Chapter 10

Deadlock

What is Deadlock?

- Two or more entities need a resource to make progress, but will never get that resource
- Examples from everyday life:
  - Gridlock of cars in a city
  - Class scheduling: Two students want to swap sections of a course, but each section is currently full.
- Examples from Operating Systems:
  - Two processes spool output to disk before either finishes, and all free disk space is exhausted
  - Two processes consume all memory buffers before either finishes

Deadlock Illustration

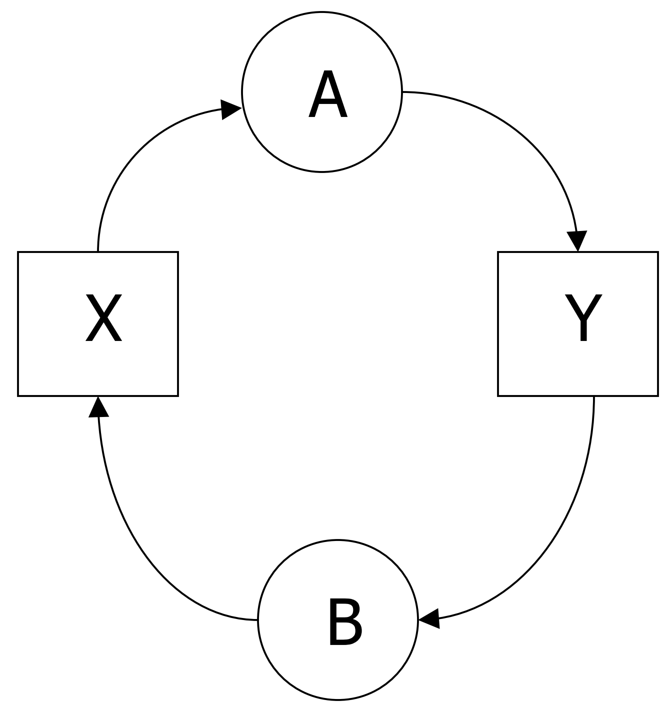
A set of processes is in a DEADLOCK state when every process is waiting for an event initiated by another process in the set

Process A	**Process B**
Request X	Request Y
Request Y	Request X
⋮	⋮
Release X	Release Y
Release Y	Release X

Deadlock Illustration

- A requests & receives X
- B requests & receives Y
- A requests Y and blocks
- B requests X and blocks

The "Deadly Embrace"



Terminology

- Preemptible vs. Non-preemptible
- Shared vs. Exclusive resource
  - Example of Shared resource: File
  - Example of Exclusive resource: Printer

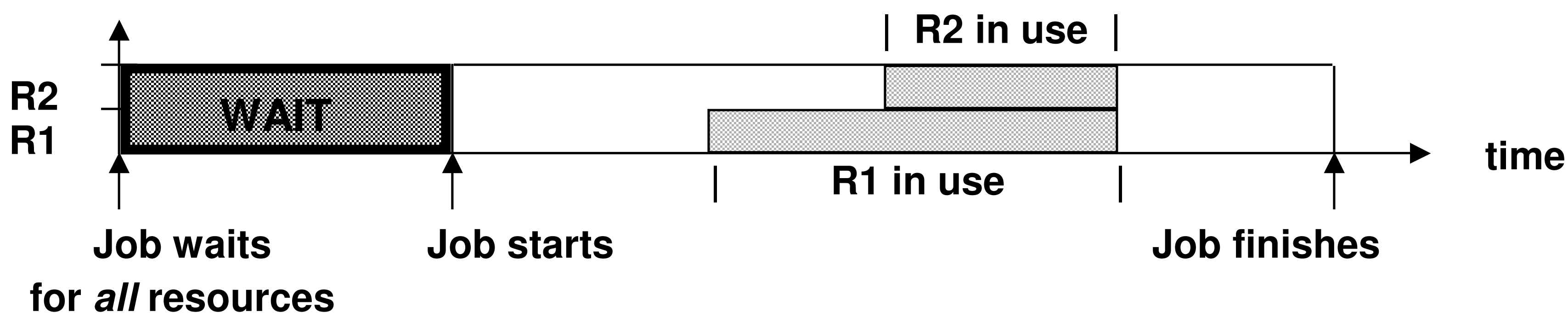
Terminology …

- Indefinite postponement
  - Job is continually denied resources needed to make progress

