Real-Time Systems

Resource Access Protocols

TECHNISCHE UNIVERSITÄT DRESDEN

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Problems: Priority Inversion

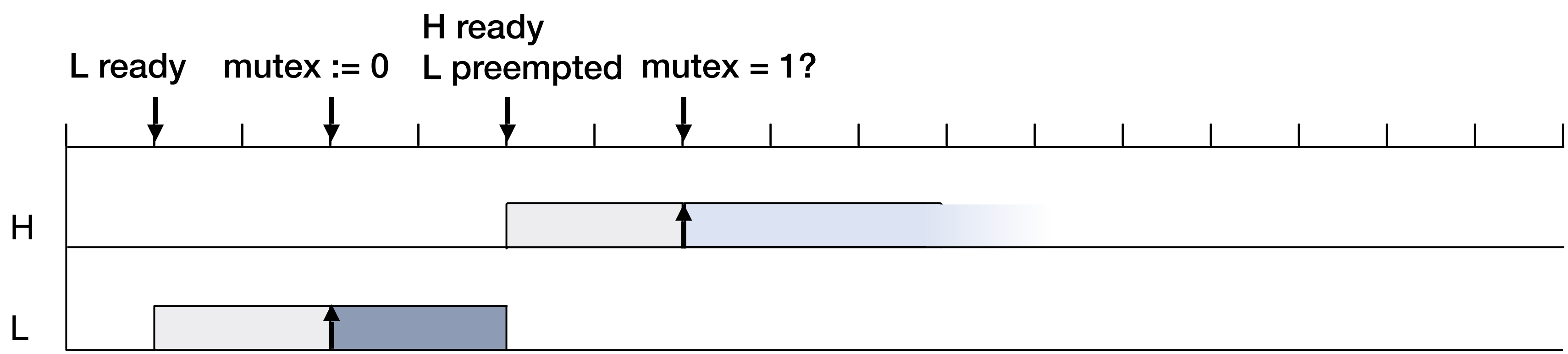
Assumptions:

- Jobs use resources in a mutually exclusive manner
- Preemptive priority-driven scheduling
- Fixed task priorities
- 1 processor

