Resource Allocation and Deadlock Handling

What is resource allocation?

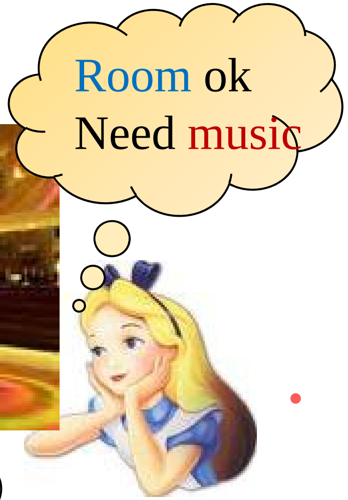
Think of planning a party:

Need resources: party room, orchestra, consumables, ...

What is a deadlock?

Conditions for Deadlock

[Coffman-etal 1971] **4 conditions must hold simultaneously** for a deadlock to occur:



- **Mutual exclusion**: only one process at a time can use a resource.

Hold and wait: a process holding some resource can request additional resources and wait for them if they are held by other processes.

- **No preemption**: a resource can only be released by the process holding it, after that process has completed its task.
  - examples preemptible/non-preemtible resources?

- **Circular wait**: there exists a circular chain of 2 or more blocked processes, each waiting for a resource held by the next proc. in the chain

Resource Allocation & Handling of Deadlocks

- Structurally restrict the way in which processes request resources
  - deadlock *prevention*: deadlock *is not* possible

- Require processes to give advance info about the (max) resources they will require; then schedule processes in a way that avoids deadlock.
  - deadlock *avoidance*: deadlock *is* possible, but OS uses advance info to avoid it

- Allow a deadlock state and then *recover*

- Ignore the problem and pretend that deadlocks never occur in the system (can be a "solution" sometimes?!…)

Roadmap: 1st station

- Structurally restrict the way in which processes request resources
  - deadlock *prevention*: deadlock *is not* possible

Resource Allocation with Deadlock Prevention

How to be RESPONSIBLE AND PREVENT?

Restrain the ways requests can be made; eliminate at least one of the 4 conditions, so that deadlocks are impossible to happen:

- **Mutual Exclusion** – (cannot do much here …)

- **Hold and Wait** – guarantee that when a process requests a resource, it does not hold any other resources.
  - process requests and be allocated all its resources at once
    - Get both room and music at once or none
- **No Preemption** – a process holding some resources requests another resource that cannot be immediately allocated, it releases the held resources and has to request them again.
  - Be polite, B releases music for At o proceed

- **Circular Wait** – impose total ordering of all resource types, and require that each process requests resources in an increasing order of enumeration
  - e.g first the room, then the music

Examples?
How to help procs do so with the synchronization tools we have?

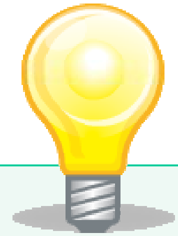
Fight the circular wait: Dining philosophers example

request forks in increasing fork-id

var f[0..n]: bin-semaphore /init all 1 /

```
P_i: (i!=n)
Repeat
      Wait(f[i])
      Wait(f[(i+1)modn])

      Eat

      Signal(f[(i+1)modn])
      Signal(f[i])

      Think
forever
```

```
Pn
Repeat
      Wait(f[(i+1)modn])
      Wait(f[i])

      Eat

      Signal(f[i])
      Signal(f[(i+1)modn])

      Think
forever
```



Idea:

- Hierarchical ordering of resources

- Proc's request their needed resources in increasing order

Fight the hold and wait: Dining philosophers example

semaphore S[N], initially 0

Semaphore mutex, init 1

int state[N]

Pi: do

<think>

take_forks(i)

<eat>

leave_forks(i)

forever

take_forks(i)

wait(mutex)

state(i) := HUNGRY

help(i)

signal(mutex)

wait(S[i])

leave_forks(i)

wait(mutex)

state(i) := THINKING

help(left(i))

help(right(i))

signal(mutex)

Idea: apply mutex algorithm for each neighbourhood, instead of for each fork

help(k)

if state(k) ==HUNGRY && state(left(k)) != EATING && state(left(k)) != EATING then

state(k) := EATING

signal(S[i])