Example: High priority processes keep CPU busy 100% of time, thereby denying CPU to low priority processes

Three Solutions to Deadlock

#1: Mr./Ms. Conservative (***Prevention***)

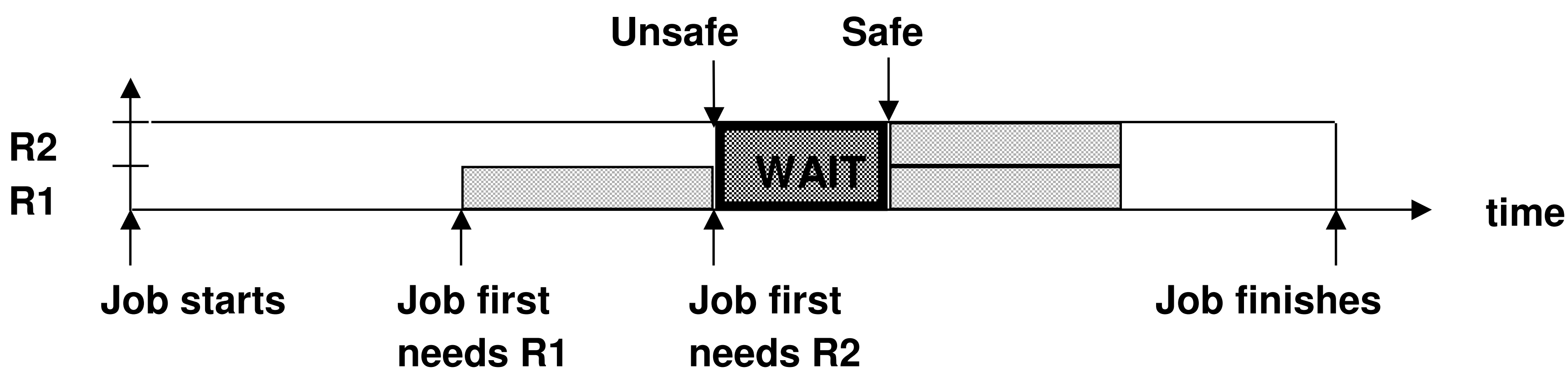


"We had better not allocate if it could ever cause deadlock"

Process **waits** until all needed resource free
Resources **underutilized**

Three Solutions to Deadlock …

#2: Mr./Ms. Prudent ***(Avoidance)***

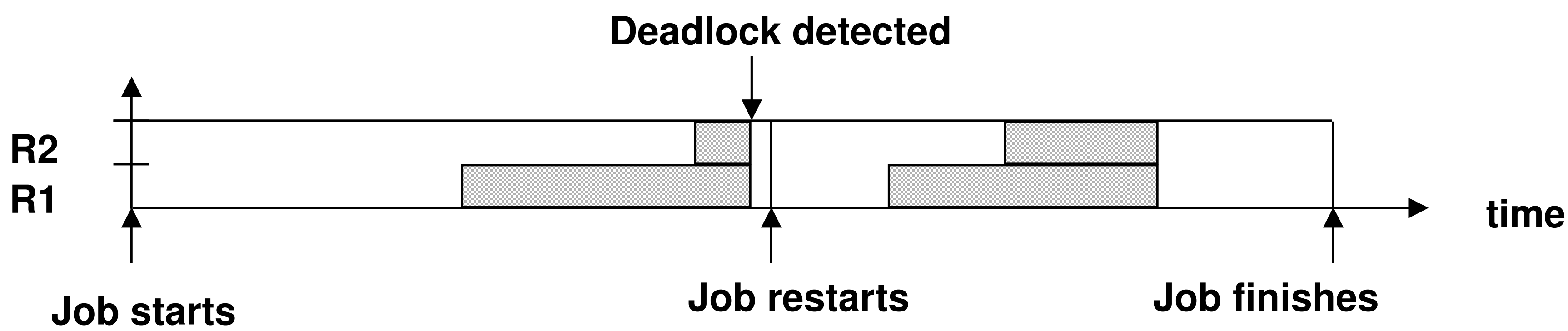


"If resource is free and with its allocation we can still guarantee that everyone will finish, **use it**."

