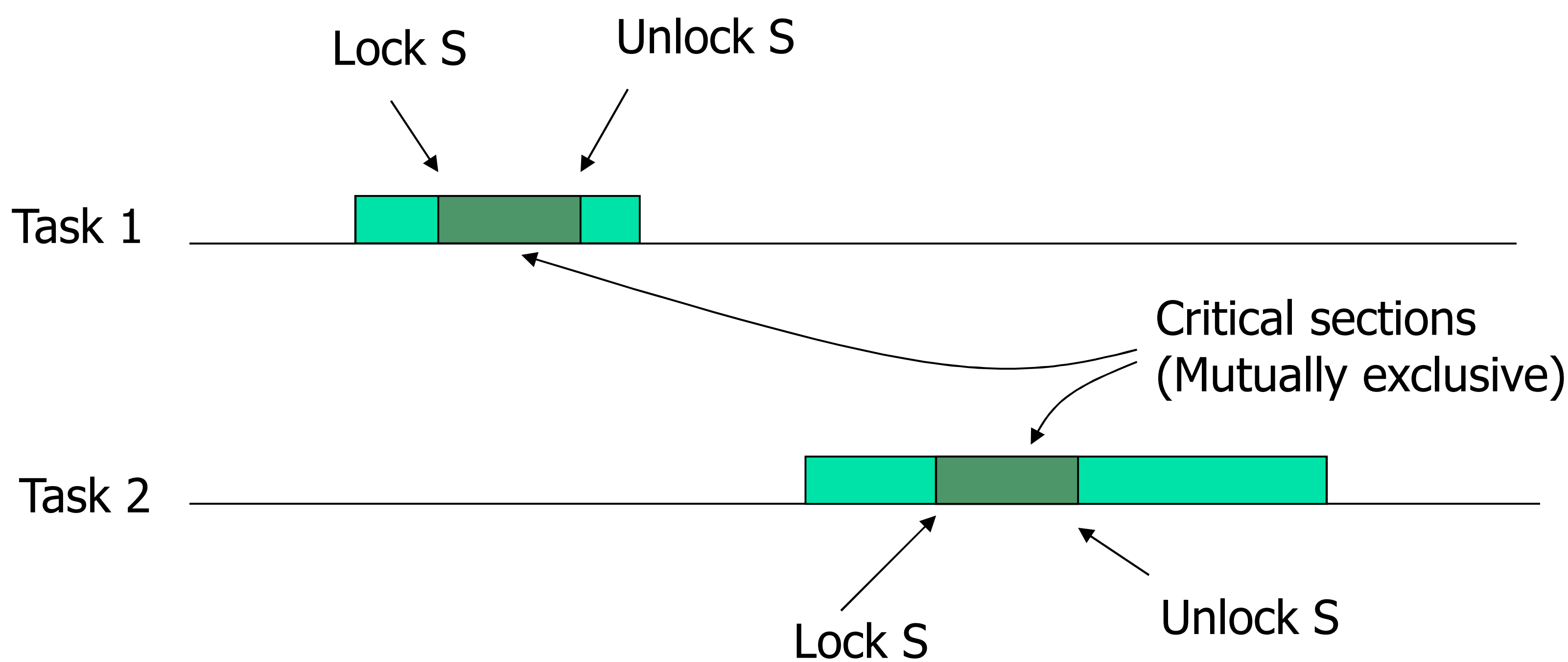


The Problem

- Tasks have synchronization constraints
  - Semaphores protect critical sections
- Blocking can cause a higher-priority task to wait on a **lower-priority** one to unlock a resource
  - Problem: In all previous derivations we assumed that a task can only wait for **higher-priority** tasks not **lower-priority** tasks
- Question
  - What is the maximum amount of time a higher-priority task can wait for a lower-priority task?
  - How to account for that time in schedulability analysis?

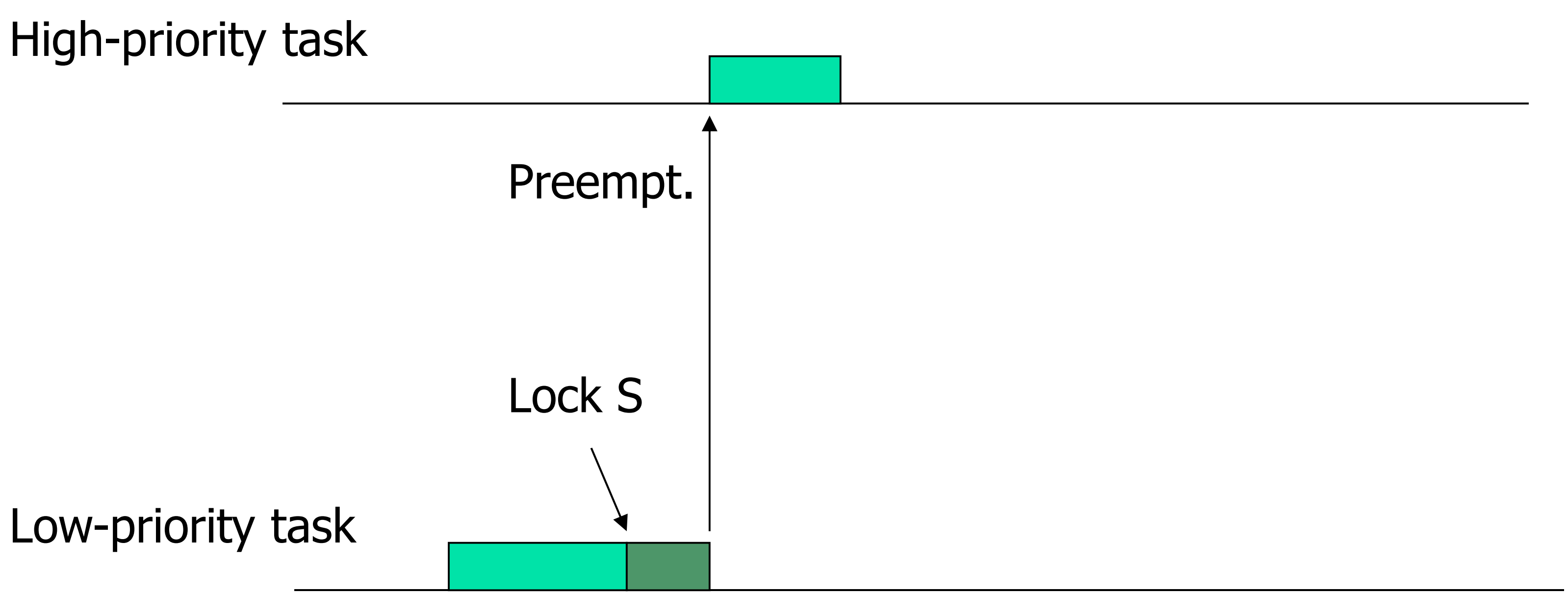
Mutual Exclusion Constraints

- Tasks that lock/unlock the same semaphore are said to have a mutual exclusion constraint