Fight the no-preemption: Dining philosophers example

```
var f[0..n]: record
    s: bin-semaphore  /init 1/
    available: boolean /init 1 /
P_i:
Repeat
    While <not holding both forks> do
        Lock(f[i])
        If !trylock(f[(i+1)modn]) then release f[i];
    od
        Eat
    Release(f[i])
    Release(f[(i+1)modn])
    Think
forever
```

```
trylock(fork):
wait(fork.s)
    If fork.available then
        fork.available := false
        ret:= true
    else ret:= false
Signal(fork.s)
Return(ret)
```

```
Lock(fork):
Repeat
Until (trylock(fork))
```

```
Release(fork):
wait(fork.s)
    fork.available := true
Signal(fork.s)
```

Idea: release held resources and retry when the next one is not available

Roadmap: 2nd station

- Require processes to give advance info about the (max) resources they will require; then schedule processes in a way that avoids deadlock.
  - deadlock *avoidance*: deadlock *is* possible, but OS uses advance info to avoid it

Deadlock avoidance: System Model

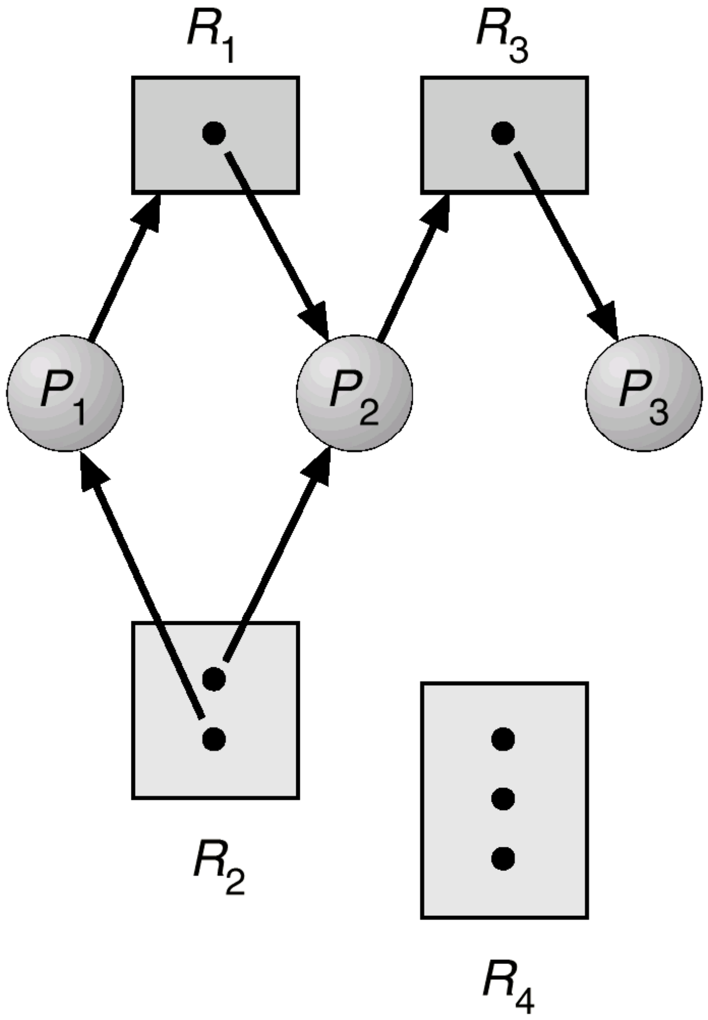
- Resource types $R_1, R_2, \ldots, R_m$
  - *e.g. CPU, memory space, I/O devices, files*
  - each resource type R_i has W_i instances.
- Each process utilizes a resource as follows:
  - request
  - use
  - release

