Lecture 10: Scheduling with priorities

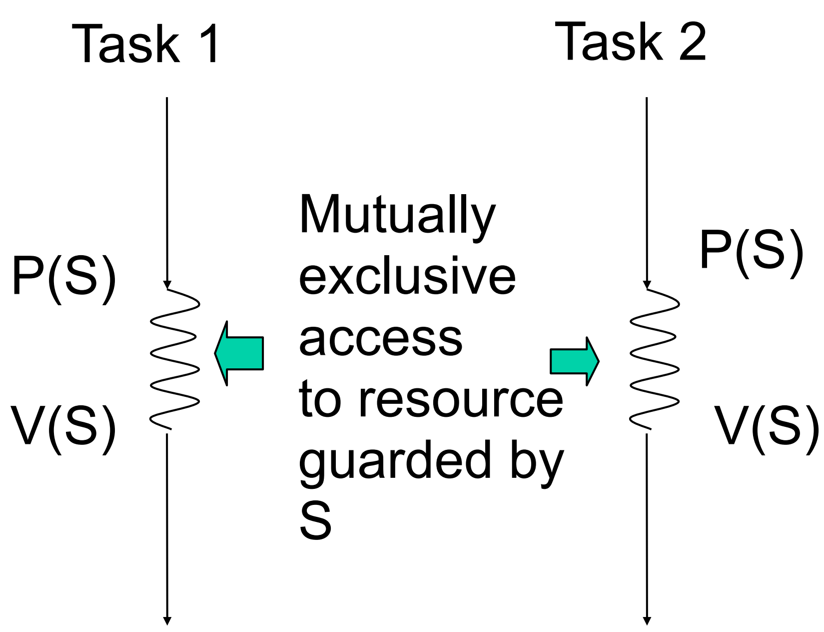
Michael O'Boyle
Embedded Software

Overview

- Scheduling dependent tasks
- Mutual exclusion
- Priority Inversion
- Priority Inheritance
    - Deadlock
- Priority Ceiling Protocol
- Summary

Resource access protocols

Critical sections: sections of code at which
exclusive access to some resource must be guaranteed.
Can be guaranteed with semaphores S or “mutexes”.



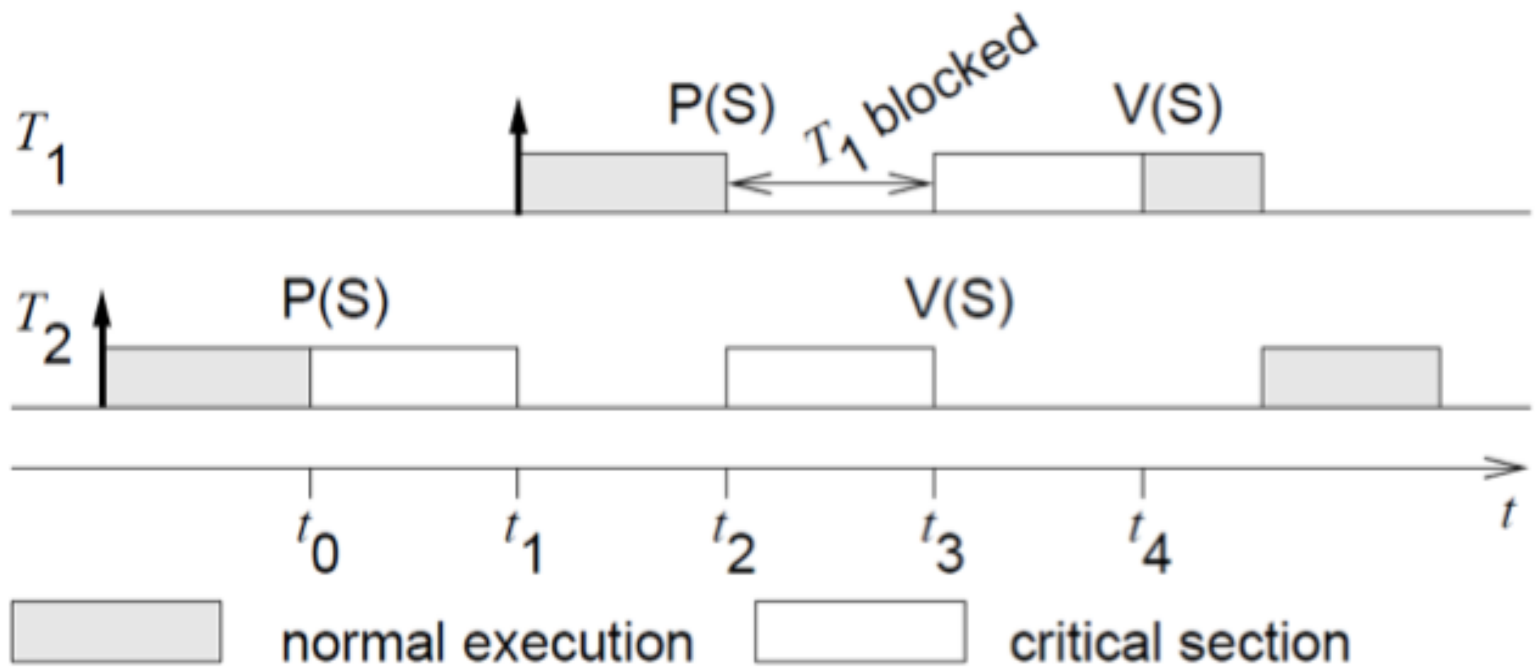
P(S) checks semaphore to see if resource is available and if yes, sets S to “used“. Uninterruptible operations! If no, calling task has to wait.

