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

Request X

Request Y

⋮

Release X

Release Y

Process B

Request Y

Request X

⋮

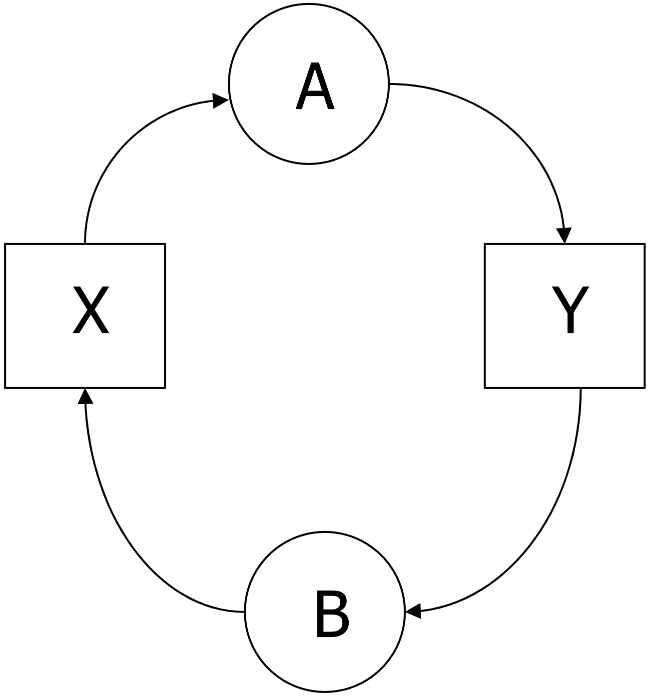
Release Y

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 …

- Reentrant vs. Non-reentrant
  - Reentrant = shared code
  - Non-reentrant = exclusively used code

  - Which type of code do you write?
  - Why is the other type useful?

