Deadlock

Definition and modeling

Stefano Quer, Pietro Laface, and Stefano Scanzio

Dipartimento di Automatica e Informatica

Politecnico di Torino

skenz.it/os stefano.scanzio@polito.it

Deadlock

- Condition for **deadlock**
  - A P/T requires an unavailable resource, it enters a waiting state, and it waits forever
- Deadlock consists in
  - A set of P/T all awaiting the occurrence of an event that can only be caused by another process in the same set
- Deadlock **implies** starvation, **not** the opposite
  - The starvation of a P/T implies that this P/T waits indefinitely, but the other P/T can proceed in the usual way (without being in deadlock)
  - All P/T in deadlock are in starvation

The Deadlock Problem

- A set of blocked processes each holding a resource and waiting to acquire a resource held by another process in the set.
  - Example: P_1 and P_2
    - each of them holds a pen drive and
    - needs another one.
  - Solution with 2 semaphores A and B, initialized to 1

P_1	P_2
wait (A)	wait(B)
wait (B)	wait(A)

Necessary conditions for occurrence of a deadlock

Conditions	Description
Mutual exclusion	Only one process at a time can use a **not sharable** resource
Hold and wait	A process **holding** at least one resource is allowed to **wait** for acquiring additional resources held by other processes
No preemption	A resource can be released only voluntarily by the process holding it, **cannot** be **preempted** by the system.
Circular wait	A set of waiting processes $\{P_1, P_2, \dots, P_n\}$ such that P_1 is **waiting** for a resource that is held by P_2, P_2 is **waiting** for a resource that is held by P_3, …, and P_n is **waiting** for a resource that is held by P_1

All must occur simultaneously to have a deadlock

Necessary but not sufficient conditions.
They are distinct but not independent (e.g., $4 \rightarrow 2$)

Summary

- Deadlock modeling
- Management strategies
  - Ignore
  - A posteriori
    - Detect
    - Recovery
  - A priori
    - Prevent
    - Avoidance

Ignore the problem assuming the probability of a deadlock in the system is very low

- Method used by many operating systems, including Windows and Unix
- Less appropriate if concurrency and complexity of the system increase

This section 01

In case of deadlock

Section 02

Section 03

In case of possibility of deadlock

Deadlock modeling

- **Resource allocation graph** G = (V, E)
  - Allows deadlock description and analysis
- The set of vertices V is composed of processes and resources
  - Process set P = {P_1, P_2, …, P_n}
    - Processes are indistinguishable and in an indefinite number
    - Each process accesses a resource via a standard protocol consisting of
      - Request
      - Utilization
      - Release

Modeling

- System resource set R = $\{R_1, R_2, \ldots, R_m\}$
  - The resources are divided into classes (types)
  - Each resource type R_j has W_i instances
  - All instances of a class are **identical**: any instance satisfies a demand for that type of resource

If not, it would be necessary to reformulate the division into classes

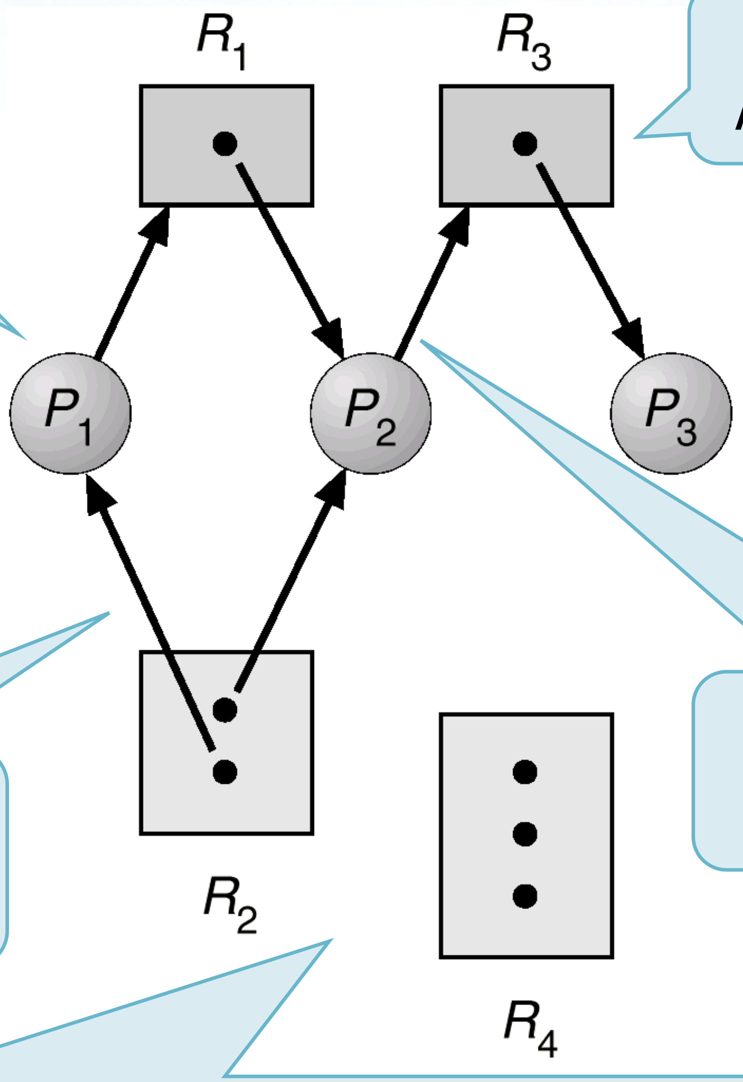
- The set of edges E is composed of
  - Request edges
    - $P_i \rightarrow R_j$, i.e., from a process to a resource type
  - Assignment edge
    - $R_j \rightarrow P_i$, i.e., from a resource to a process