Declaration
for the following slides

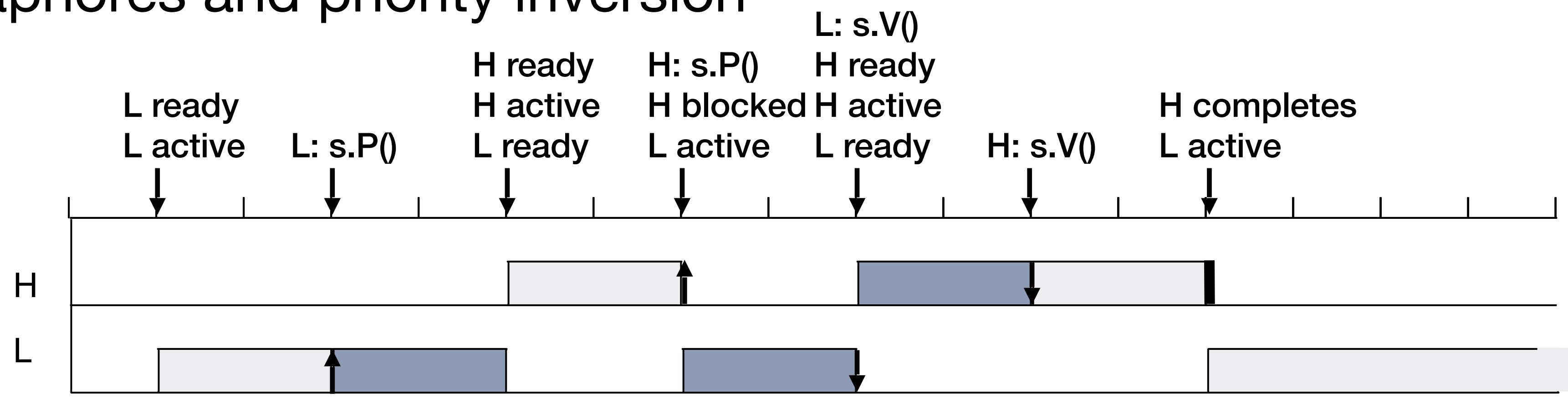
L(R) $\uparrow$ U(R) $\downarrow$

Busy waiting and priority inversion

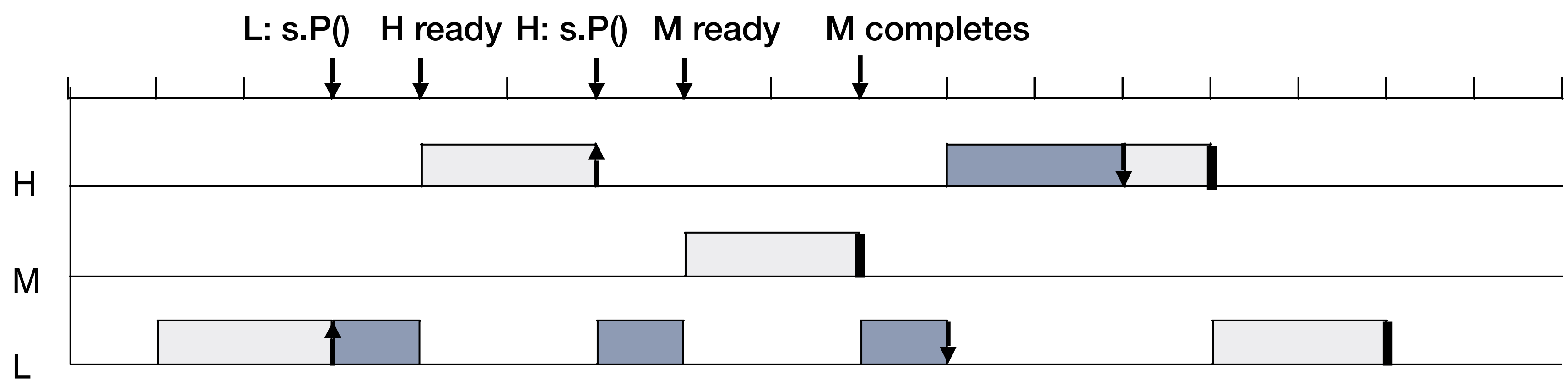


Problems: Priority Inversion

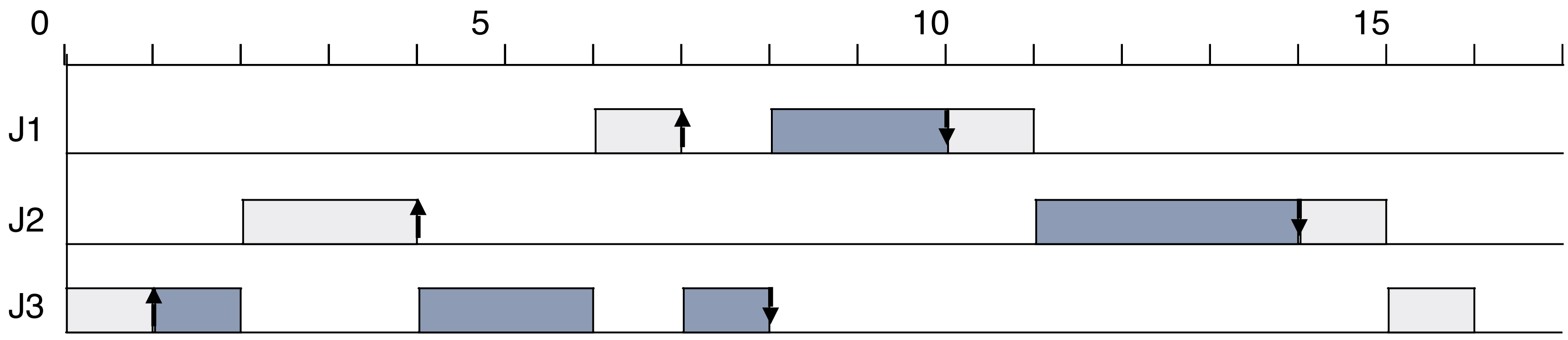
Semaphores and priority inversion



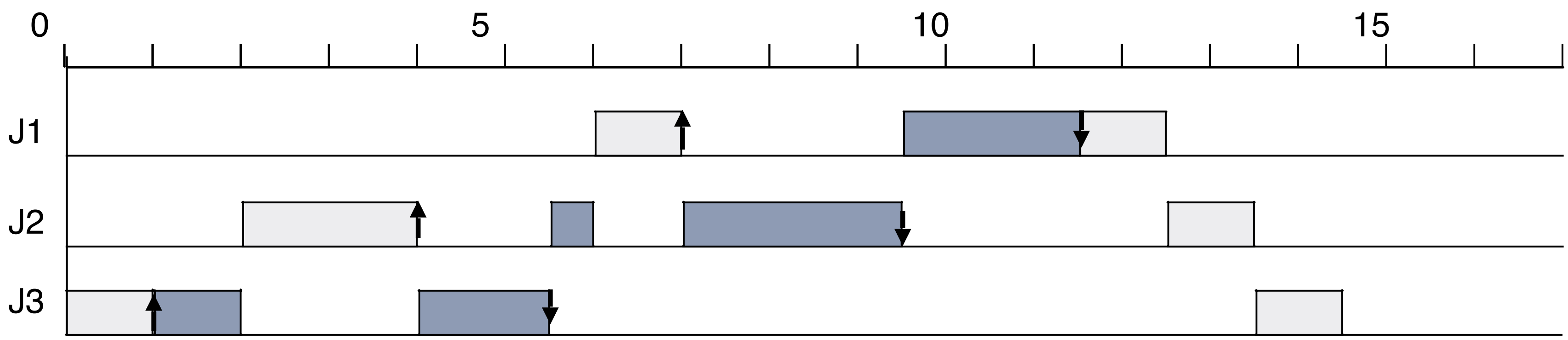
M: medium-prioritized job (not using s)



Problems: Timing Anomalies



Reduction of resource usage of J3 by 1.5:



Problems: Deadlocks

- exclusive resources
- non-preemptive resources
- sequential acquire
- cyclic wait-condition

Assumptions and Notations

1 processor, preemptive priority-driven scheduling,
jobs are not self-suspending

- $R_1,\ldots, R_r$ — resources; nonpreemptable, exclusive
- $L(R_k)$, $U(R_k)$ — acquire/release of R_k; release: LIFO

  $\uparrow R_k \quad \downarrow R_k$
- $J_1,\ldots, J_n$ — jobs
- J_h, J_l — job of high/low priority
- $p_1,\ldots, p_n$ — assigned priorities (highest priority: 1); w.l.o.g.: J_i ordered according to priorities
- $p_i(t)$ — current priority of J_i

Assumptions and Notations

- **Jobs conflict with one another**
  operate with a common resource
- **Jobs contend for a resource**
  one job requests the resource that another job already owns
- **Blocked job**
  scheduler does not grant the requested resource
- **Priority inversion**
  J_l executes while J_h is blocked

