Real-Time Systems

Resource Access Protocols

WS 2018/19

TECHNISCHE UNIVERSITÄT DRESDEN

Problems: Priority Inversion

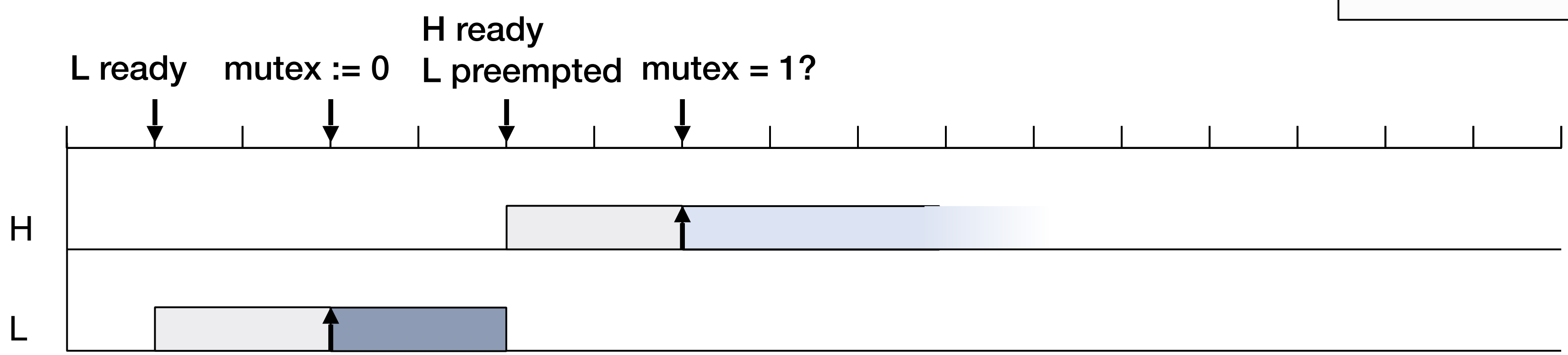
Assumptions:

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

Declaration for the following slides

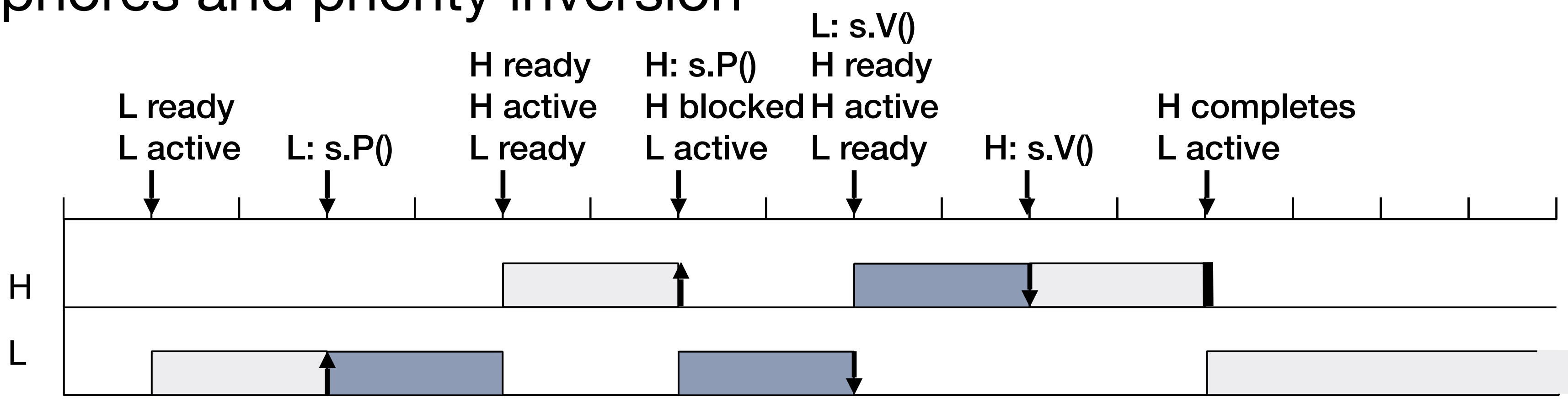
L(R) ↑ U(R) ↓

Busy waiting and priority inversion

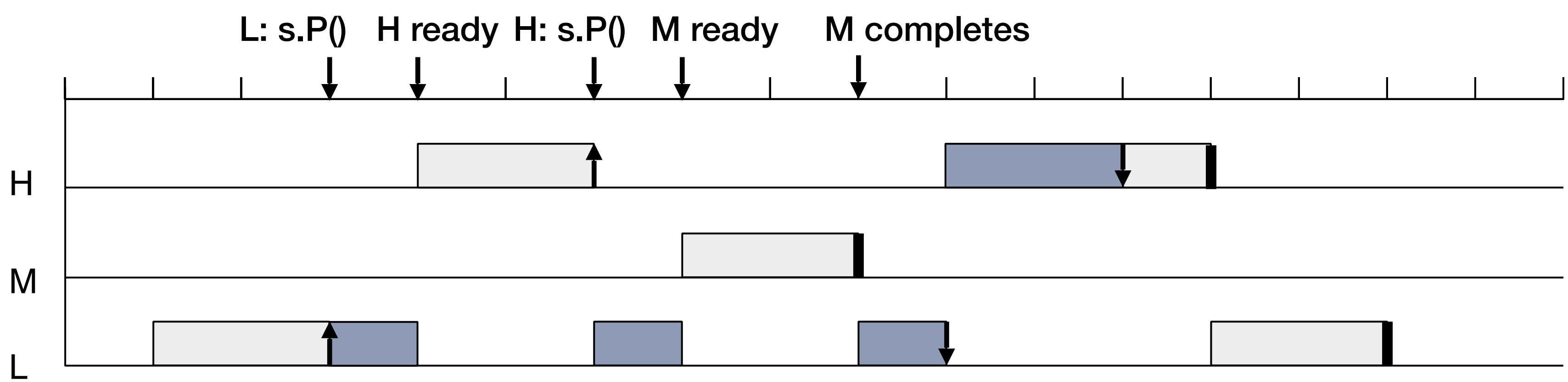


Problems: Priority Inversion

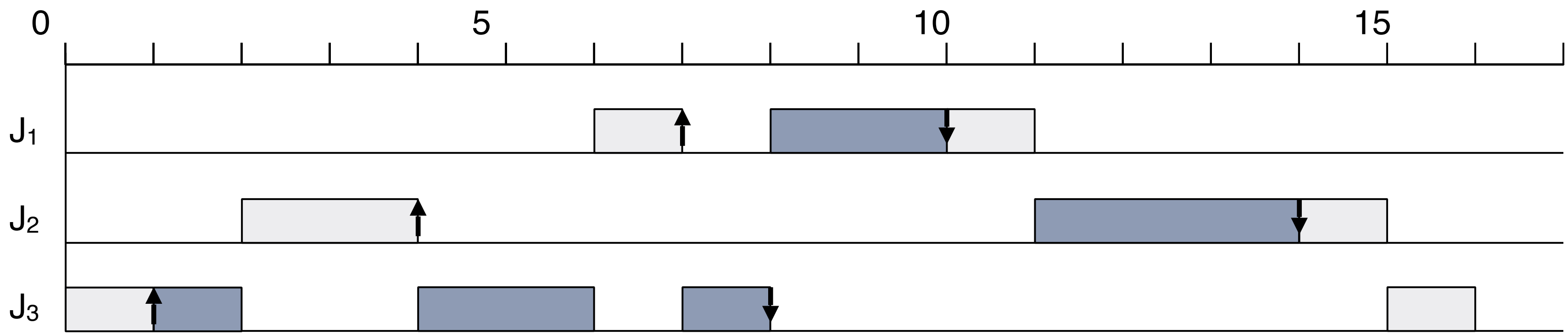
Semaphores and priority inversion



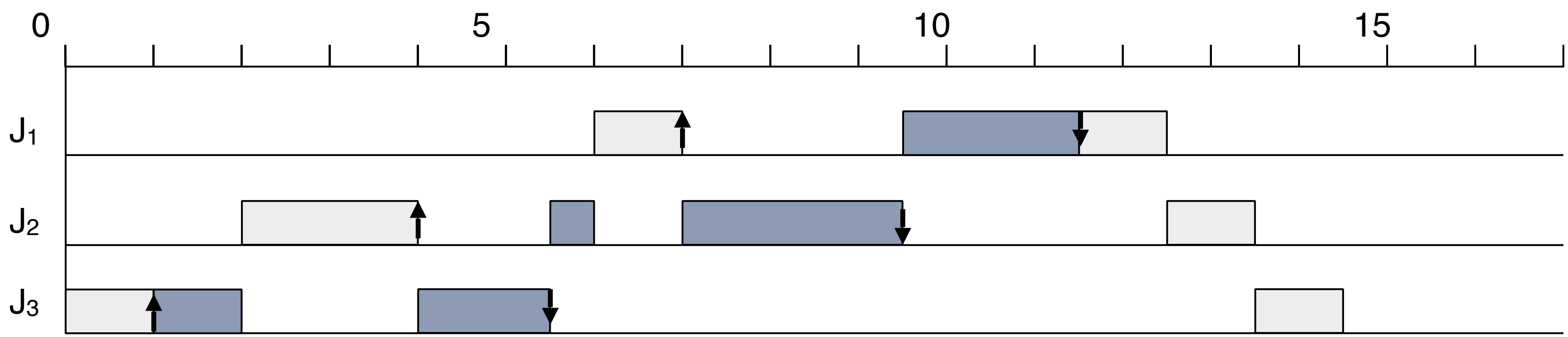
M: medium-prioritized job (not using s)