Priority Inversion

- Locks and priorities may be at odds. Locking results in priority inversion



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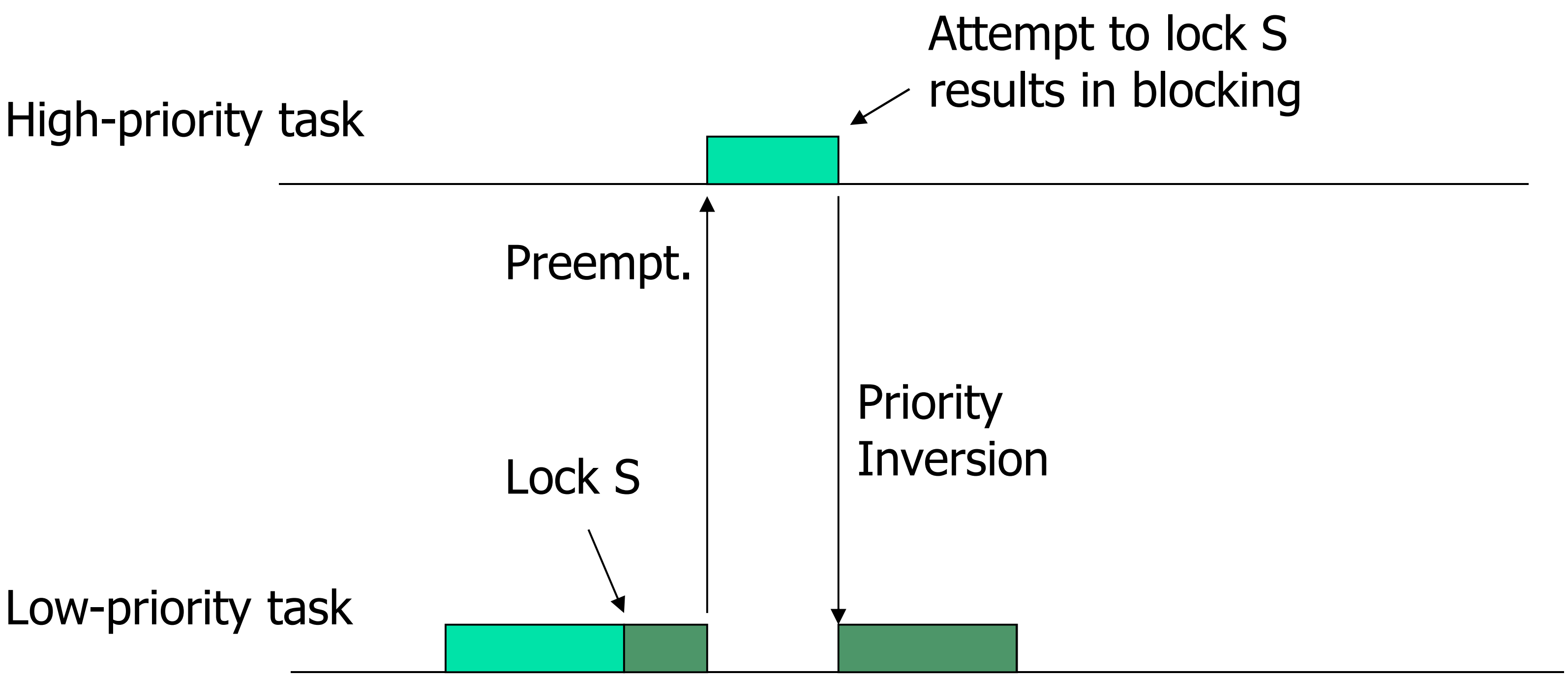
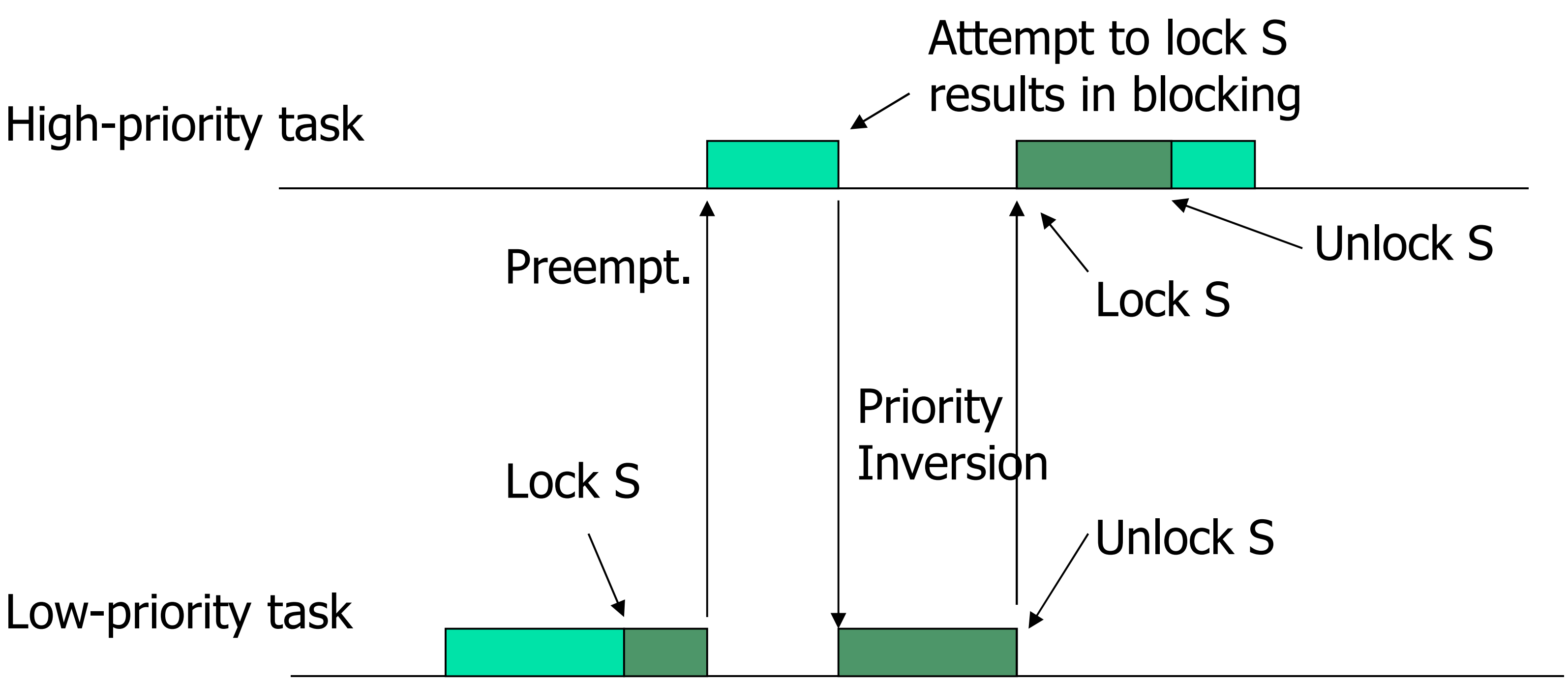