V(S): sets S to “unused“ and starts sleeping task (if any).

Note: Preemption still possible in critical sections

Blocking due to mutual exclusion

Priority T_1 assumed to be > than priority of T_2.
If T_2 requests exclusive access first (at t_0), T_1 has to wait until T_2 releases the resource (at time t_3):



For 2 tasks:
blocking is bounded by the length of the critical section

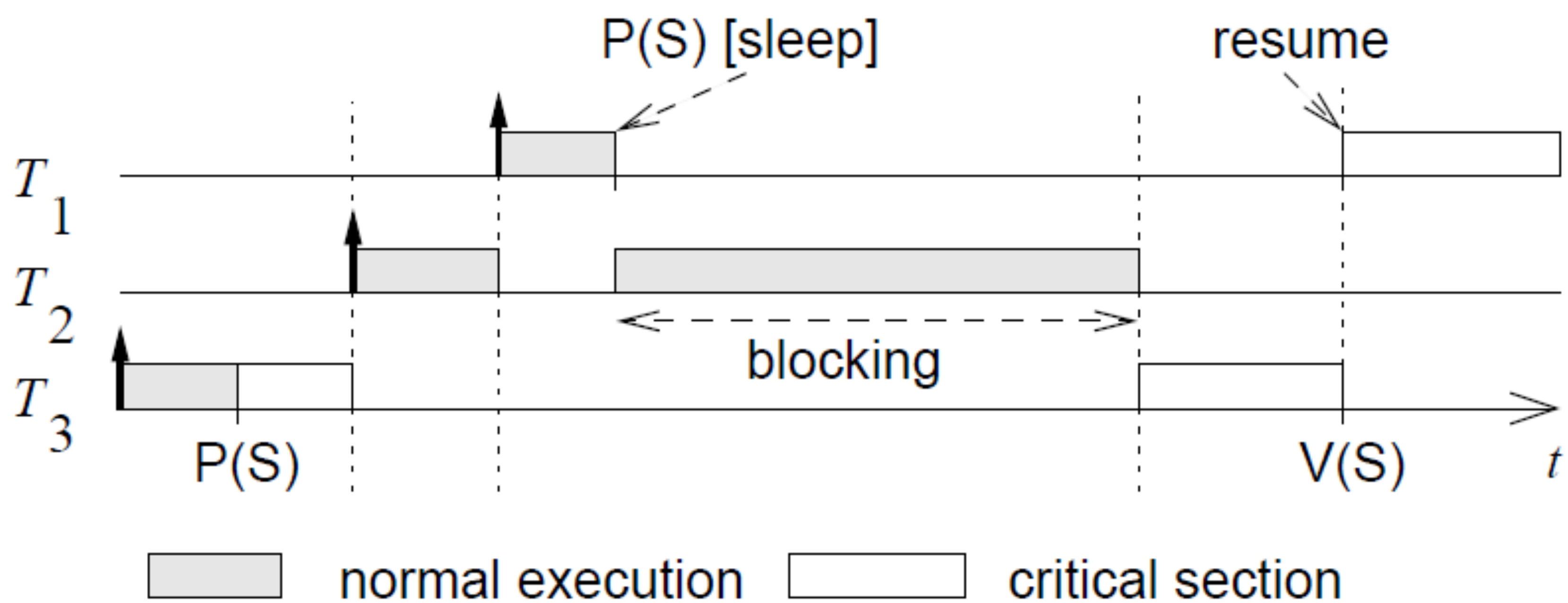
However not true in general

Priority inversion

Priority of T_1 > priority of T_2 > priority of T_3.

T_2 preempts T_3:

T_2 can prevent T_3 from releasing the resource.



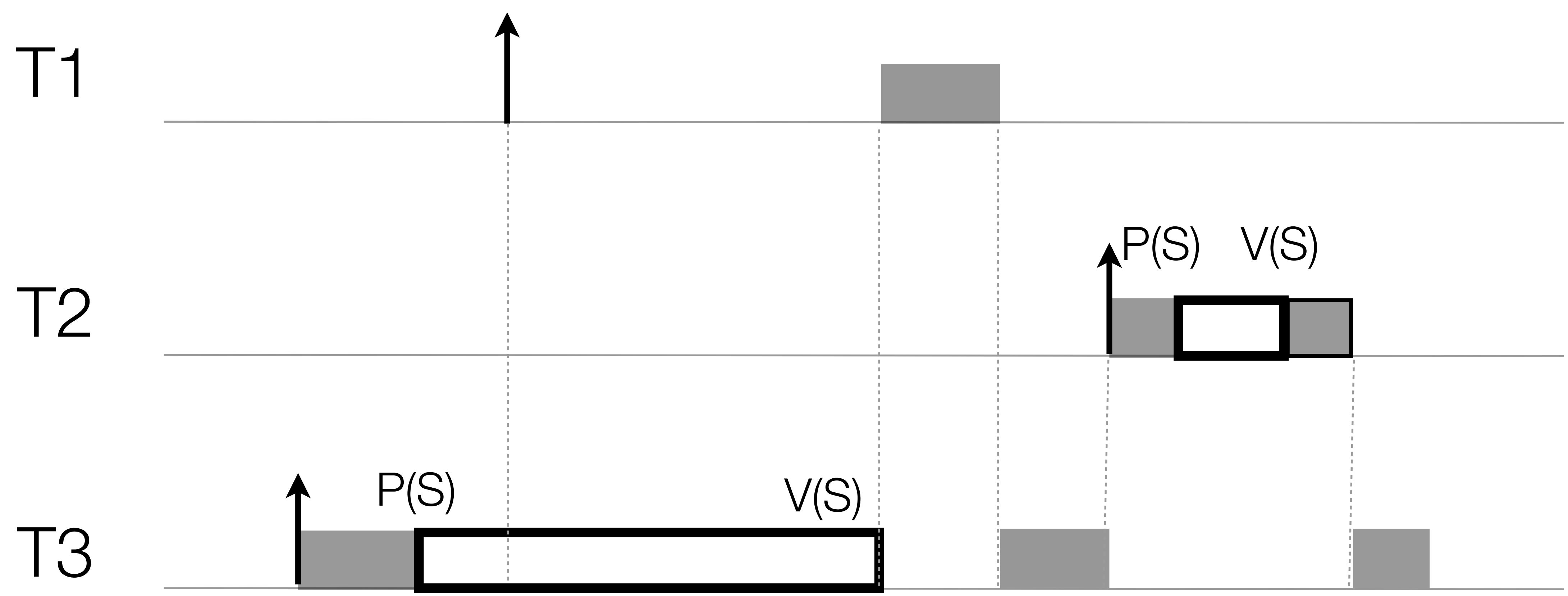
Blocking with > 2 tasks can exceed the length of any critical section