Resource-Allocation Graph

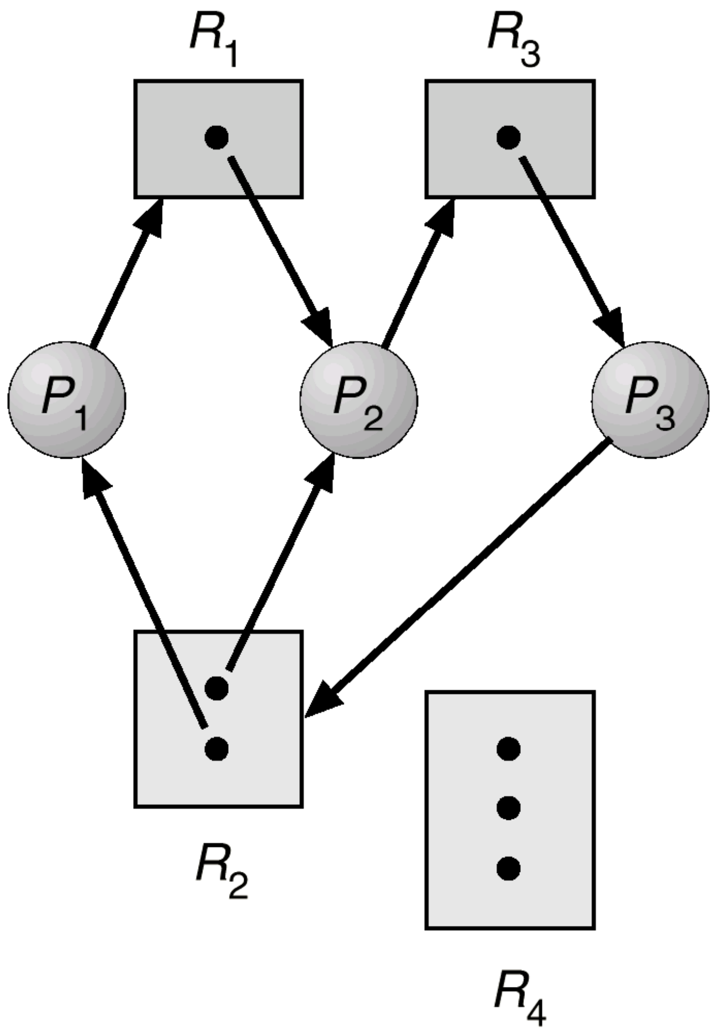
A set of vertices V and a set of edges E.

- V is partitioned into two sets:
  - $P = \{P_1, P_2, \ldots, P_n\}$ the set of processes
  - $R = \{R_1, R_2, \ldots, R_m\}$ the set of resource types
- request edge: $P_i \rightarrow R_j$
- assignment edge: $R_j \rightarrow P_i$