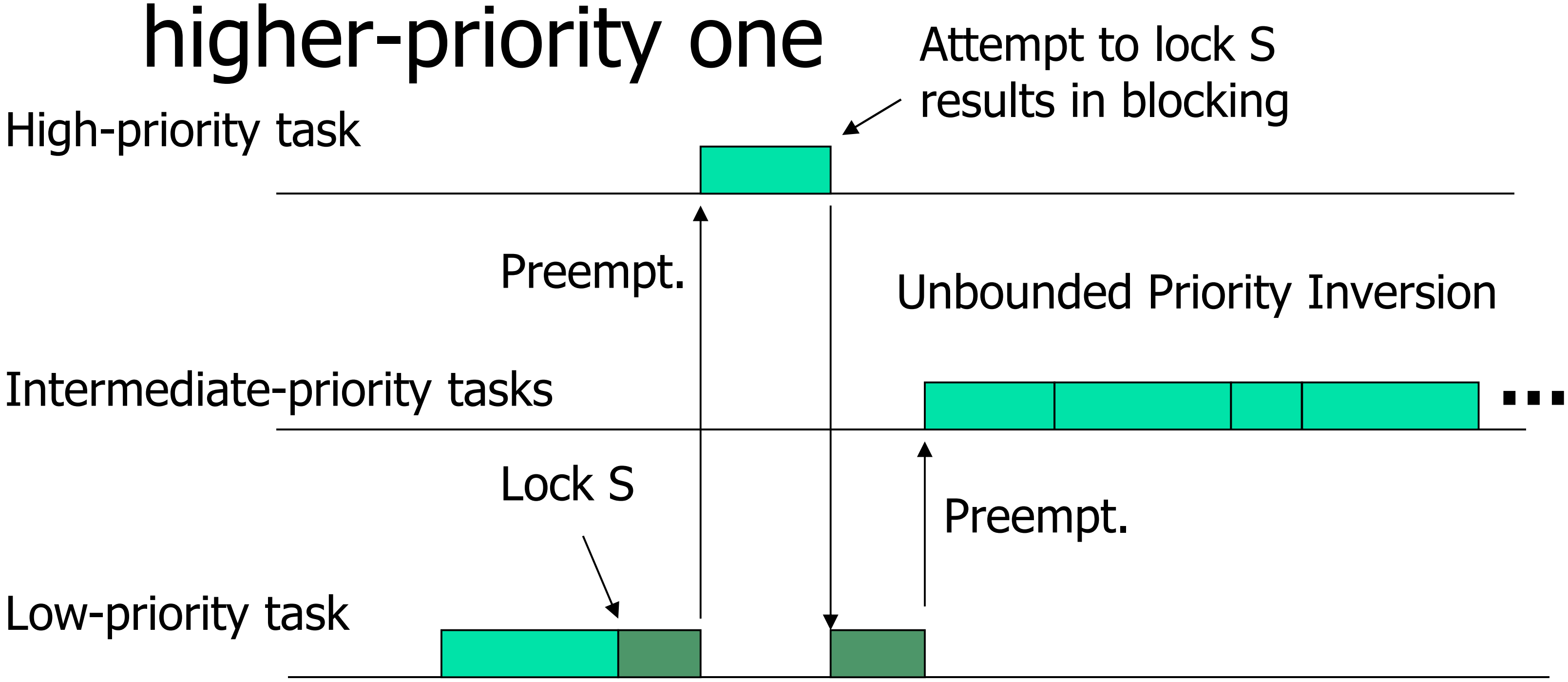
Priority Inversion

- How to account for priority inversion?



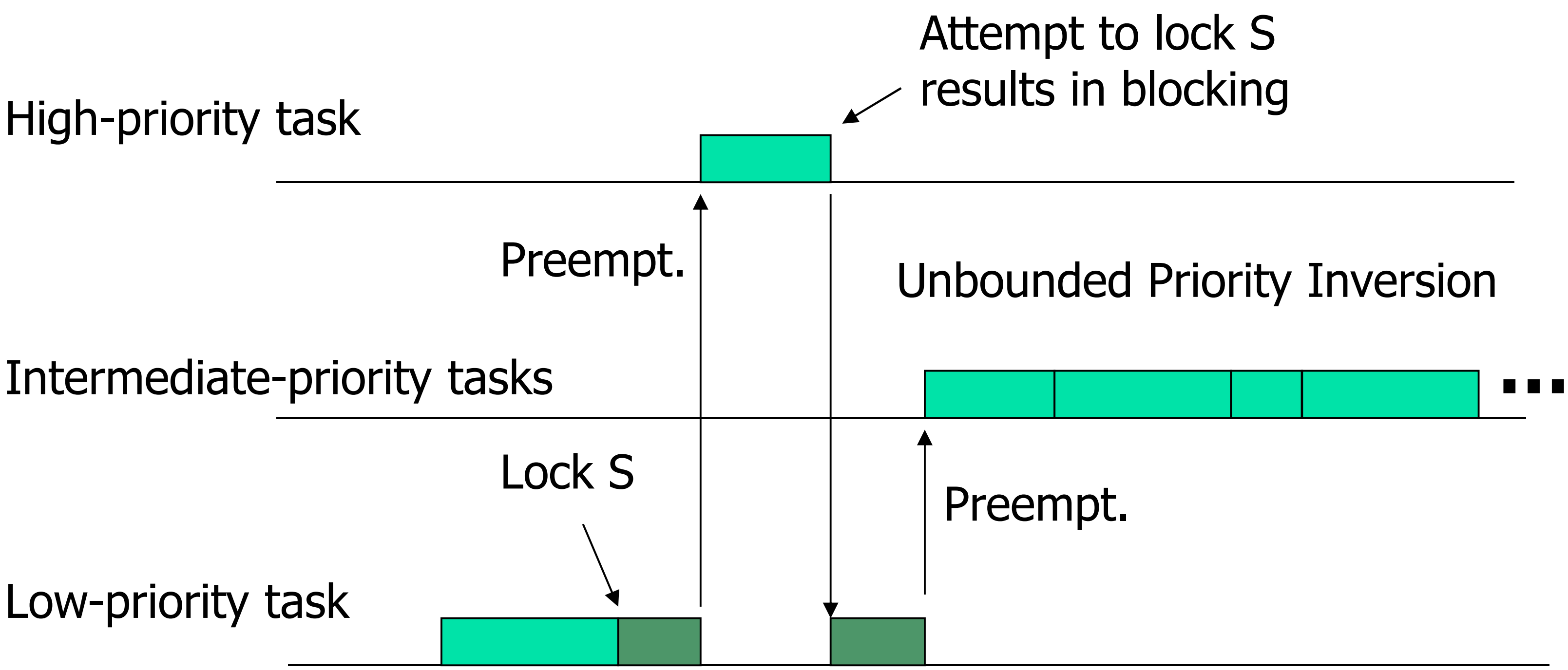
Unbounded Priority Inversion

- Consider the case below: a series of intermediate priority tasks is delaying a higher-priority one