T2 not involved in critical section but ends up affecting T1

Solution: Forbid preemption in critical sections

Seems a good idea but leads to problems

T1 has high priority but is blocked T1 independent of lock



Priority inheritance can help

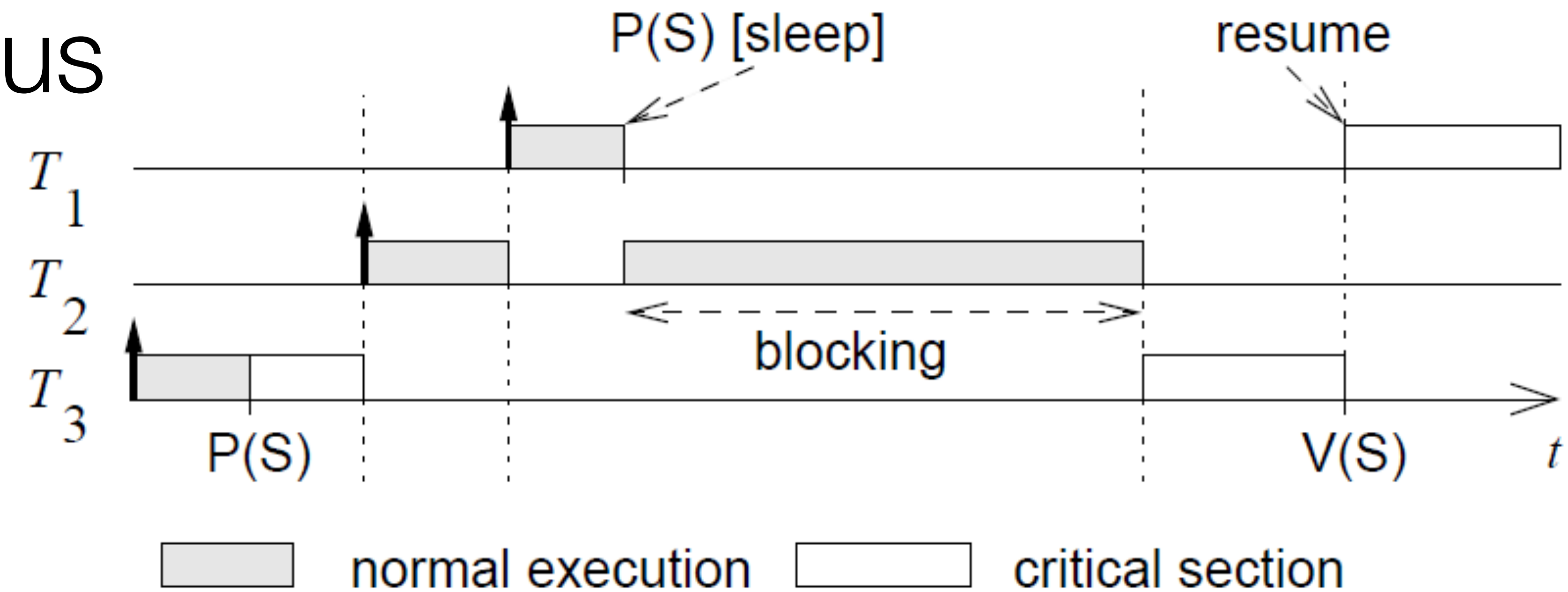
- The idea is that if an important task is blocked by an unimportant one,
  - the unimportant one is elevated and executed quickly to release the lock
- Tasks are scheduled according to their active priorities.
  - Tasks with the same priorities are scheduled.
    - First come first served. As usual
- Rule: tasks inherit the highest priority of tasks blocked by it.