Problems: Timing Anomalies



Reduction of resource usage of J_3 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

  $\uparrow R_k$ $\downarrow R_k$
- ***$J_1,\ldots, J_n$*** 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 at time t

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.

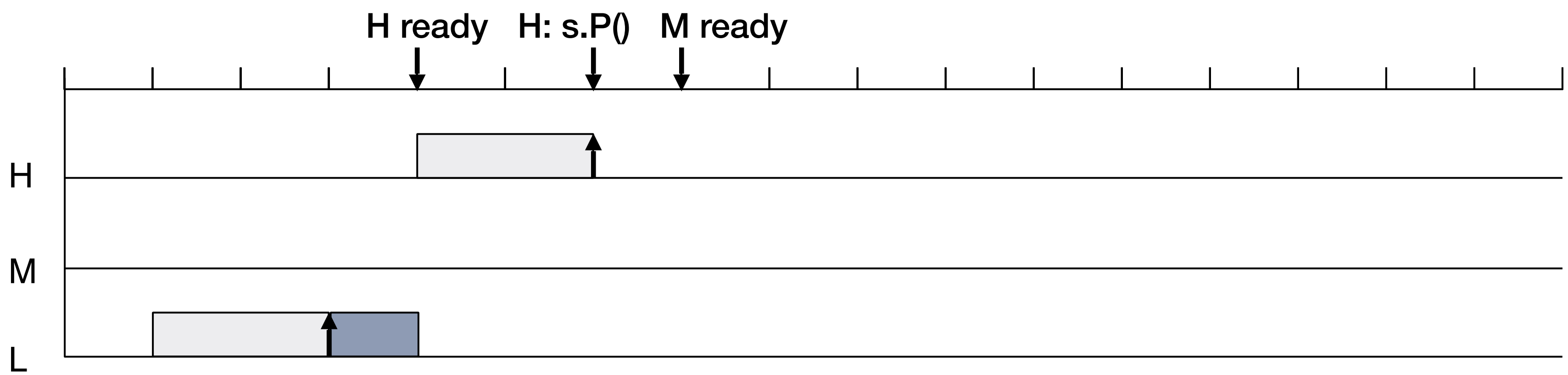
(3) **Priority-Inheritance Rule**

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:

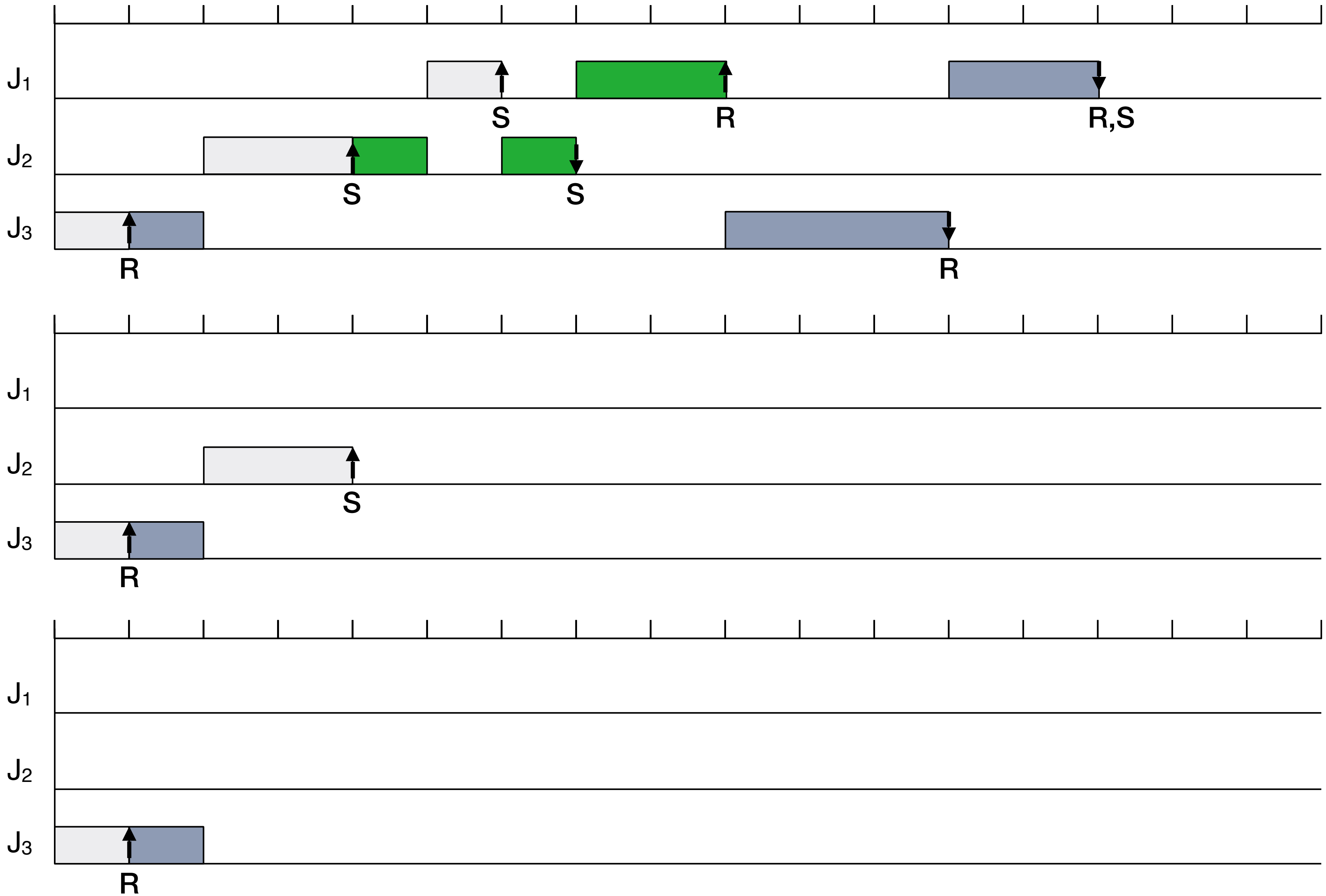


Priority Inheritance – Properties

Properties

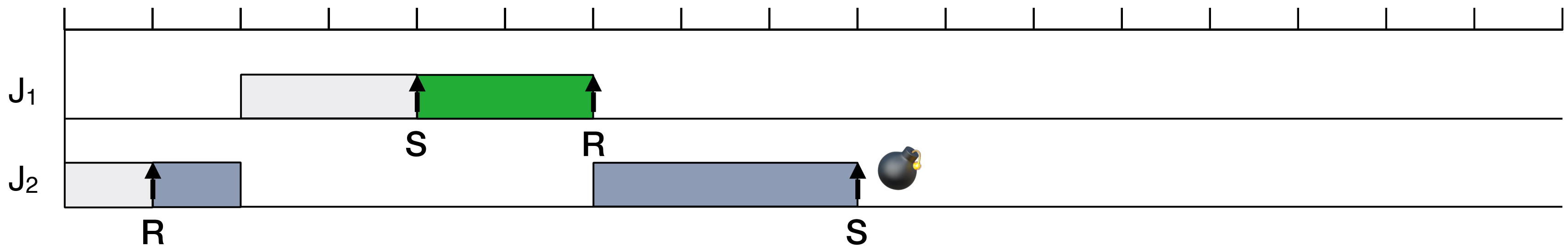
- Priority inheritance is transitive.
- No unbounded uncontrolled priority inversion.
- Priority inheritance does not reduce the blocking times as small as possible.

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
  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*
- $\hat{P}(t)$ 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 of J: $p(t) := p$

(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**

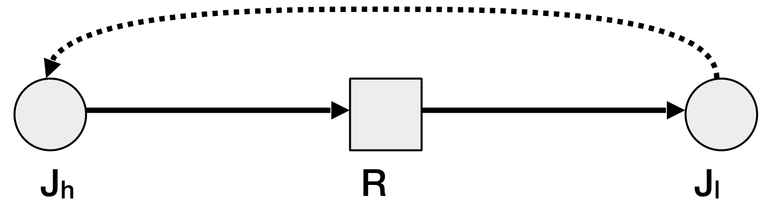
When J becomes blocked by J_l, J_l inherits J's current priority $p(t)$

- 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 $p_l(t')$