Better resource utilization
Process still waits

Three Solutions to Deadlock…

<u>#3: Mr./Ms. Liberal</u> ***(Detection/Recovery)***



"If it's free, use it -- why wait?"

Good resource utilization, minimal process wait time
Until deadlock occurs….

Names for Three Methods on Last Slide

1) Deadlock Prevention

   – Design system so that possibility of deadlock is avoided *a priori*

2) Deadlock Avoidance

   – Design system so that if a resource request is made that *could* lead to deadlock, then block requesting process.

   – Requires knowledge of future requests by processes for resources.

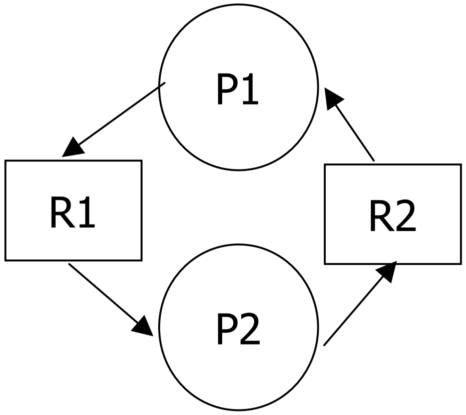
3) Deadlock Detection and Recovery

   – Algorithm to detect deadlock

   – Recovery scheme

4 Necessary Conditions for Deadlock

- Mutual Exclusion
  - Non-sharable resources
- Hold and Wait
  - A process must be holding resources and waiting for others
- No pre-emption
  - Resources are released voluntarily
- Circular Wait



Deadlock Prevention

Deny one or more of the necessary conditions

- Prevent “Mutual Exclusion”
  - Use only sharable resources

    => Impossible for practical systems

Deadlock Prevention …

- Prevent “Hold and Wait”

  (a) Preallocation - process must request and be allocated all of its required resources before it can start execution

  (b) Process must release all of its currently held resources and re-request them along with request for new resources

  => Very inefficient

  => Can cause "indefinite postponement": jobs needing lots of resources may never run

Deadlock Prevention …

- Allow "Resource Preemption"
  - Allowing one process to acquire exclusive rights to a resource currently being used by a second process

=> Some resources can not be preempted without detrimental implications (e.g., printers, tape drives)

=> May require jobs to restart

Deadlock Prevention …

- Prevent Circular Wait
  - Order resources and
  - Allow requests to be made only in an increasing order

Preventing Circular Wait

Impose an ordering on Resources:

1 W
2 X
3 Y
4 Z

Process:	A	B	C	D	A	B	C	D
Request:	W	X	Y	Z	X	Y	Z	W

After first 4 requests:

A / W

D / Z

B / X

C / Y

Process D cannot request resource W without voluntarily releasing Z first

Problems with Linear Ordering Approach

(1) Adding a new resource that upsets ordering requires all code ever written for system to be modified!

(2) Resource numbering affects efficiency

=> A process may have to request a resource well before it needs it, just because of the requirement that it must request resources in ascending sequence

Deadlock Avoidance

- OS never allocates resources in a way that could lead to deadlock

  => Processes must tell OS in advance how many resources they will request

Banker's Algorithm

- Banker's Algorithm runs <u>each</u> time:
  - a process requests resource - *Is it Safe*?
  - a process terminates - *Can I allocate released resources to a suspended process waiting for them*?
- A new state is <u>safe</u> if and only if every process can complete after allocation is made

=> Make allocation, then check system state and de-allocate if safe/unsafe

Definition: Safe State

- State of a system
  - An enumeration of which processes hold, are waiting for, or might request which resources
- Safe state
  - No process is deadlocked, and there exists no possible sequence of future requests in which deadlock could occur.

    or alternatively,

  - No process is deadlocked, and the current state will not lead to a deadlocked state

Deadlock Avoidance

Safe State:

	Current Loan	Max Need
Process 1	1	4
Process 2	4	6
Process 3	5	8

Available = 2

Deadlock Avoidance

Unsafe State:

	Current Loan	Max Need
Process 1	8	10
Process 2	2	5
Process 3	1	3

Available = 1

Safe to Unsafe Transition

Current state being safe does not necessarily imply future states are safe

Current Safe State:

	Current Loan	Maximum Need	
Process 1	1	4	
Process 2	4	6	
Process3	5	8	**Available = 2**

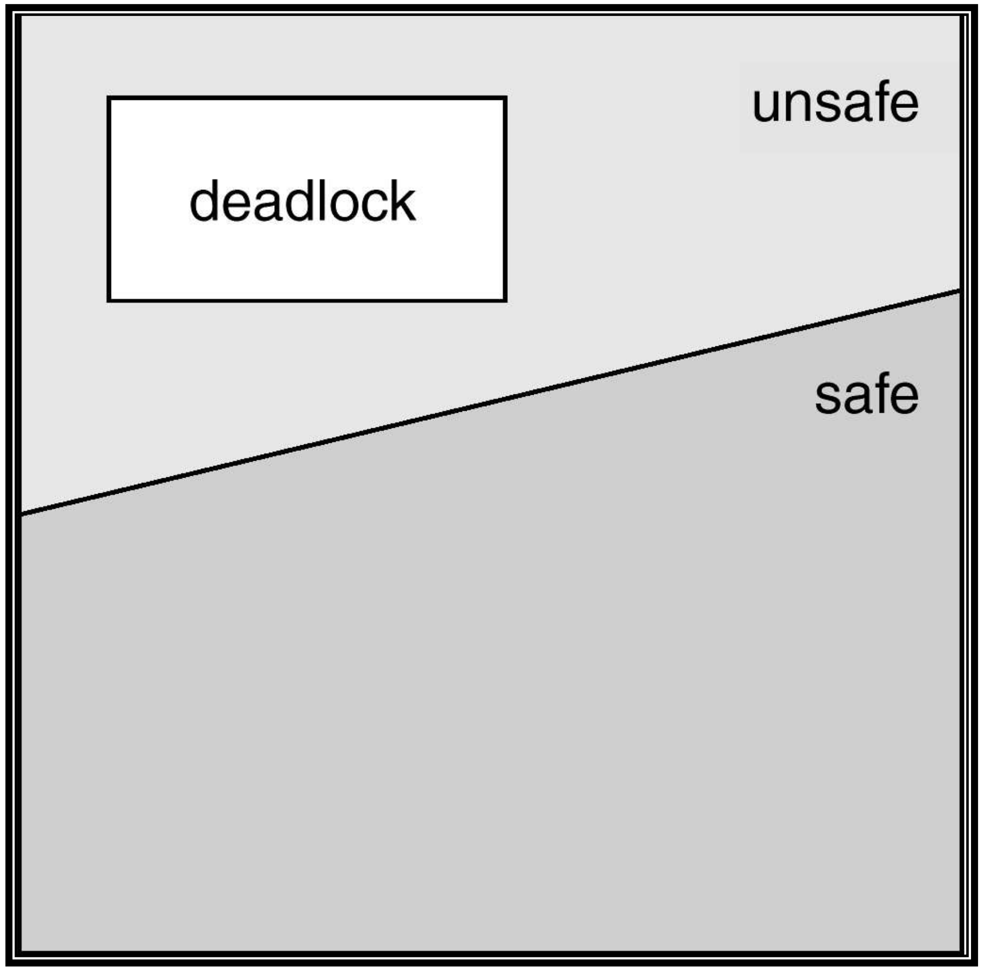
Suppose Process 3 requests and gets one more resource

	Current Loan	Maximum Need	
User1	1	4	
User2	4	6	
User3	6	8	**Available = 1**

Basic Facts

- If a system is in safe state $\Rightarrow$ no deadlocks.
- If a system is in unsafe state $\Rightarrow$ possibility of deadlock.
- Avoidance $\Rightarrow$ ensure that a system will never enter an unsafe state.