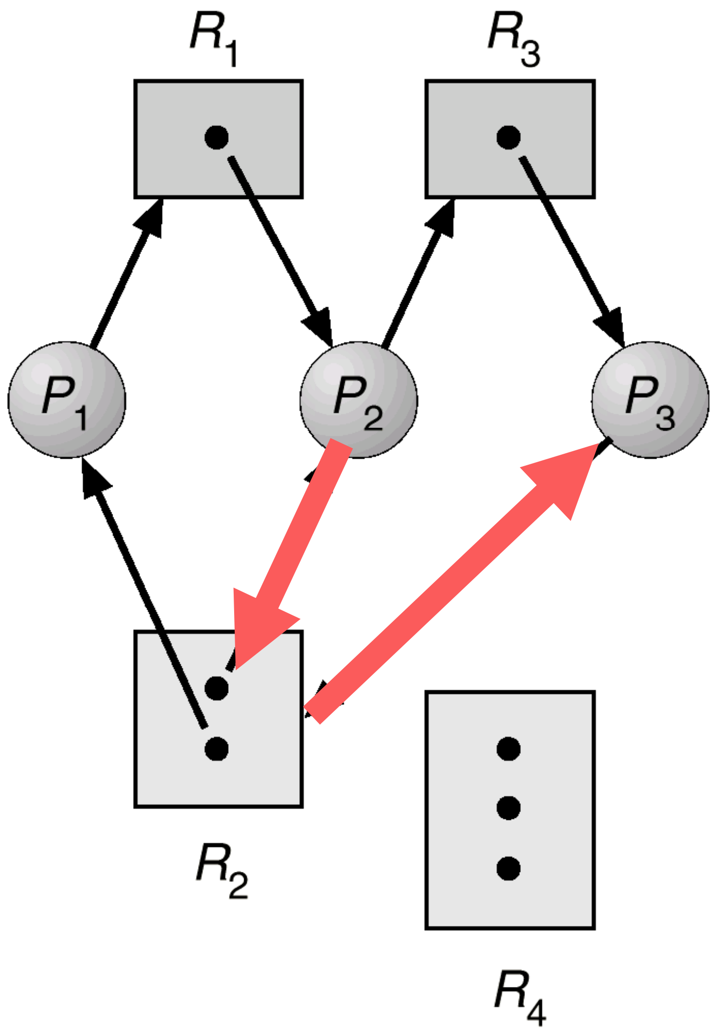
Example of a Resource Allocation Graph



Resource Allocation Graph With A Deadlock



Resource Allocation Graph With A cycle but no Deadlock



Basic Facts

- graph contains no cycles ⇒ no deadlock.
  (i.e. cycle is always a necessary condition for deadlock)

- If graph contains a cycle ⇒
  - if one instance per resource type, then deadlock.
  - if several instances per resource type, then possibility of deadlock
    - Thm: if immediate-allocation-method, then knot ⇒ deadlock.
      - Knot= strongly connected subgraph (no sinks) with no outgoing edges

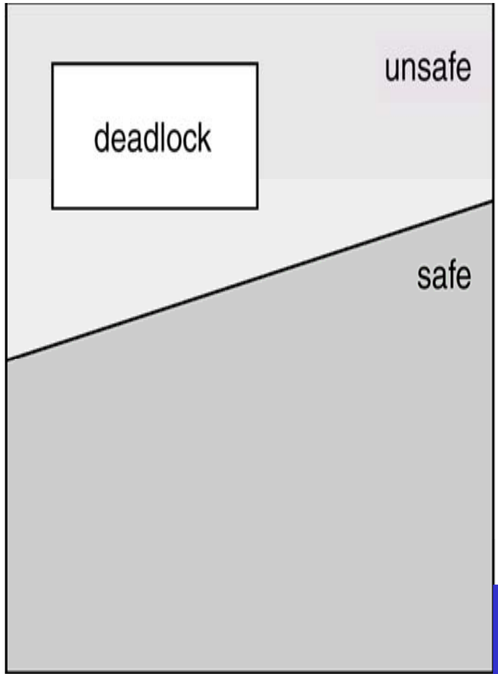
Resource Allocation with Deadlock Avoidance

Requires *a priori information* available.

- e.g.: each *process* declares *maximum number* of resources of each type that it *may need* (e.g memory/disk pages).

Deadlock-avoidance algo:

- examines the resource-allocation state…
  - *available and allocated resources*
  - *maximum possible demands* of the processes.
- …to ensure there is *no potential for a circular-wait*:
  - safe state ⇒ no deadlocks in the horizon.
  - unsafe state ⇒ deadlock might occur (later…)
  - Q: how to do the safety check?
- *Avoidance* = ensure that *system will not enter an unsafe* state.