Priority inheritance can help

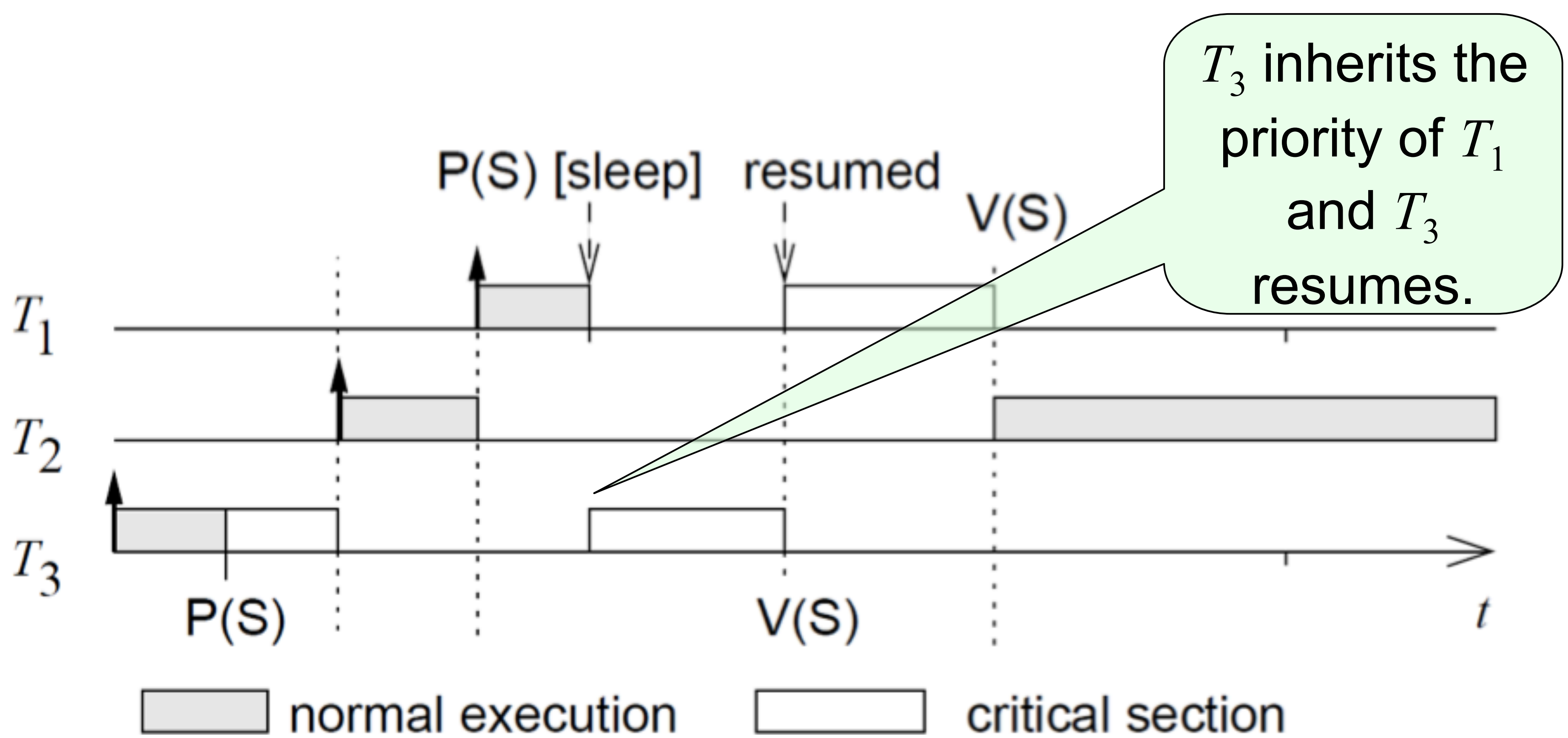
- Rule: tasks inherit the highest priority of tasks blocked by it.
- So if a task T_1 executes P(S) & exclusive access already granted to T_2, then T_1 will become blocked.
- If priority(T_2) < priority(T_1): T_2 inherits the priority of T_1.
  - T_2 resumes.
- When T_2 executes V(S), its priority is decreased to the highest priority of the tasks blocked by it.
- If no other task blocked by T_2: priority(T_2):= original value.
  Highest priority task so far blocked on S is resumed.
- Transitive: if T_2 blocks T_1 and T_1 blocks T_0,
  then T_2 inherits the priority of T_0.