Safe, Unsafe , Deadlock State



Banker's Algorithm

Taken from Operating System Concepts, 6th Ed, Silberschatz, et al, 2003

- Multiple instances of resources.
- Each process must a priori claim maximum use.
- When a process requests a resource it may have to wait.
- When a process gets all its resources it must return them in a finite amount of time.

Data Structures for the Banker's Algorithm

Let *n* = number of processes, and *m* = number of resources types.

- *Available:* Vector of length *m*. If available [*j*] = *k*, there are *k* instances of resource type R_j available.
- *Max: n x m* matrix. If *Max* [*i,j*] = *k*, then process P_i may request at most *k* instances of resource type R_j.
- *Allocation:* *n* x *m* matrix. If Allocation[*i,j*] = *k* then P_i is currently allocated *k* instances of R_j.
- *Need:* *n* x *m* matrix. If *Need*[*i,j*] = *k*, then P_i may need *k* more instances of R_j to complete its task.

$$Need\,[i,j] = Max[i,j] - Allocation\,[i,j].$$

Safety Algorithm

1. Let *Work* and *Finish* be vectors of length *m* and *n*, respectively. Initialize:

   Work = *Available*

   Finish [*i*] = *false* for *i* = 1,2,3, …, *n.*

2. Find an *i* such that both:

   (a) *Finish* [*i*] = *false*

   (b) $Need_i \leq Work$

   If no such *i* exists, go to step 4.

3. $Work = Work + Allocation_i$
   Finish[*i*] = *true*
   go to step 2.

4. If *Finish* [*i*] == true for all *i*, then the system is in a safe state.

Safety Algorithm

1. Let *Work* and *Finish* be vectors of length *m* and *n*, respectively. Initialize:

   Work = *Available*

   Finish [*i*] = *false* for *i* = 1,2,3, …, *n.*

```
i=1;
while (i <= n) Do {
    if (!Finish[i]  && Need_i <= Work ) {
          Finish[i] = True;
          Work = Work + Allocation_i;
          i  =  1;
    }
    else i++;
}
if  (Finish [i] == true for all i,) return ( SAFE )
else return ( UNSAFE );
```

Resource-Request Algorithm for Process P_i

Request = request vector for process P_i. If $Request_i[j] = k$ then process P_i wants k instances of resource type R_j.

1. If $Request_i \leq Need_i$ go to step 2. Otherwise, raise error condition, since process has exceeded its maximum claim.
2. If $Request_i \leq Available$, go to step 3. Otherwise P_i must wait, since resources are not available.
3. Pretend to allocate requested resources to P_i by modifying the state as follows:

$$Available = Available - Request_i;$$

$$Allocation_i = Allocation_i + Request_i;$$

$$Need_i = Need_i - Request_i;$$

- If safe $\Rightarrow$ the resources are allocated to P_i.
- If unsafe $\Rightarrow$ P_i must wait, and the old resource-allocation state is restored

Example of Banker's Algorithm

- 5 processes P_0 through P_4; 3 resource types A (10 instances), B (5 instances), and C (7 instances).
- Snapshot at time T_0:

	Allocation	*Max*	*Available*
	A B C	A B C	A B C
P_0	0 1 0	7 5 3	3 3 2
P_1	2 0 0	3 2 2	
P_2	3 0 2	9 0 2	
P_3	2 1 1	2 2 2	
P_4	0 0 2	4 3 3	

Example (Cont.)

- The content of the matrix. *Need* is defined to be *Max* – *Allocation*.

	Need
	A B C
P_0	7 4 3
P_1	1 2 2
P_2	6 0 0
P_3	0 1 1
P_4	4 3 1

- The system is in a safe state since the sequence $< P_1, P_3, P_0, P_2, P_4 >$ satisfies safety criteria.

Example P_1 Request (1,0,2) (Cont.)

- Check that *Request* ≤ *Available* (that is, (1,0,2) ≤ (3,3,2) ⇒ true.

	Allocation	*Need*	*Available*
	A B C	A B C	A B C
P_0	0 1 0	7 4 3	2 3 0
P_1	3 0 2	0 2 0	
P_2	3 0 1	6 0 0	
P_3	2 1 1	0 1 1	
P_4	0 0 2	4 3 1	

- Executing safety algorithm shows that sequence <P_1, P_3, P_0, P_2, P_4> satisfies safety requirement.
- Can request for (3,3,0) by P_4 be granted?
- Can request for (0,2,0) by P_0 be granted?