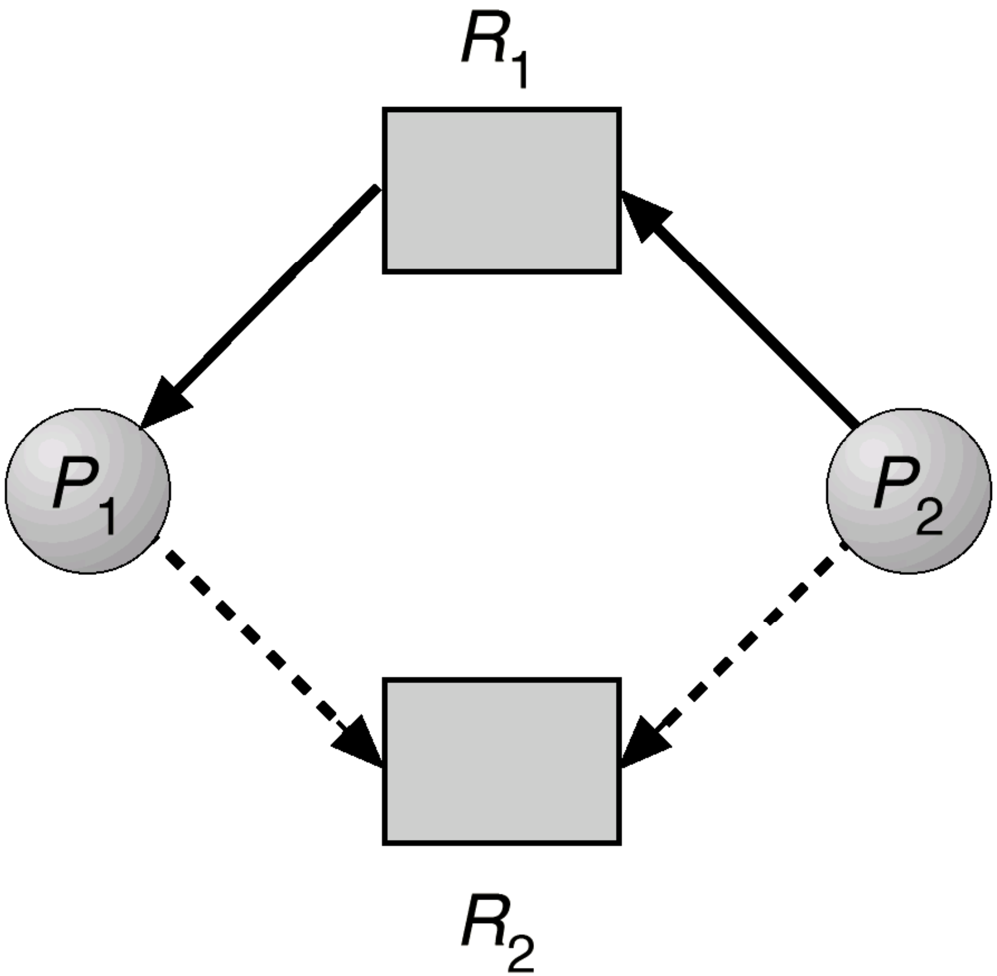
Idea: If *satisfying a request* will result in an *unsafe state*, the *requesting process is suspended until enough resources are free-ed* by processes that will terminate in the meanwhile.

Enhanced Resource Allocation Graph for Deadlock Avoidance

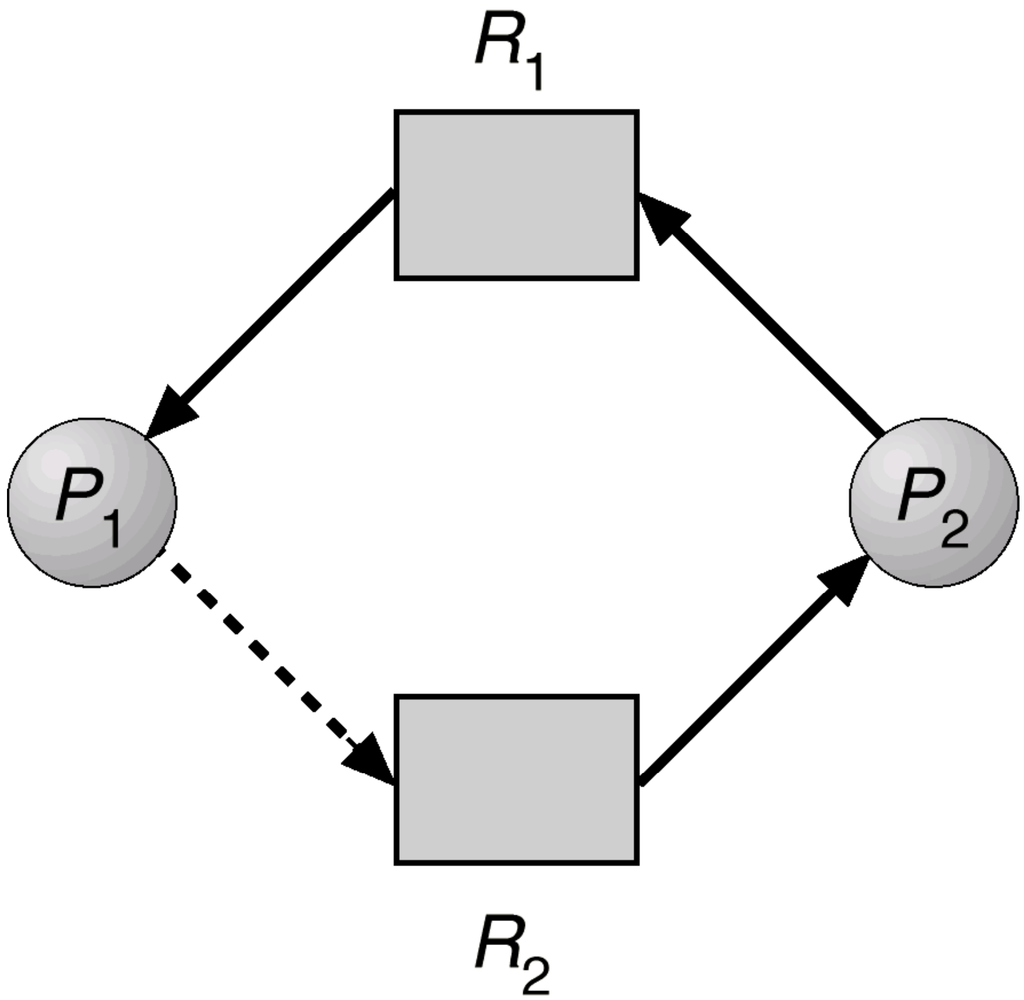
- *Claim edge* $P_i \rightarrow R_j$: P_j may request resource R_j
  - represented by a dashed line.
- Claim edge converts to request edge when a process requests a resource.
- When a resource is released by a process, assignment edge reconverts to a claim edge.