Priority inheritance in previous example

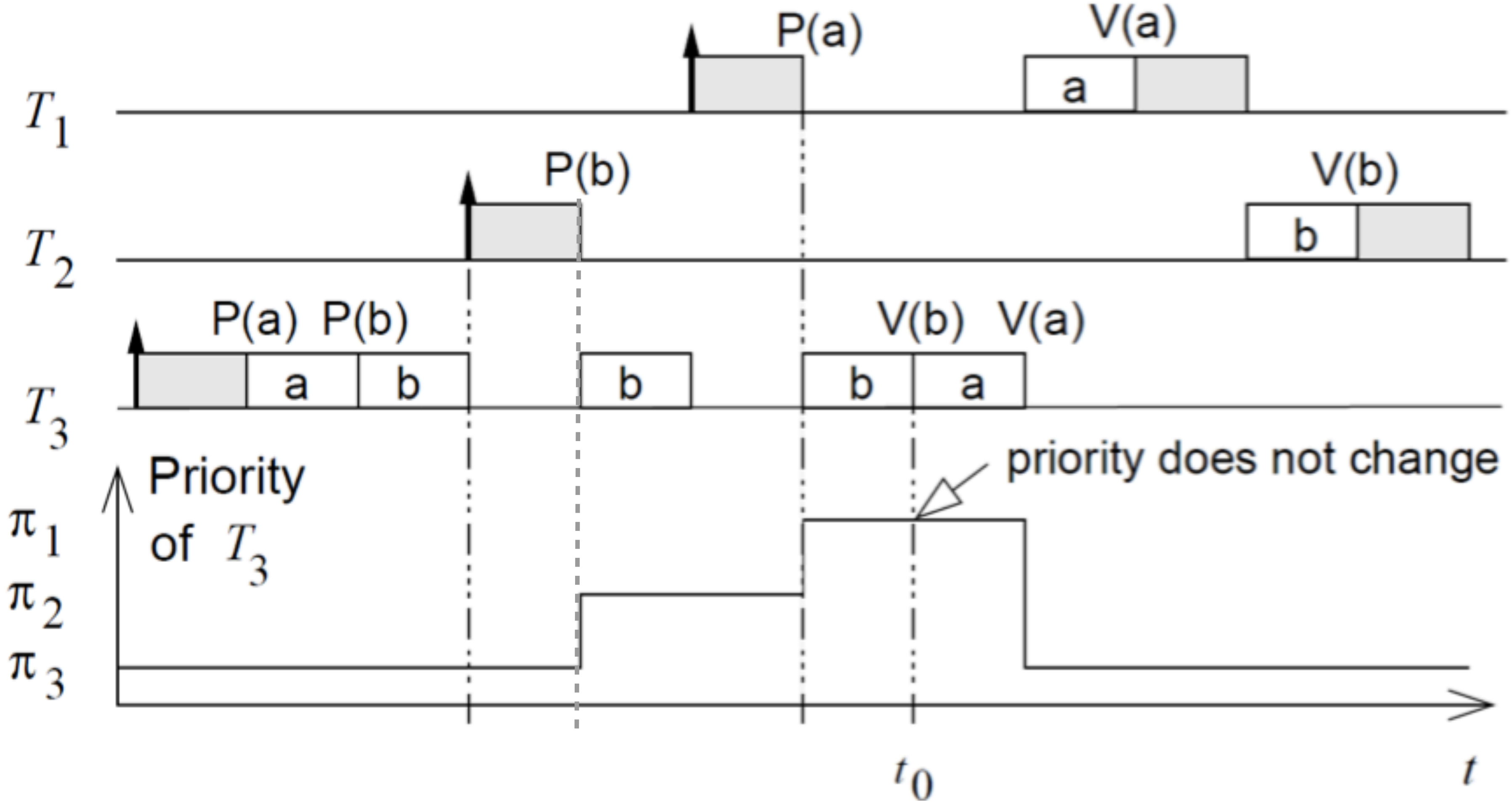
Previous



New

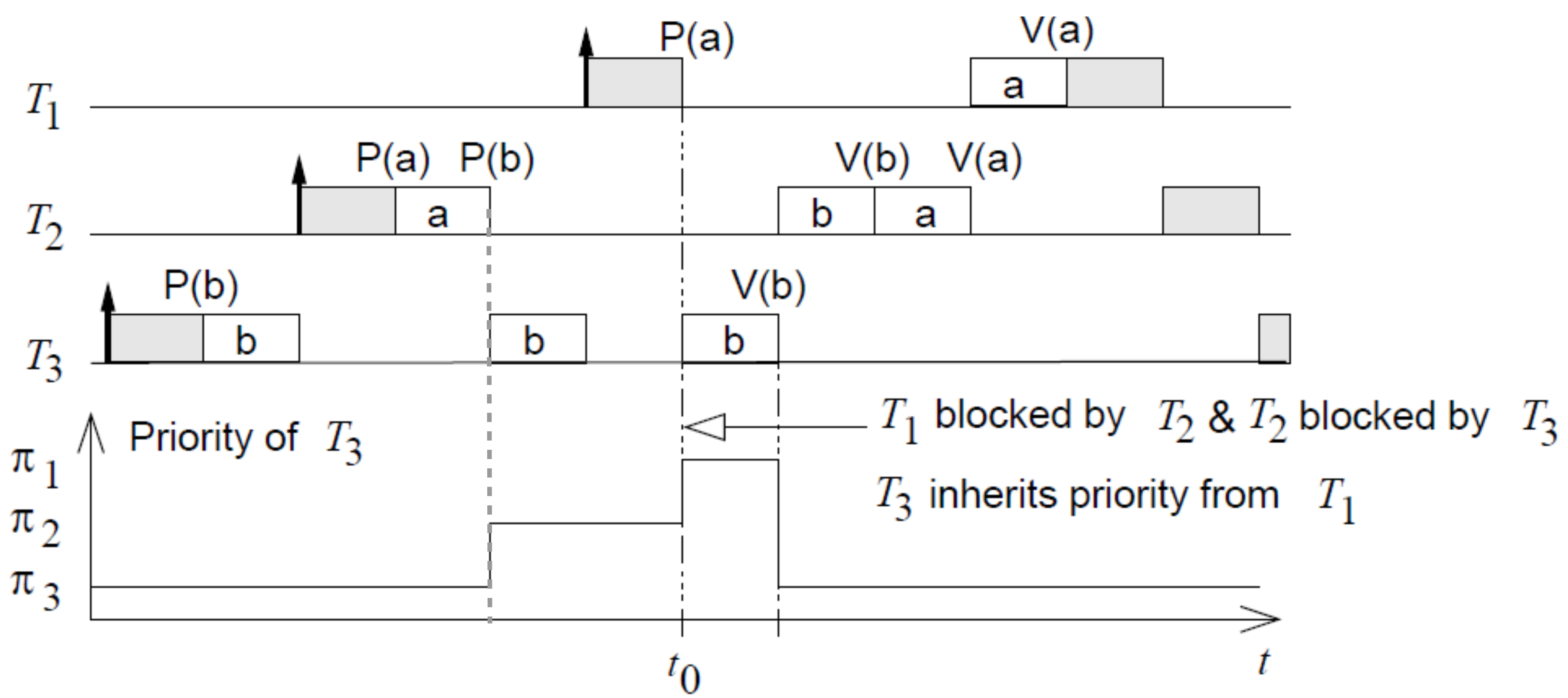


Nested Critical Sections



π: used to denote priority

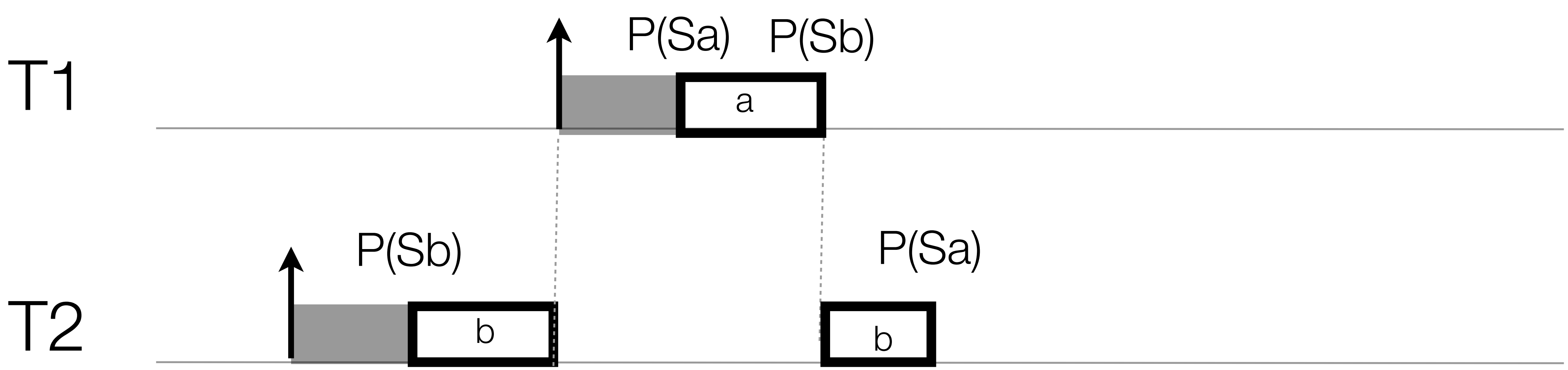
Transitivity of Priority Inheritance



Priority Inheritance Deadlock

π T1 > π T2: Priority of T1 > T2

```
T1:: ... lock(Sa); .a. lock(Sb); ... unlock(Sb) ... unlock(Sa);
T2:: ... lock(Sb); .b. lock(Sa); ... unlock(Sa) ... unlock(Sb);
```



Priority Ceiling Protocol

- The priority ceiling protocol prevents deadlock and reduces worst case blocking time
- Priority Ceiling (PC) of a resource or semaphore S:
  - PC(S) = highest priority of all processes that may lock S
- A process P is allowed to start a new critical section only if: P's priority > PC's of all semaphores locked by processes other than P