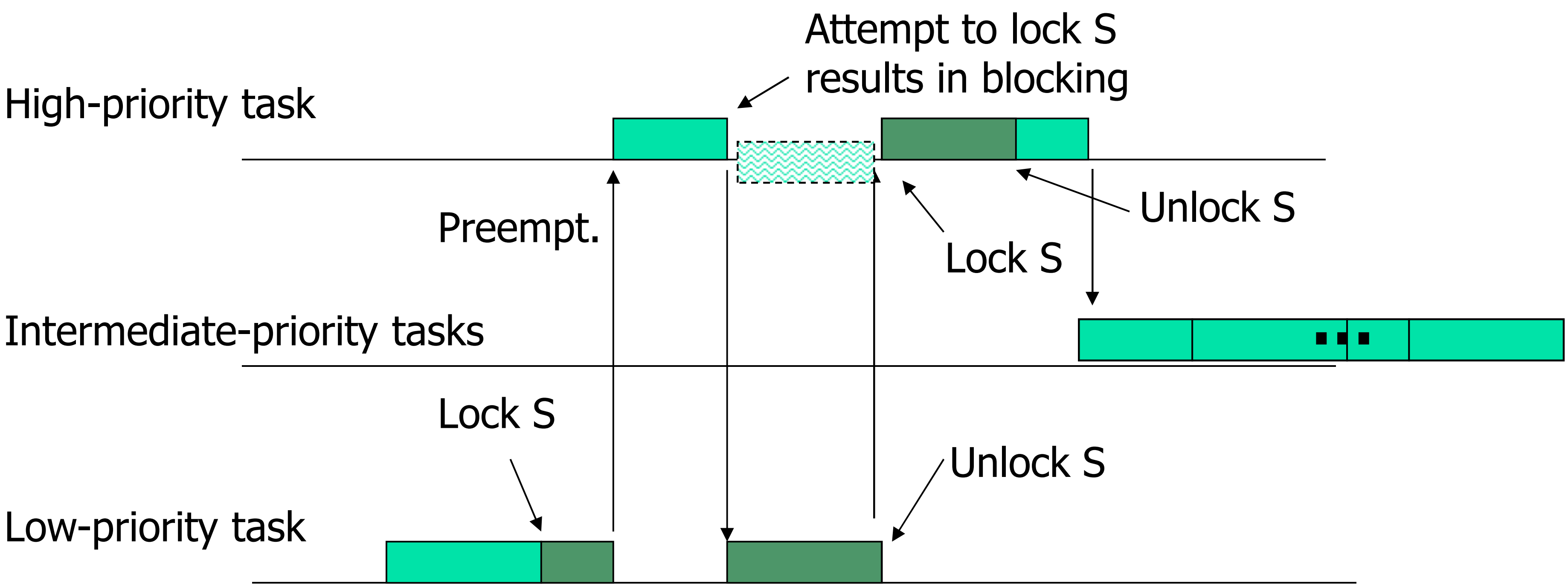
Unbounded Priority Inversion

- How to prevent unbounded priority inversion?



Priority Inheritance Protocol

- Let a task inherit the priority of any higher-priority task it is blocking

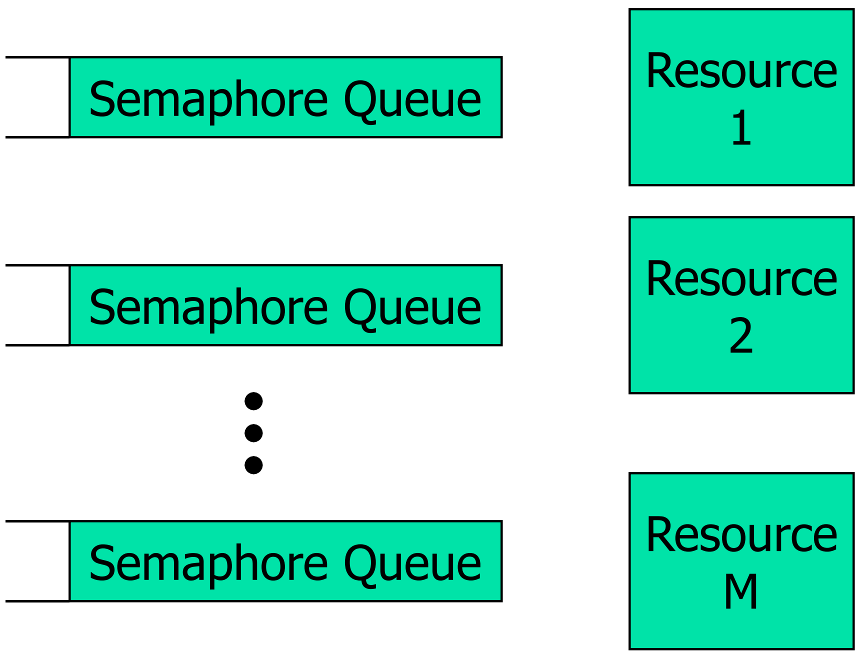


Priority Inheritance Protocol

- Question: What is the longest time a task can wait for lower-priority tasks?
  - Let there be N tasks and M semaphores
  - Let the largest critical section of task i be of length B_i
- Answer: ?

Computing the Maximum Priority Inversion Time

- Consider the instant when a high-priority task that arrives.
  - What is the most it can wait for lower priority ones?



If I am a task, priority inversion occurs when
(a) Lower priority task holds a resource I need (direct blocking)
(b) Lower priority task inherits a higher priority than me because it holds a resource the higher-priority task needs (push-through blocking)

Maximum Blocking Time

- If all critical sections are equal (of length B):
  - Blocking time = $B \min(N, M)$
    (Why?)
- If they are not equal?