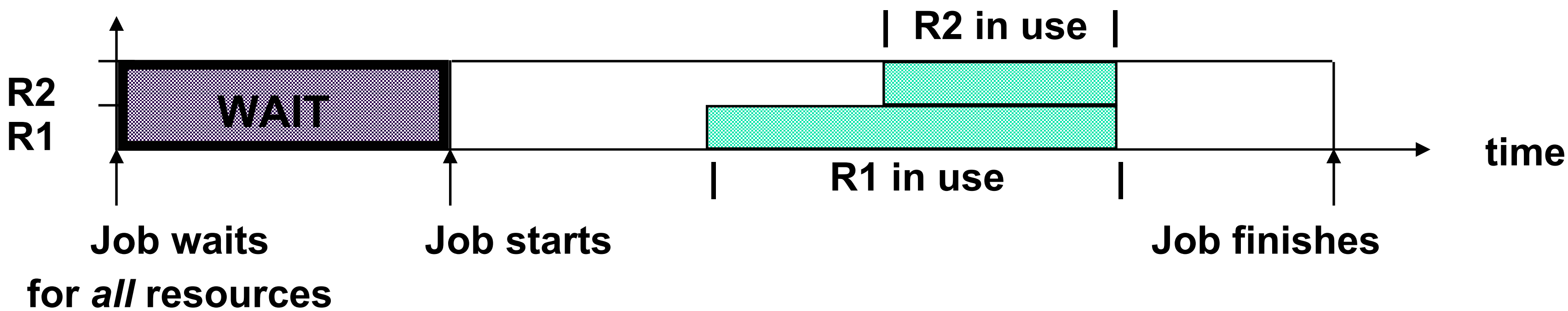
Terminology …

- 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**)*

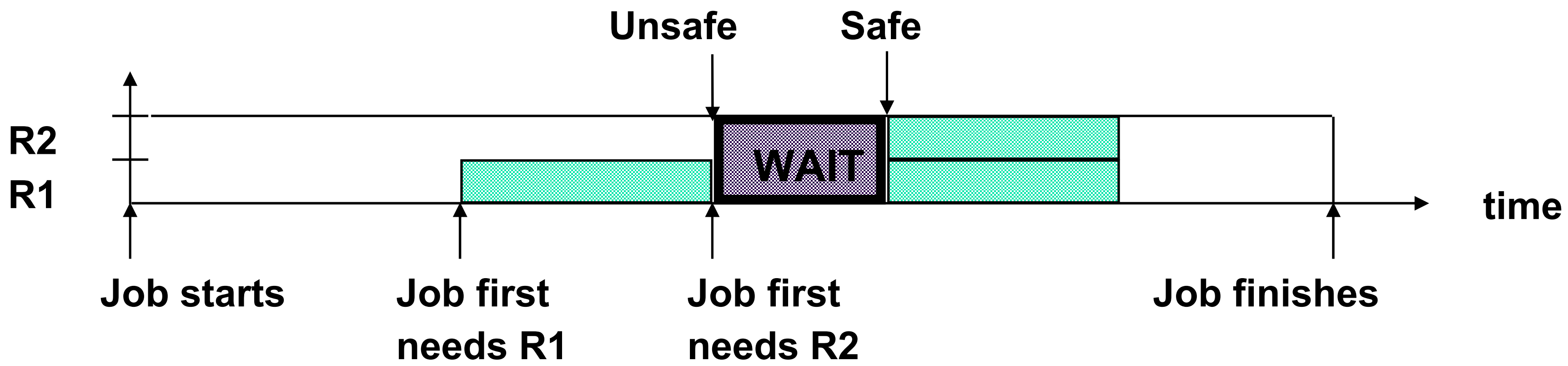


"We had better not allocate if it could ever cause deadlock"

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

Three Solutions to Deadlock …

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

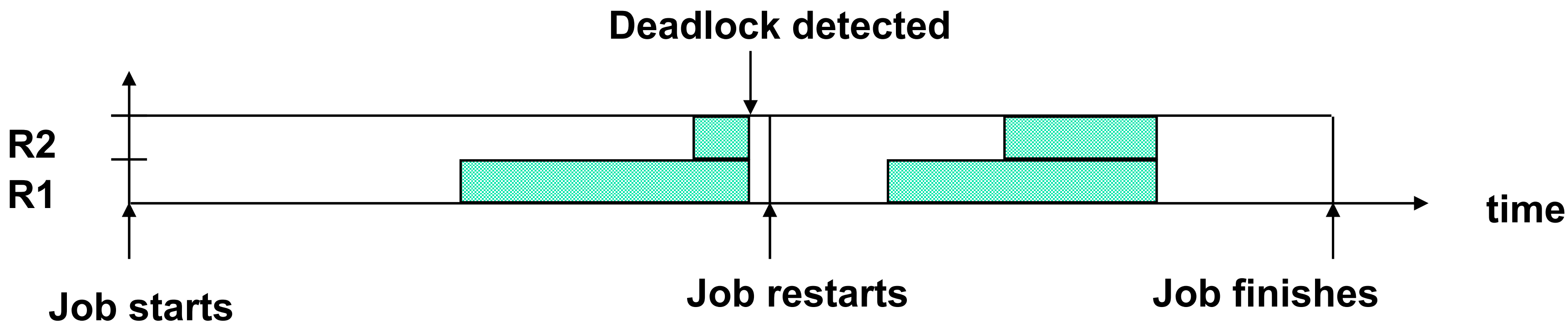


"If resource is free and with its allocation we can still guarantee that everyone will finish, **use it**."

Better resource utilization
Process still waits

Three Solutions to Deadlock…

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



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

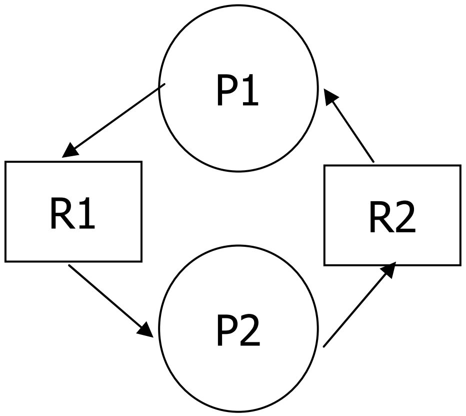
Good resource utilization, minimal process wait time
Until deadlock occurs….