- If P is suspended, the process (say, Q) which holds the lock is blocking P
  - Q then inherits P 's priority - execution then follows Priority Inheritance protocol
- A property of this protocol is that any process can be blocked for at most the duration of a single critical section of a lower-priority process
  - A significant gain
- Note assumes fixed known number of tasks and prorities

Example

Consider three processes P1,P2,P3, s.t. $\pi_{P1} > \pi_{P2} > \pi_{P3}$, with code:

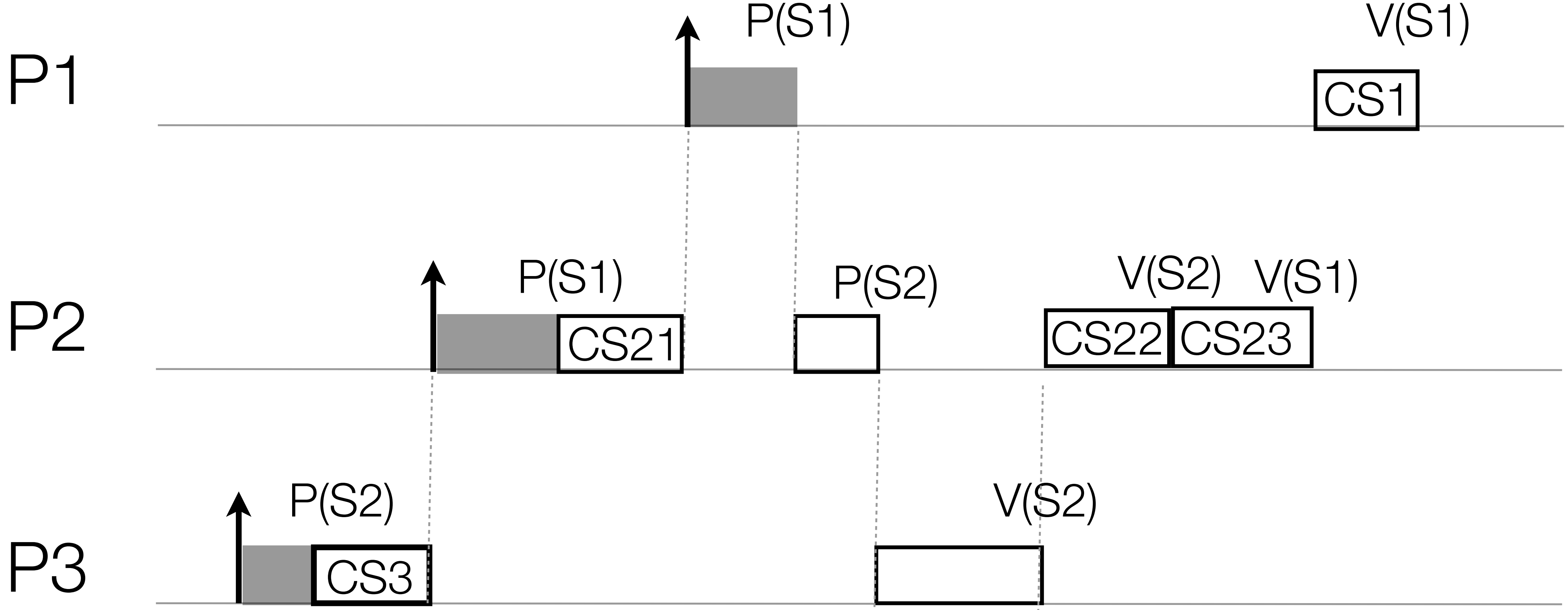
```
P1:: begin ... lock (S1); CS1; unlock(S1); ... end
P2:: begin ... lock(S1); CS21; lock(S2); CS22;
               unlock(S2);CS23; unlock (S1); ... end
P3:: begin ... lock(S2); CS3; unlock(S2); ... end
```