- Resources must be claimed *a priori* in the system.

Example Resource-Allocation Graph For Deadlock Avoidance: Safe State



Example Resource-Allocation Graph For Deadlock Avoidance: Unsafe State



Banker's Algorithm for Resource Allocation with Deadlock Avoidance

Max [i,j] = k:
P_i may request max k instances of resource type R_j.

Allocation[i,j] = k:
Pi holds k instances of Rj

Need [i,j] =
Max[i,j] – Allocation[i,j]:
potential max request by Pi for resource type Rj

Available [j] = k :
k instances of resource type Rj are available.

RECALL: *Avoidance* = ensure that *system will not enter an unsafe* state.

Idea:

If *satisfying a request* will result in an *unsafe state*,
then *requesting process is suspended*
until enough resources are free-ed by processes that will terminate in the meanwhile.

Safety checking: More on Safe State

safe state = there exists a *safe sequence* <P_1, P_2, …, P_n> of terminating all processes:

for each P_i, the requests that it can still make can be granted by currently available resources + those held by P_1, P_2, …, P_{i-1}

- The system can schedule the processes as follows:
  - if P_i 's resource needs are not immediately available, then it can
    - wait until all P_1, P_2, …, P_{i-1} have finished
    - obtain needed resources, execute, release resources, terminate.
  - then the next process can obtain its needed resources, and so on.

Banker's algorithm: Resource Allocation

For each new *Request*$_i$ do /* *Request*$_i$[*j*] = *k*: P_i wants *k* instances of R_j. */

/* Check consequence if request is granted */

remember the current resource-allocation state;

Available := *Available* - *Request*$_i$;

Allocation$_i$:= *Allocation*$_i$ + *Request*$_i$;

Need$_i$:= *Need*$_i$ – *Request*$_i$;

If safety-check OK ⇒ *the resources are allocated to* P_i.

Else (unsafe) ⇒

P_i must wait and

the old resource-allocation state is restored;

Banker's Algorithm: safety check

- *Work* and *Finish*: auxiliary vectors of length *m* and *n*, respectively.
- Initialize:

  Work := *Available*

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

- While there exists *i* such that both do

  (a) *Finish* [*i*] = *false*
  (b) $Need_i \leq Work$.