Priority Inheritance Protocol

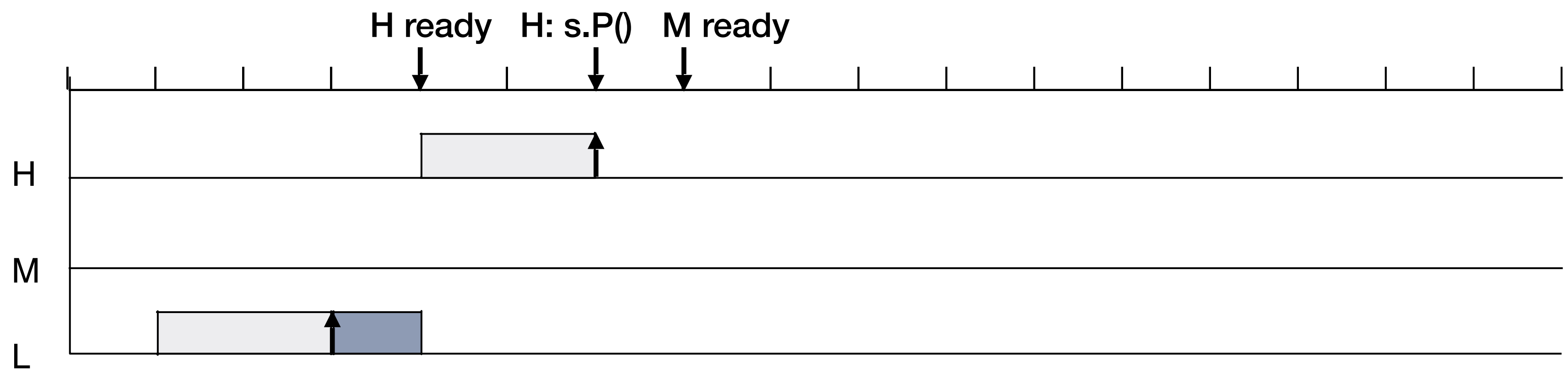
for preemptive priority-driven scheduling — Sha et al., 1990

Basic Priority-Inheritance Protocol

- (1) ***Scheduling Rule***
  - A ready job J is scheduled according to its current priority $p(t)$; at release time t: $p(t) := p$.
- (2) **Allocation Rule**
  - J requests R at time t.
    - (a) R free: R is allocated to J until J releases R.
    - (b) R not free: request is denied, J is blocked.
- (3) **Priority-Inheritance Rule**
  - When J becomes blocked by J_l, then J_l inherits the current priority of J, i.e. $p_l(t) := p(t)$.
  - J_l executes at this priority until it releases R at time t″.
  - Now the priority of J_l returns to its previous priority: $p_l(t'') := p_l(t')$ t′: time when J_l acquires R.

Priority Inheritance – Example

- 2 jobs: no effect!
- 3 jobs:

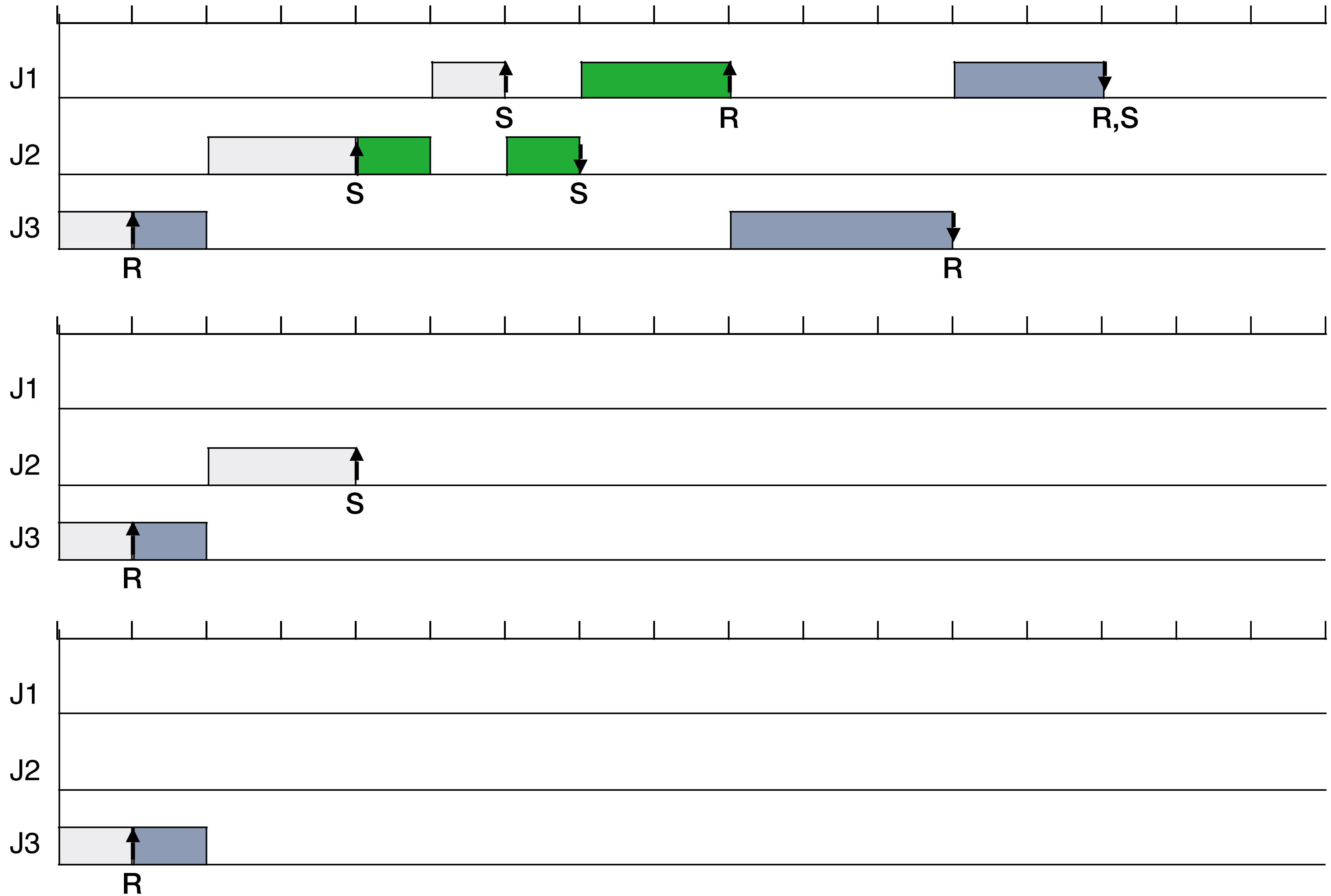


Priority Inheritance – Properties

Properties

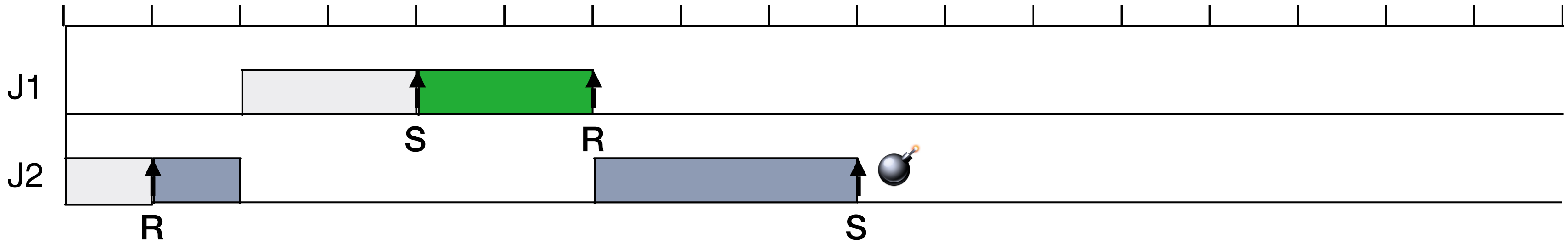
- Priority inheritance is transitive.
- No unbounded uncontrolled priority inversion.
- Priority inheritance does not reduce the blocking times as small as possible.

Priority Inheritance – Properties



Priority Inheritance – Properties

Priority inheritance does not prevent deadlocks.



Priority Ceilings – Notations

Sha/Rajkumar/Lehoczky, 1990

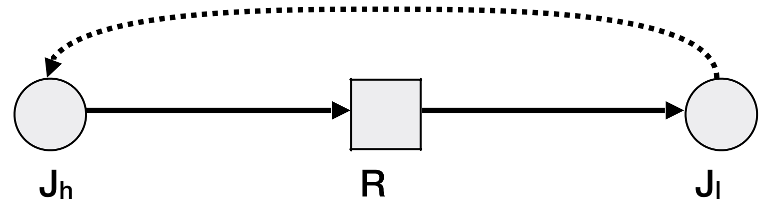
- **Assumptions and Notations**
  - 1 processor, preemptive priority-driven scheduling
    no self-suspension
  - Assigned priorities p_i are fixed
    priorities: natural numbers, 1 highest, Ω lowest priority
  - The resources required by all jobs are known a priori
- ***P(R)*** priority ceiling of *R*
  highest priority of all jobs that require *R*
- $\boldsymbol{\hat{P}(t)}$ priority ceiling of the system at time *t*
  highest priority ceiling of all resources that are in use at time *t*