Maximum Blocking Time

- If all critical sections are equal (of length B):
  - Blocking time = $B \min(N, M)$ (Why?)
- If they are not equal
  - Find the worst (maximum length) critical section for each resource
  - Add up the top $\min(N, M)$ sections in size
- The total priority inversion time for task i is called B_i

Schedulability Test

$$\forall i, 1 \le i \le n,$$

$$\frac{B_i}{P_i} + \sum_{k=1}^{i} \frac{C_k}{P_k} \le i(2^{1/i} - 1)$$

Schedulability Test

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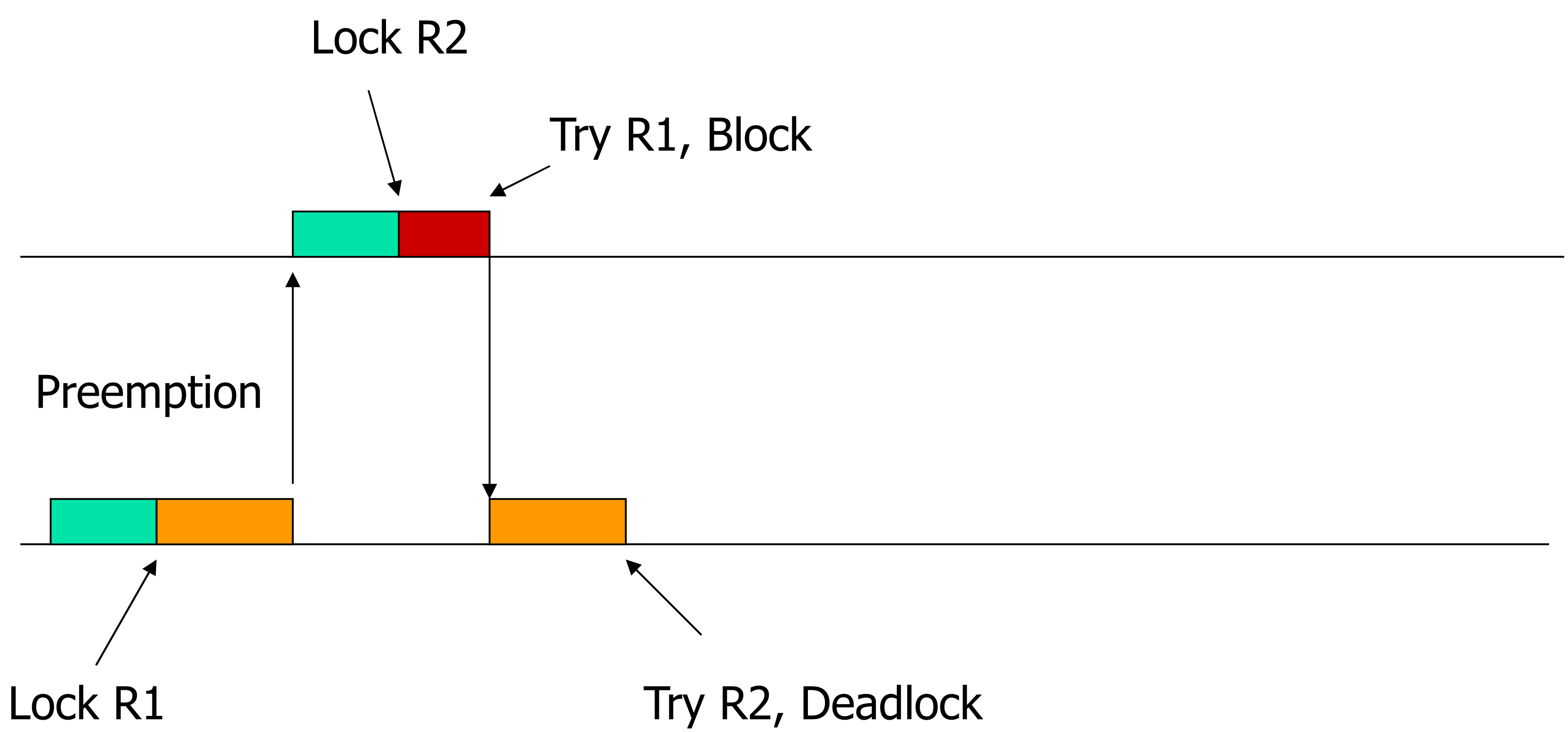
Why do we have to test each task separately? Why not just one utilization-based test like it used to?