Banker's Algorithm: Summary

(+) PRO's:

☺ Deadlock never occurs.

☺ More flexible & more efficient than deadlock prevention. (Why?)

(-) CON's:

☹ Must know max use of each resource when job starts.

=> No truly dynamic allocation

☹ Process might block even though deadlock would never occur

Deadlock Detection

Allow deadlock to occur, then recognize that it exists

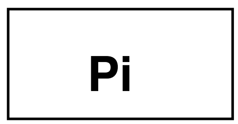
- Run deadlock detection algorithm whenever locked resource is requested
- Could also run detector in background

Resource Graphs

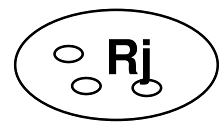
Graphical model of deadlock

Nodes:

1) Processes

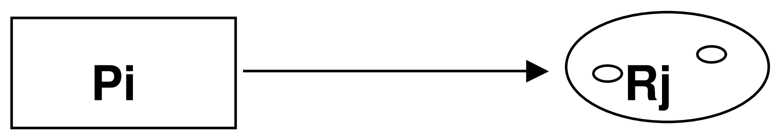


2) Resources

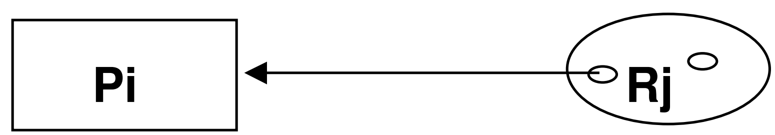


Edges:

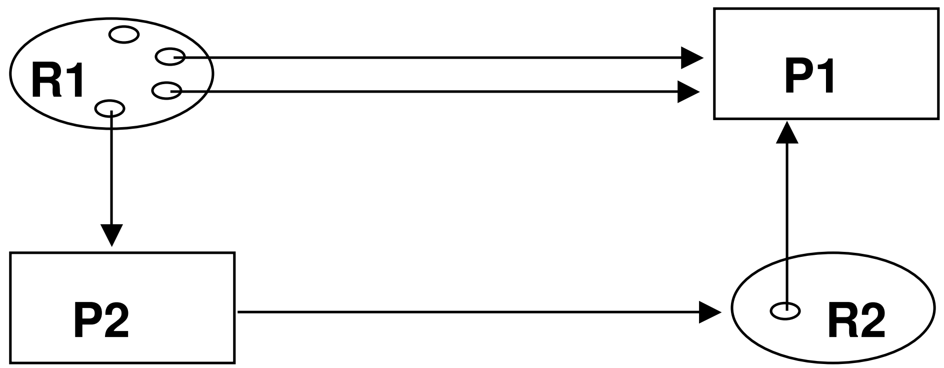
1) Request



2) Allocate



Resource Graphs: Example



P1 holds 2 units of R1

P1 holds 1 unit of R2

R1 has a total inventory of 4 units

P2 holds 1 unit of R1

P2 requests 1 unit of R2 (and is blocked)

Operations on Resource Graphs: An Overview

1) Process requests resources: Add arc(s)

2) Process acquires resources: Reverse arc(s)

3) Process releases resources: Delete arc(s)

Graph Reductions

- A graph is <u>reduced</u> by performing operations 2 and 3 (reverse, delete arc)
- A graph is <u>completely reducible</u> if there exists a sequence of reductions that reduce the graph to a set of isolated nodes
- A process P is <u>not</u> deadlocked if and only if there exists a sequence of reductions that leave P unblocked
- If a graph is completely reducible, then the system state it represents is not deadlocked

Operations on Resource Graphs: Details

1) P requests resources (<u>Add arc</u>)

<u>Precondition:</u>

- P must have no outstanding requests
- P can request any number of resources of any type

<u>Operation:</u>

- Add one edge (P, Rj) for each resource copy Rj requested

2) P acquires resources (<u>Reverse arc</u>)