Run through execution sequence starting with just P3 starting first with P2 then P1 entering later

First look at standard priority inheritance

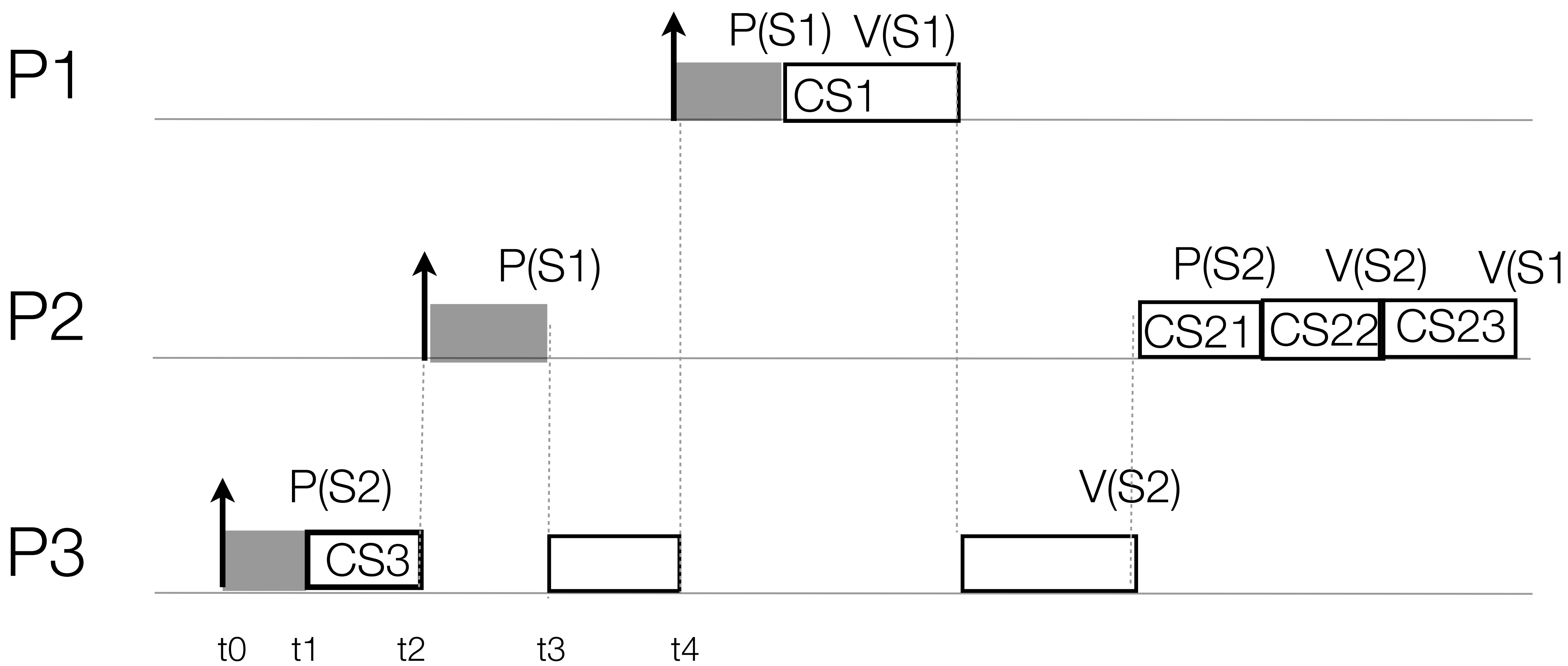
Then look at priority ceiling protocol

Priority Inheritance delays critical task



Priority Ceiling overcomes this

- $PC(S_1) = max(\pi_{P1}, \pi_{P2}) = \pi_{P1}$
- $PC(S_2) = max(\pi_{P2}, \pi_{P3}) = \pi_{P2}$