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**

Essence of Banker's Algorithm

- Find an allocation schedule satisfying maximum claims that allows to complete jobs

  => Schedule exists <u>iff</u> safe

- Method: "Pretend" you are the CPU.

  1. Scan table (PCB?) row by row and find a job that can finish
  2. Add finished job's resources to number available.

  Repeat 1 and 2 until
  - all jobs finish (**<u>safe</u>**), or
  - no more jobs can finish, but some are still "waiting" for their maximum claim (resource) request to satisfied <u>(**unsafe**)</u>

Banker's Algorithm

Constants

```
int    N {number of processes}
int    Total_Units
int    MaximumNeed[i]
```

Variables

```
int    i {denotes a process}
int    Available
int    CurrentLoan[i]
boolean    Cannot_Finish[i]
```

Function

```
Claim[i]  =   MaximumNeed[i] - CurrentLoan[i];
```

Banker's Algorithm

```
Begin
    Available  =  Total_Units;

    For  i  =  1  to  N  Do
        Begin
        Available  =  Available - CurrentLoan [i];
        Cannot_Finish [i]  =  TRUE;
        End;

    i = 1;
    while ( i <= N ) Do
        begin
            If ( Cannot_Finish [i]  AND  Claim [i] <= Available )
                Then Begin
                    Cannot_Finish [i]  =  False;
                    Available  =  Available  +  CurrentLoan [i];
                    i  =  1;
                    End;
                Else i = i+1;
        End;
    If  ( Available  ==  Total_Units )
        Then Return ( SAFE )
        Else Return ( UNSAFE );
End;
```

Initialize

Find schedule to complete all jobs

Banker's Example #1

Total_Units = 10 units
N = 3 processes

Process:	1	2	3	1
Request:	2	3	4	1

Can the fourth request be satisfied?

Process	Current Loan	Maximum Need	Claim	Cannot Finish
1		4		
2		4		
3		8		

Available =
i =

Banker's Example #2

Total_Units = 10 units
N = 3 processes

Process:	1	2	3	1
Request:	4	1	1	2

Can the fourth request by satisfied?

Process	Current Loan	Maximum Need	Claim	Cannot Finish
1		10		
2		6		
3		3		

Available =
i =

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

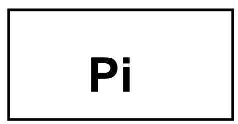
- Run deadlock detection algorithm whenever locked resource is requested
- Could also run detector in background

Resource Graphs

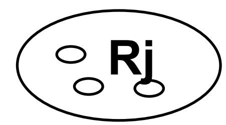
Graphical model of deadlock

Nodes:

1) Processes

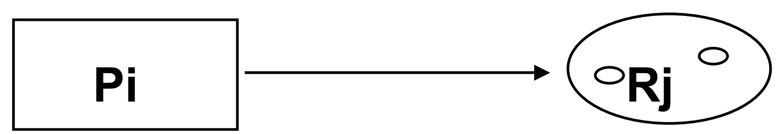


2) Resources

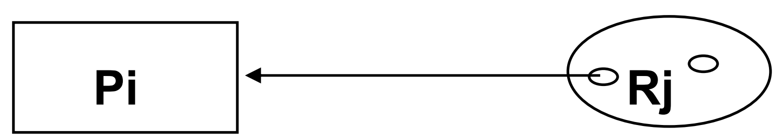


Edges:

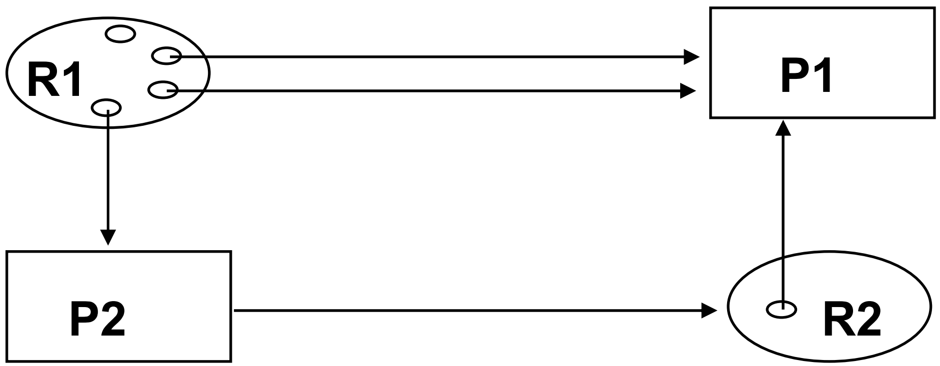
1) Request



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 reduced by performing operations 2 and 3 (reverse, delete arc)
- A graph is completely reducible if there exists a sequence of reductions that reduce the graph to a set of isolated nodes
- A process P is not 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 (Add arc)

Precondition:

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

Operation:

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

2) P acquires resources (Reverse arc)

Precondition:

- Must be available units to grant all requests
- P acquires all requested resources

Operation:

- Reverse all request edges directed from P toward resources

Operations on Resource Graphs: Details …

3) P releases resources (Delete arc)

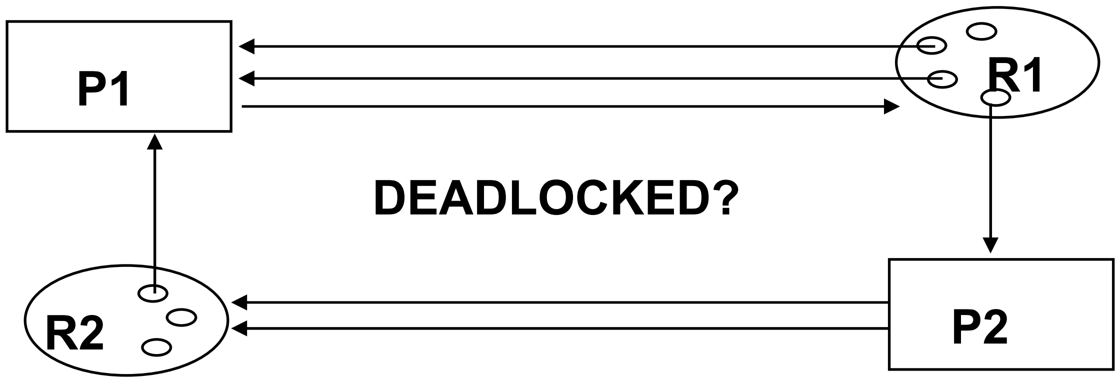
Precondition:

- 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

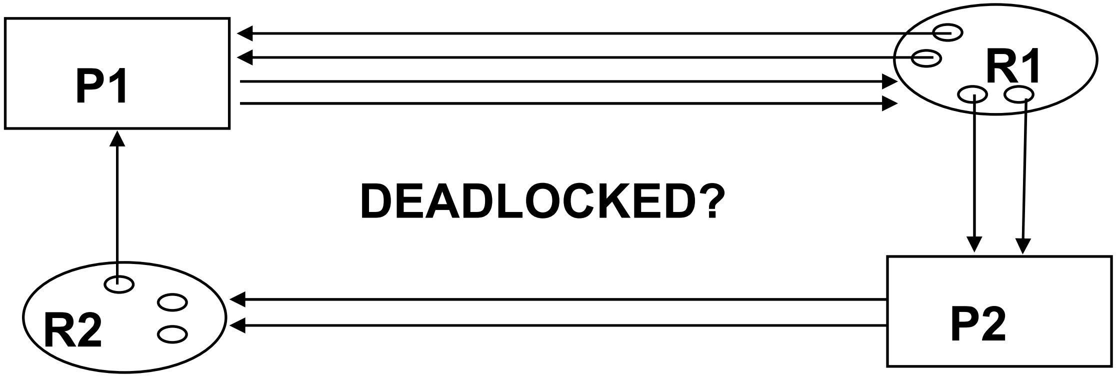
Resource Graphs



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?

?

Can deadlock occur with just one copy of 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