  Work := *Work* + $Allocation_i$

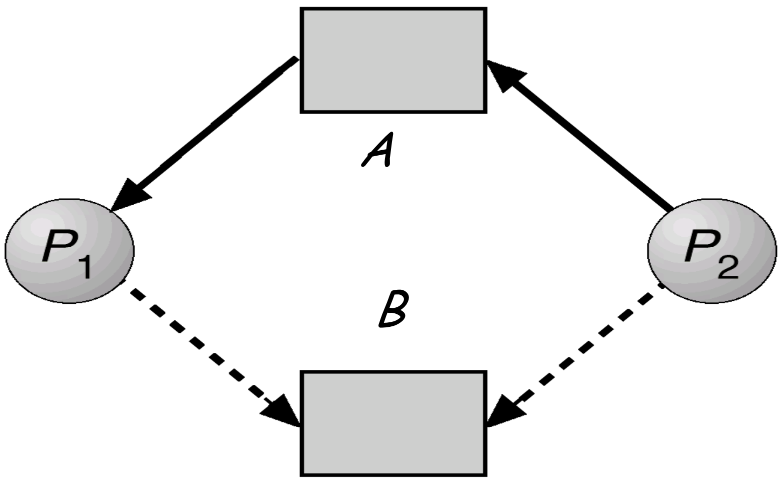
  Finish[*i*] := *true*

- If *Finish* [*i*] = true for all *i*, then the system is in a safe state else state is unsafe

Very simple example execution of Bankers Algo (snapshot 1)

	Allocation	Max	Need	Available
	A B	A B	A B	A B
P_1	1 0	1 1	0 1	0 1
P_2	0 0	1 1	1 1	

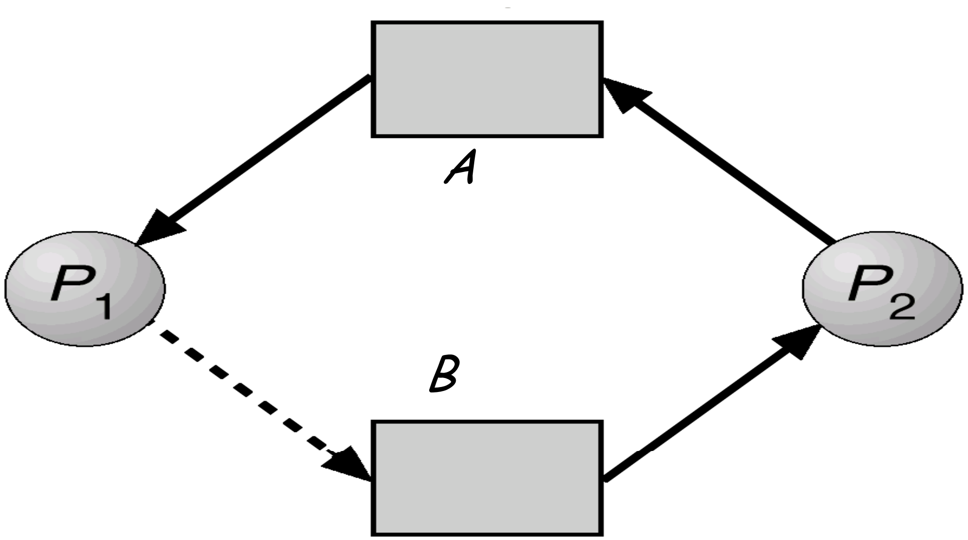
- The system is in a safe state since the sequence < P_1, P_2> satisfies safety criteria.



Very simple example execution of Bankers Algo (snapshot 2)

	Allocation	*Max*	*Need*	*Available*
	A B	*A B*	*A B*	*A B*
P_1	1 0	1 1	0 1	0 0
P_2	0 1	1 1	1 0	

- Allocating B to P_2 leaves the system in an unsafe state since there is no sequence that satisfies safety criteria (*Available* vector is 0 !).



Roadmap: 3rd station

- Allow a deadlock state and then *recover*

GO BACK
YOU HAVE COME
WRONG WAY

Deadlock Detection & Recovery

- Detection algorithm:
  - what we did for checking safety in enhanced graph, can serve for checking no-deadlock in the resource allocation graph
    - Using resource-allocation graphs
    - Using Banker's algo idea

- Need also: Recovery scheme

Deadlock Detection

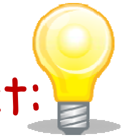
Note:

- similar as detecting unsafe states using Banker's algo
- Q: how is similarity explained?
- Q: if they cost the same why not use avoidance instead of detection&recovery?