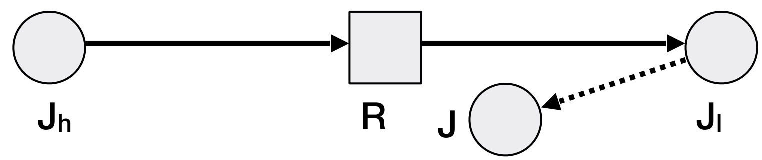
(t': time when it was granted the resource)

Basic Priority-Ceiling Protocol – Properties

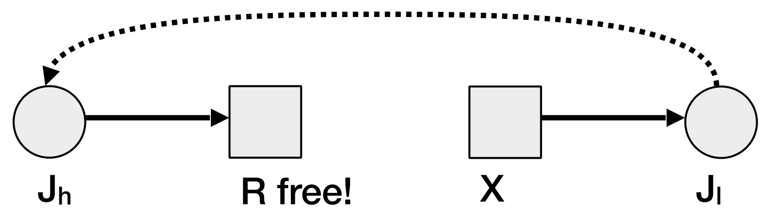
- Difference to priority inheritance: three ways to blocking
  - direct:



  - inheritance:



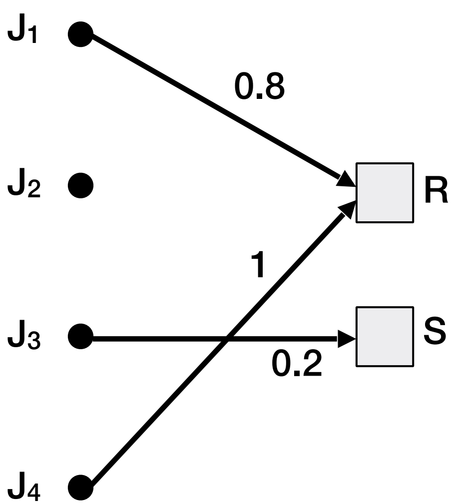
  - ceilings:



- 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:



	J_1	J_2	J_3	J_4

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

(1) $\hat{P}(t) = \Omega$, when all R are free,
$\hat{P}(t)$ is updated whenever a resource is allocated or freed

(2) Scheduling Rule

- After J is released, it is blocked until $p > \hat{P}(t)$
- Priority-driven scheduling based on assigned priorities (!)

(3) 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