Problem: Deadlock

Deadlock occurs if two tasks locked two semaphores in opposite order

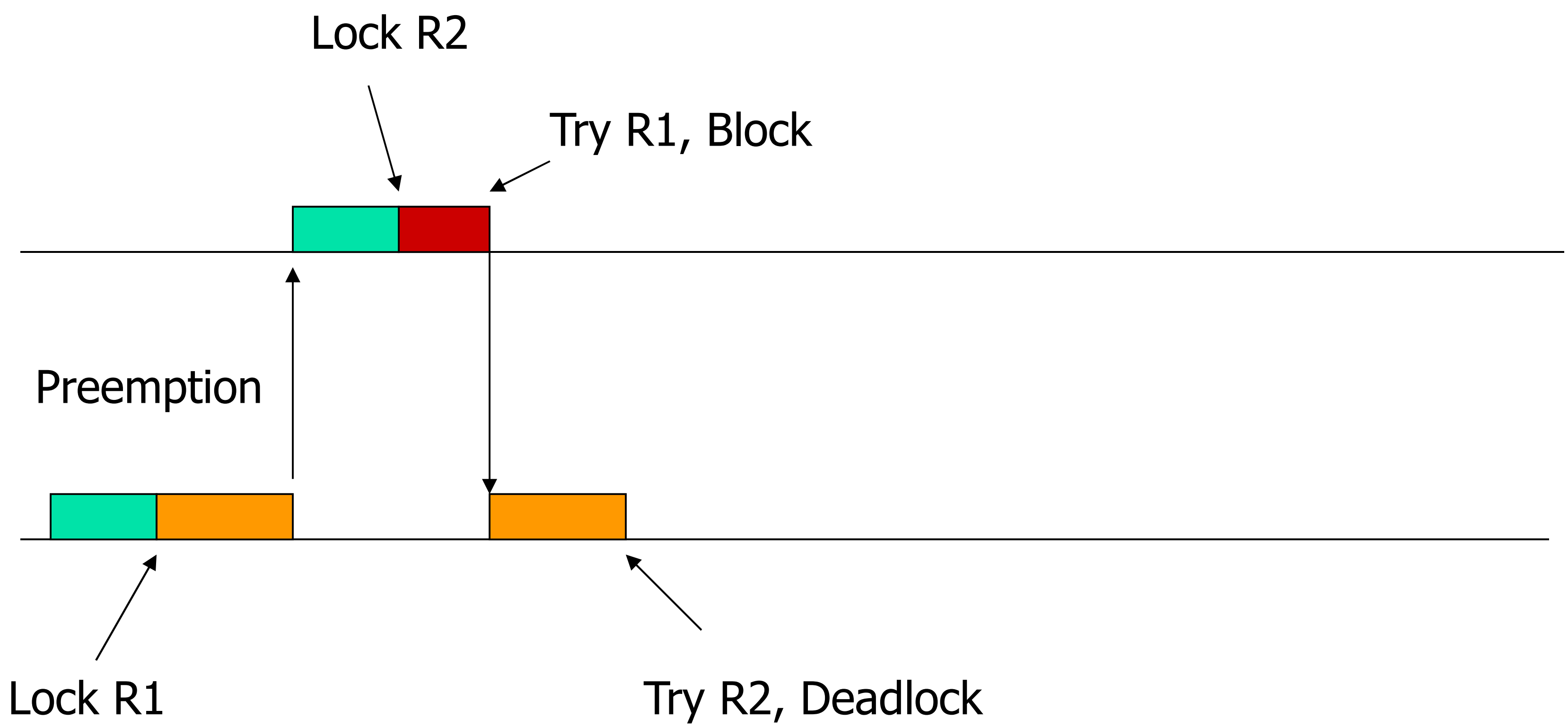


Priority Ceiling Protocol

- Definition: The priority ceiling of a semaphore is the highest priority of any task that can lock it
- A task that requests a lock R_k is denied if its priority is not higher than the highest priority ceiling of all currently locked semaphores (say it belongs to semaphore R_h)
  - The task is said to be blocked by the task holding lock R_h
- A task inherits the priority of the top higher-priority task it is blocking

Problem: Deadlock?

Deadlock used to occur if two tasks locked two semaphores in opposite order. Can it still occur in priority ceiling?