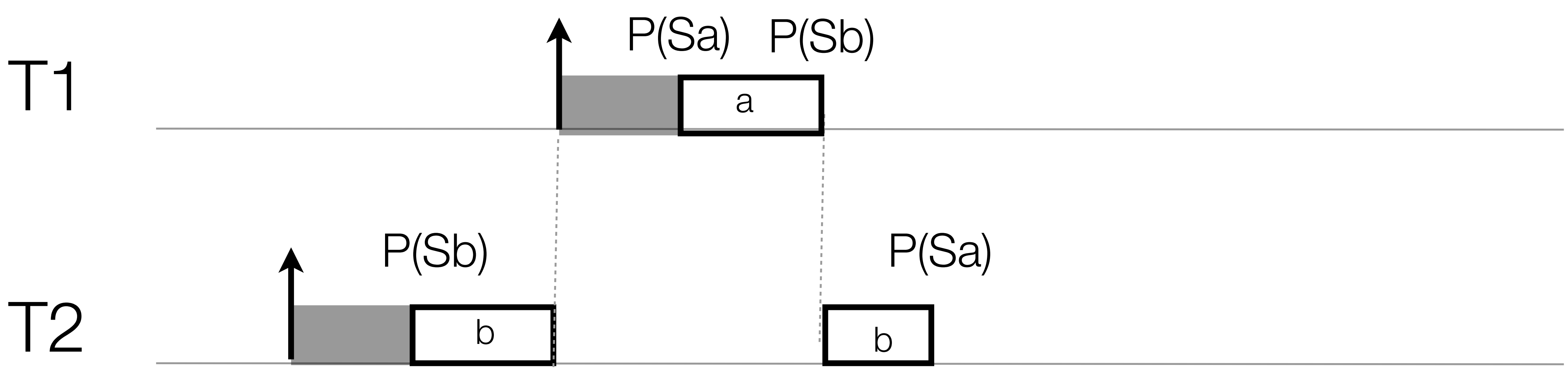
Walk through of example

- At t0, P3 is ready & starts executing; at t1, P3 locks S2
- At t2, P2 preempts P3 (because $\pi(P2) > \pi(P3)$)
- At t3, P2 attempts to lock S1; however, $\pi(P2) \not> PC(S2)$, which is currently locked by P3
- So, P2 is suspended (not allowed to lock S1), and P3 inherits P2's priority and continues executing its CS
- At t4, P1 preempts P3 (because $\pi(P1) > \pi(P3)$)
- When P1 attempts to lock S1 sometime later, it secures the lock, because $\pi(P1) > PC(S2)$, the only other semaphore currently locked by another process
- When P1 finishes, P3 resumes, finishes its CS & unlocks S2, at which point, its priority reverts back to $\pi(P3)$
- P2 can then preempt P3 (because now, $\pi(P2) > \pi(P3)$) to obtain S2 & execute its critical section

Priority Ceiling overcomes deadlock

π T1 > π T2: Priority of T1 > T2

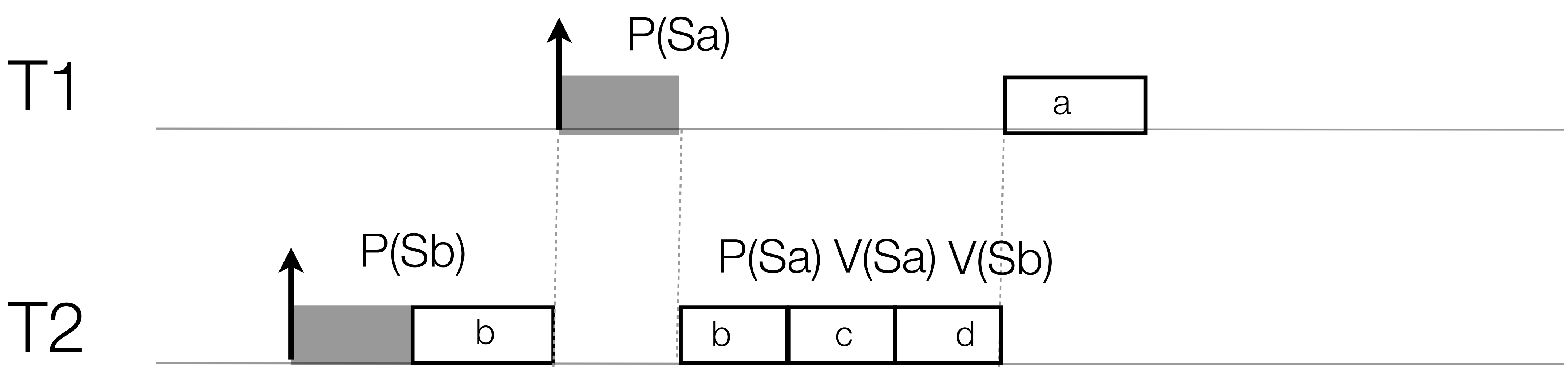
```
T1:: ... lock(Sa); .a. lock(Sb); ... unlock(Sb) ... unlock(Sa);
T2:: ... lock(Sb); .b. lock(Sa); ... unlock(Sa) ... unlock(Sb);
```



Priority Ceiling Solution

π T1 > π T2: Priority of T1 > T2

```
T1:: ... lock(Sa); .a. lock(Sb); ... unlock(Sb) ... unlock(Sa);
T2:: ... lock(Sb); .b. lock(Sa); .c. unlock(Sa) .d. unlock(Sb);
```



Summary

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- Priority Inheritance
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- Priority Ceiling Protocol