<u>Precondition:</u>

- Must be available units to grant <u>all</u> requests
- P acquires all requested resources

<u>Operation:</u>

- Reverse <u>all</u> request edges directed from P toward resources

Operations on Resource Graphs: Details …

3) P releases resources (Delete arc)

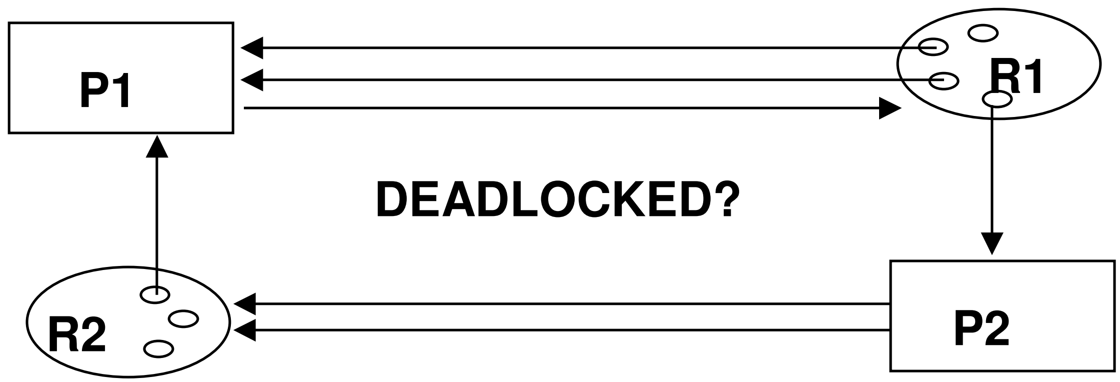
Precondition:

- P must have no outstanding requests
- P can release any subset of resources that it holds

Operation:

- Delete one arc directed away from resource for each released resource

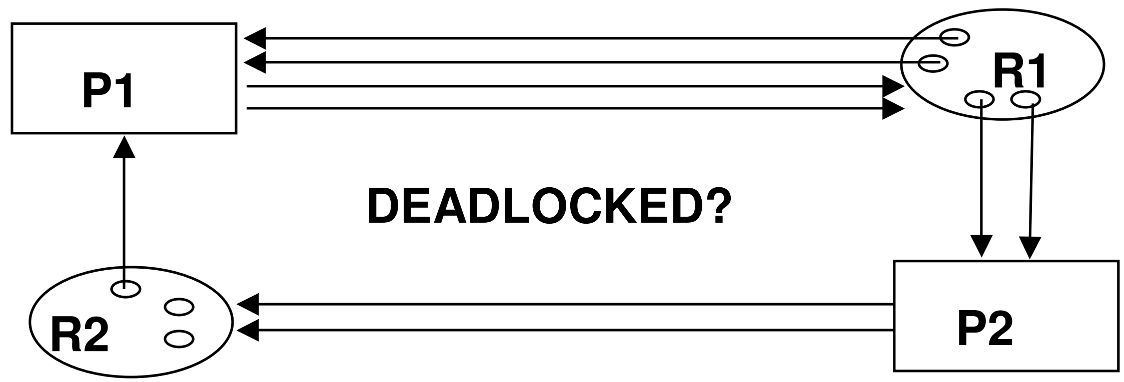
Resource Graphs



NO….One sequence of reductions:

1) **P1 acquires 1 unit of R1**
2) **P1 releases all resources (finishes)**
3) **P2 acquires 2 units of R2**
4) **P2 releases all resources (finishes)**

Resource Graphs …



NO…. One sequence of Reductions:

1) P2 acquires 2 units of R2
2) P2 releases all resources (finishes)
3) P1 acquires 2 units of R1
4) P1 releases all resources (finishes)

Resource Graphs…

What if there was only 2 available unit of R2 ?

?

Can deadlock occur with multiple copies of just one resource?

Recovering from Deadlock

Once deadlock has been detected, the system must be restored to a non-deadlocked state

1) Kill one or more processes

- Might consider priority, time left, etc. to determine order of elimination

2) Preempt resources

- Preempted processes must rollback
- Must keep ongoing information about running processes