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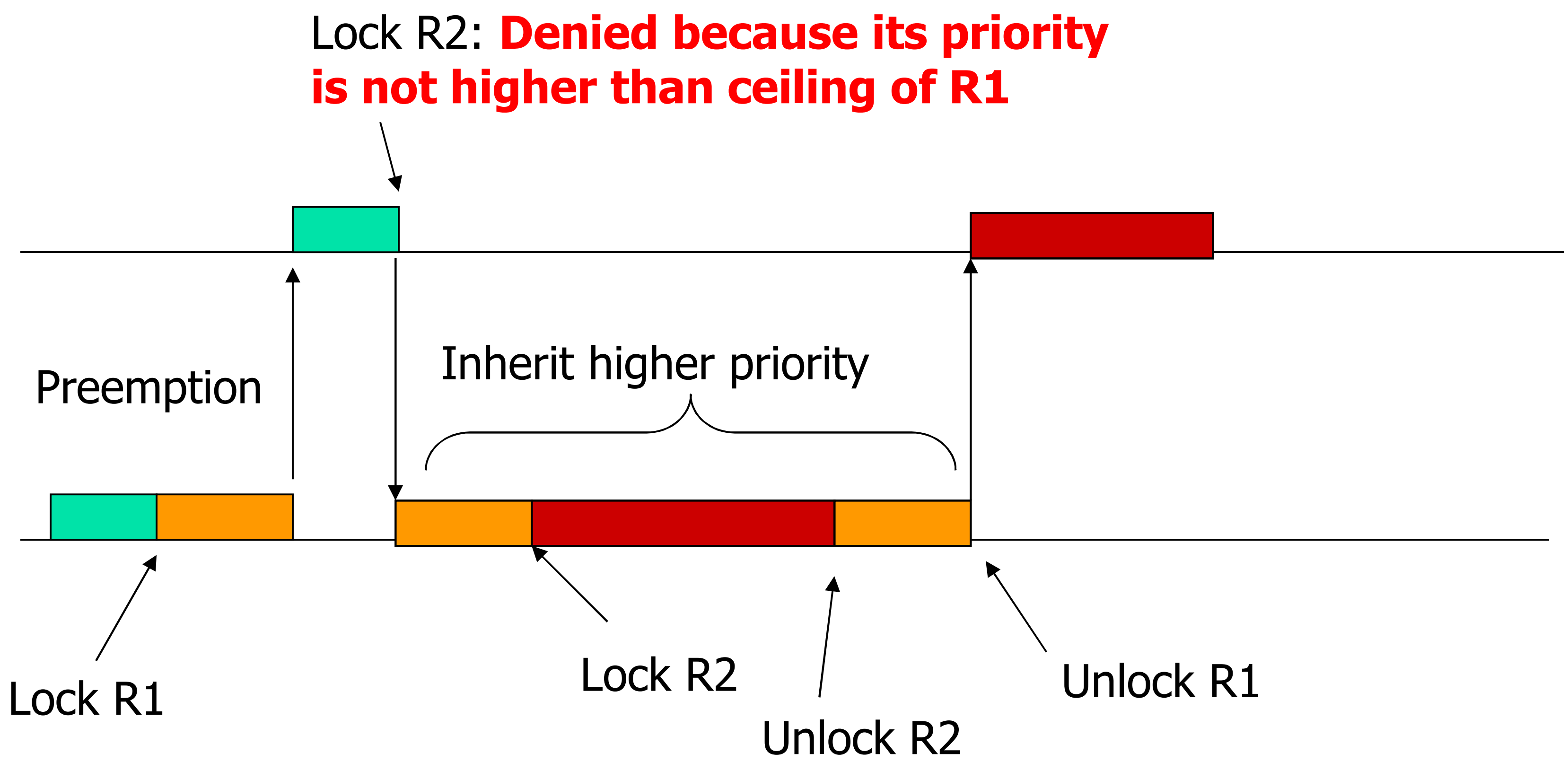
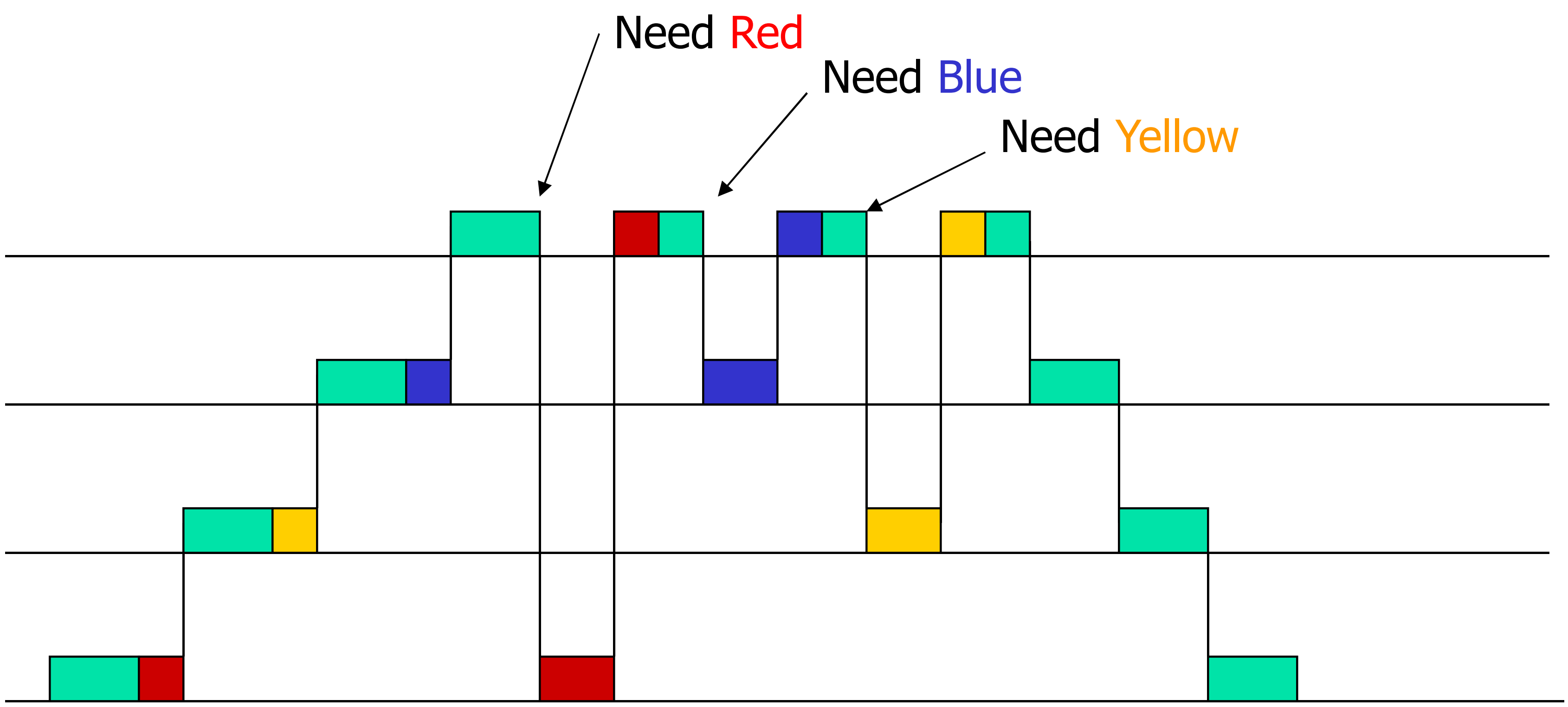
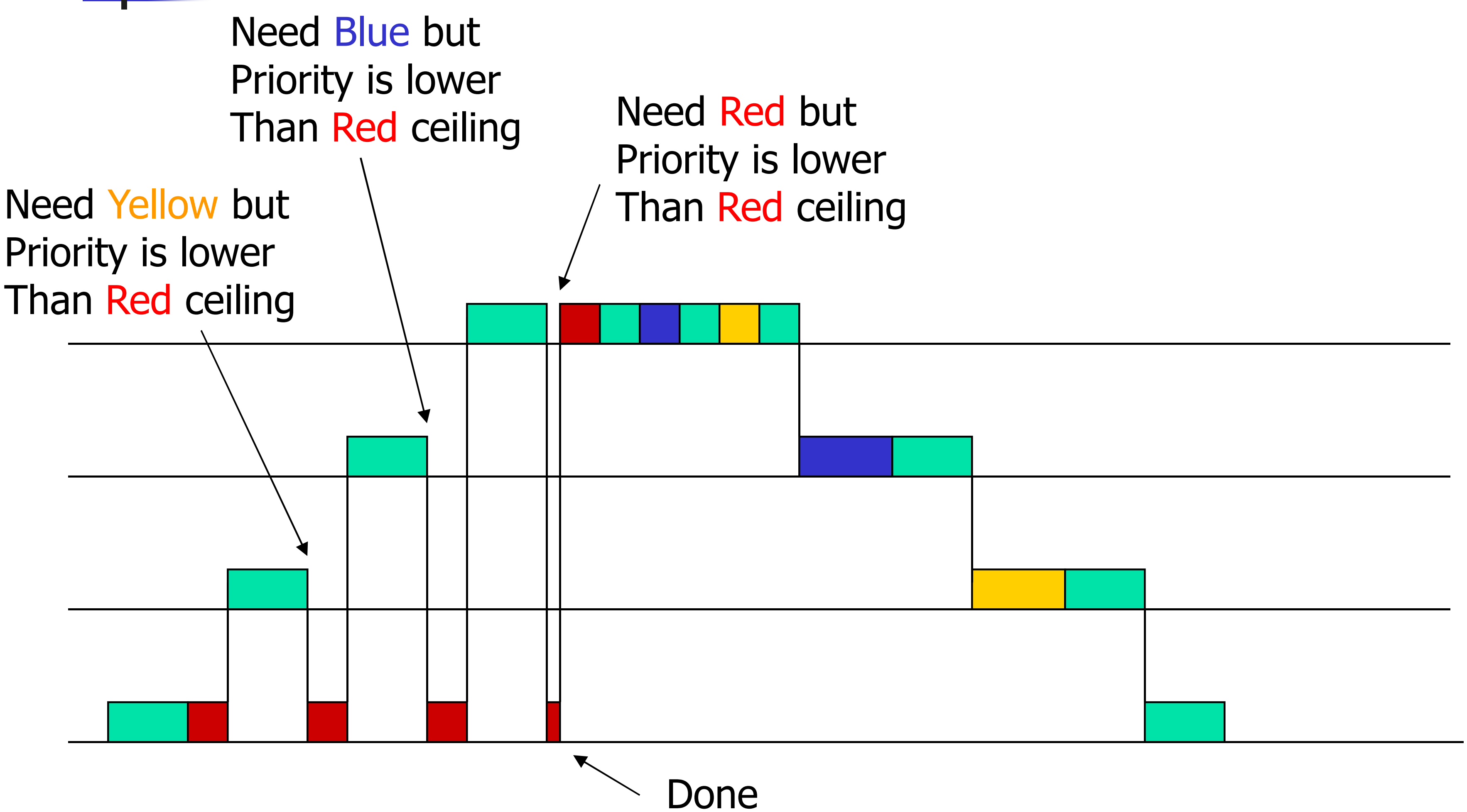