Data structures:

- *Available:* vector of length *m:* number of available resources of each type.
- *Allocation:* $n \times m$ matrix: number of resources of each type currently allocated to each process.
- *Request:* $n \times m$ matrix: **current request** of each process. *Request* [*ij*] = *k:* P_i is requesting *k* more instances of resource type R_j.

Detection-Algorithm Usage

- When, and how often, to invoke:
- We don't want to be too late to detect: 
- Be there before this:
- Hence think
  - How often a deadlock is likely to occur?
  - How many processes will need to be rolled back?

- Reason: If algorithm is invoked arbitrarily,
  - there may be many cycles in the resource graph $\Rightarrow$ we would not be able to tell which of the many deadlocked processes "caused" the deadlock.

Recovery from Deadlock: (1) Process Termination

- Abort all deadlocked processes.
- Abort one process at a time until deadlock is eliminated.
- In which order should we choose to abort? Criteria?
  - effect of the process' computation (breakpoints & rollback)
  - Priority of the process.
  - How long process has computed, and how much longer to completion.
  - Resources the process has used/needs to complete.
  - How many processes will need to be terminated.

Recovery from Deadlock: (2) Resource Preemption

- Select victim and rollback – return to some safe state, restart process from that state
  - Must do checkpointing for this to be possible.
- Selection criteria
  - minimize cost.
  - watch for starvation – same process may always be picked as victim, include number of rollbacks in cost factor.

Resource Allocation & Handling of Deadlocks?

- Ignore the problem and pretend that deadlocks never occur in the system
  - (can be a "solution" sometimes?!...)
  - With the increased popularity of embeded OS this gets less popular

Combined Approach to Deadlock Handling

- Combine the three basic approaches (prevention, avoidance, detection), allowing the use of the optimal approach for each type of resources in the system:
  - Partition resources into hierarchically **ordered classes** (deadlocks may arise only within each class, then)
  - use most appropriate technique for handling deadlocks within each class, e.g:
    - internal (e.g. interactive I/O channels): *prevention by ordering*
    - process resources (e.g. files, main memory): *avoidance by knowing max needs, prevention by preemption*
    - swap space (blocks in disk, drum, …): *prevention by preallocation (all the loan in advance)*

RA & Deadlock Handling in Distributed Systems

- Note: no centralized control here!
  - Each site only knows about its own resources
  - Deadlock may involve distributed resources

Resource Allocation in Message-Passing Systems

Deadlock Prevention (recall strategies: no cycles; request all resources at once; apply preemptive strategies) (apply in gen. din.phil)

- using *priorities/hierarchical ordering* of resources
  - Use mutex (each fork is a mutex, execute Rikart&Agrawala for each)
- No hold&wait:
  - Each process is mutually exclusive with both its neighbours => each group of 3 neighbours is 1 Rikart&Agrawala "instance"
- **No Preemption** – If a process holding some resources requests another resource that cannot be immediately allocated, it releases the held resources and has to request them again
  - risk for starvation
  - cf optional reference, StyerPeterson-ACM-PODC89 (not included in study material) algo for avoiding starvation.

Distributed R.A. with Deadlock Avoidance or Deadlock Detection&Recovery

- Centralized control – one site is responsible for safety check or deadlock detection
  - Can be a bottleneck (in performance and fault-tolerance)
- Distributed control – all processes cooperate in the safety check or deadlock detection function
  - need of *consistent global state*
  - straightforward (expensive) approach: all processes try to learn global state
  - less expensive solutions in the literature tend to be complicated and/or unrealistic

- Distributed deadlock avoidance or detection&recovery has not been very practical
  - Checking global states involves considerable processing overhead for a distributed system with a large number of processes and resources
  - Also: who will check if procs are all blocked?!

Roadmap

Done: classics in synchronization, resource allocation

NEXT: efficiency in multiprocessor synchronization, some "extras"