Basic Priority-Ceiling Protocol

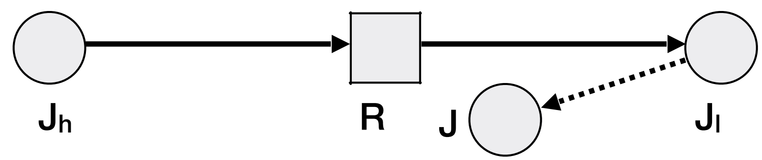
- (1) **Scheduling Rule**
  - At release time t^{rel} of J: $p(t^{rel}) := p$
- (2) **Allocation Rule**
  - J requests R at time t
  - (a) R held by another job: request denied, J blocks ("on R")
  - (b) R free:
    - (α) $p(t) > \hat{P}(t)$: R is allocated to J
    - (β) otherwise: R is allocated to J only if J is the job holding the resource(s) R' with $P(R') = \hat{P}(t)$, otherwise J blocks
- (3) **Priority-Inheritance Rule**
  - When J becomes blocked by J_l, J_l inherits J's current priority $p(t)$
  - J_l (preemptively) executes at this priority until it releases every resource whose priority ceiling is at least $p(t)$
  - At that time, J_l's priority returns to $p_l(t')$
    (t': time when it was granted the resource)

Basic Priority-Ceiling Protocol – Properties

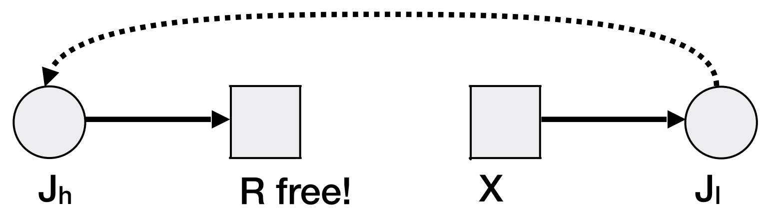
- Difference to priority inheritance: three ways to blocking
  - direct:



  - inheritance:



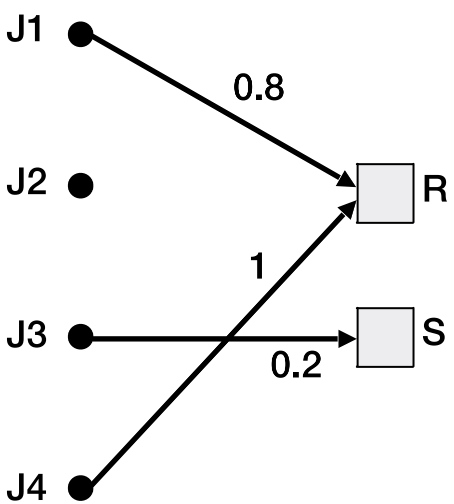
  - ceilings:



- Deadlocks can never occur
- There can be no transitive blocking

Basic Priority-Ceiling Protocol – Example

- A job can be blocked for at most one resource request
- Computation of blocking time – Example:



	J1	J2	J3	J4

Stack-Based Priority-Ceiling Protocol

- **Further Assumptions**
  - Common run-time stack for all jobs (no self-suspension)
  - Stack space of an active job is on the top of the stack (preemption)
  - Stack space is freed when the job completes
- **Protocol**
  - (0) $\hat{P}(t) = \Omega$, when all R are free,
    $\hat{P}(t)$ is updated whenever a resource is allocated or freed
  - (1) **Scheduling Rule**
    - After J is released, it is blocked until $p > \hat{P}(t)$
    - Priority-driven scheduling based on assigned priorities (!)
  - (2) **Allocation Rule**
    - Whenever a job requests a resource, it is granted the resource (!)
- **Properties**
  - When a job begins execution, all resources it will ever need are free
  - Both protocols result in the same longest blocking time of a job
  - Deadlocks cannot occur