Priority Inheritance Protocol: Maximum Blocking Time



Priority Ceiling Protocol: Maximum Blocking Time



Schedulability

- A task can be preempted by only one critical section of a lower priority task (that is guarded by a semaphore of equal or higher priority ceiling). Let max length of such section be B_i

$$\forall i, 1 \le i \le n,$$

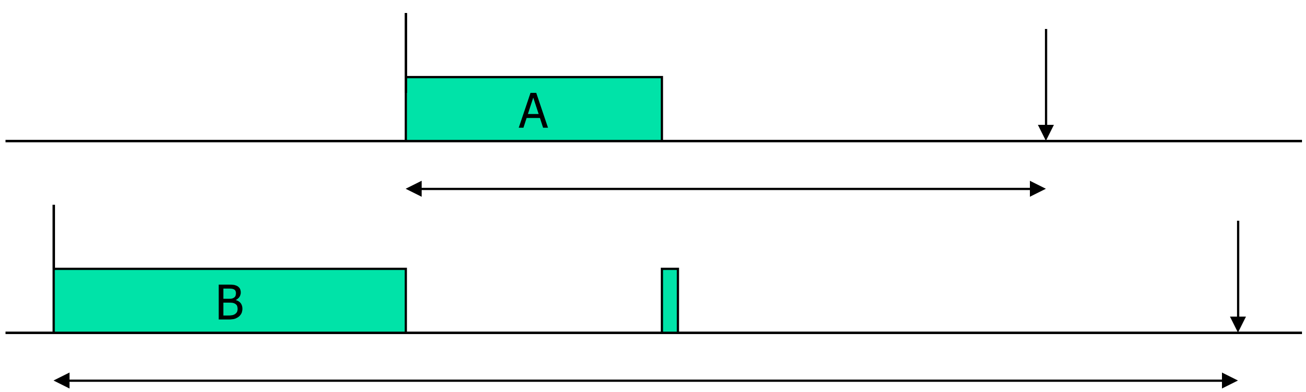
$$\frac{B_i}{P_i} + \sum_{k=1}^{i} \frac{C_k}{P_k} \le i(2^{1/i} - 1)$$

Slack Resource Policy

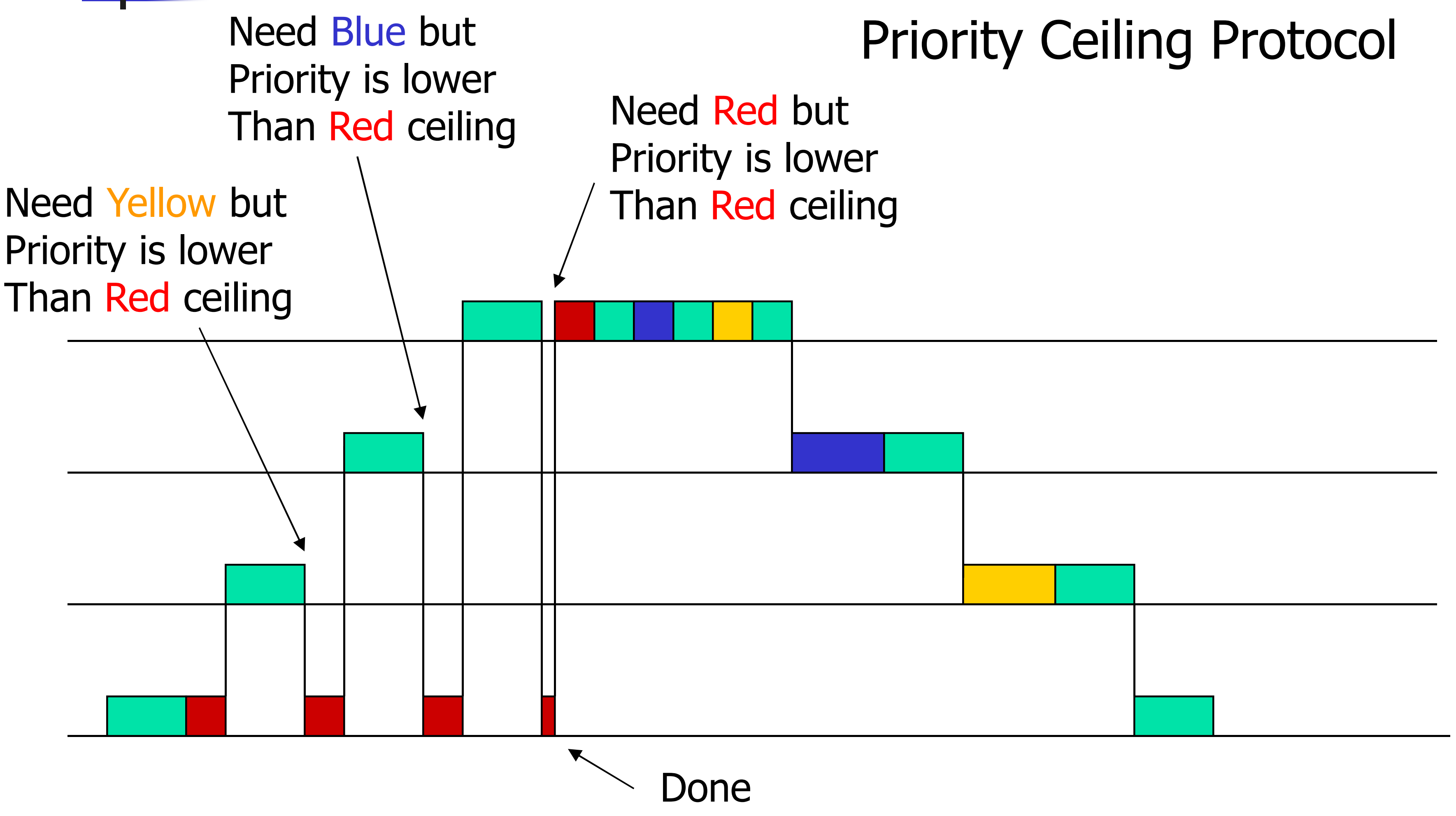
- Priority:
  - Any static or dynamic policy (e.g., EDF, RM, …)
- Preemption Level
  - Any *fixed value* that satisfies: If A arrives after B and Priority (A) > Priority (B) then PreemptionLevel (A) > PreemptionLevel (B)
- Resource Ceiling
  - Highest preemption level of all tasks that might access the resource
- System Ceiling
  - Highest resource ceiling of all currently locked resources
- A task can preempt another if:
  - It has the highest priority
  - Its preemption level is higher than the system ceiling

Example: EDF

- Priority is proportional to the absolute deadline
- Preemption level is proportional to the relative deadline (shoter → higher priority).
- Observe that:
  - If A arrives after B and Priority (A) > Priority (B) then PreemptionLevel (A) > PreemptionLevel (B)



Maximum Blocking Time



Maximum Blocking Time

Slack Resource Policy

Can't preempt
Preemption level is not higher than ceiling