Modeling

Vertices: Processes
P_1, P_2, P_3

Vertices: Resources
An instance of R_1 and R_3

P_1 holds R_2 and is waiting for R_1



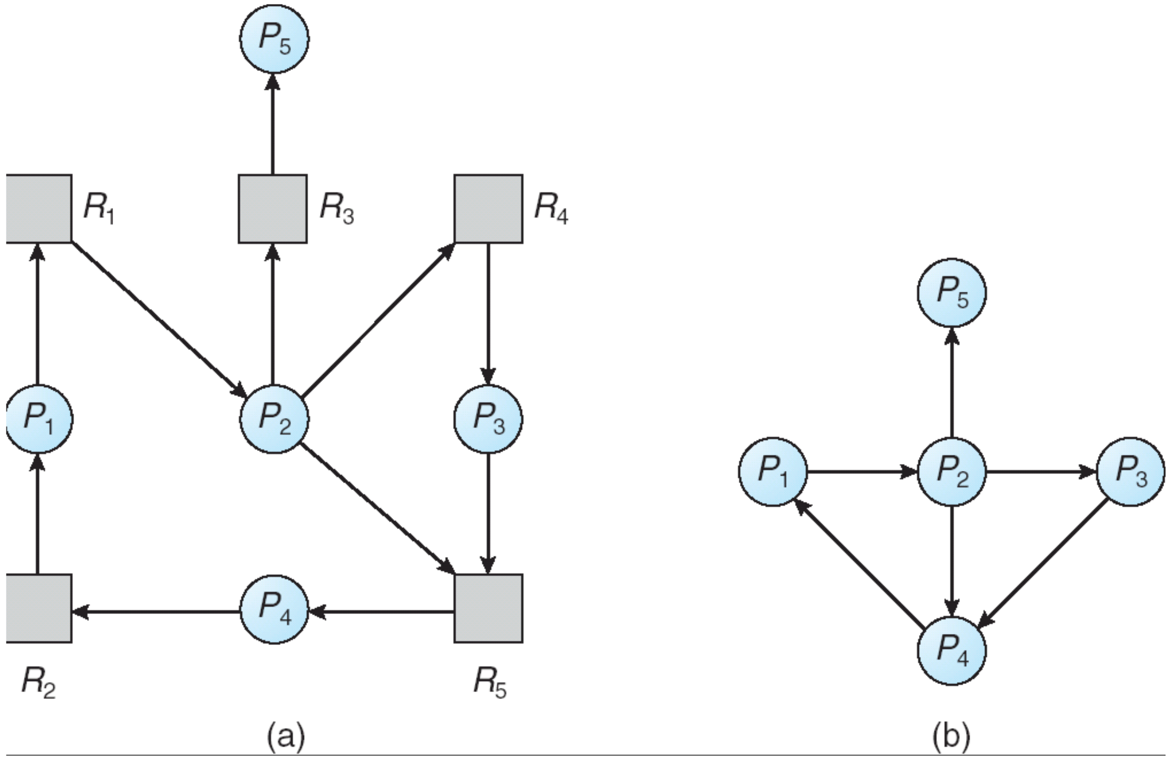
Request edge:
P_2 requests for a R_3 type resource

Assignment edge:
P_1 holds R_2

Vertices: Resources
R_2 and R_4 with 2 and 3 instances, respectively

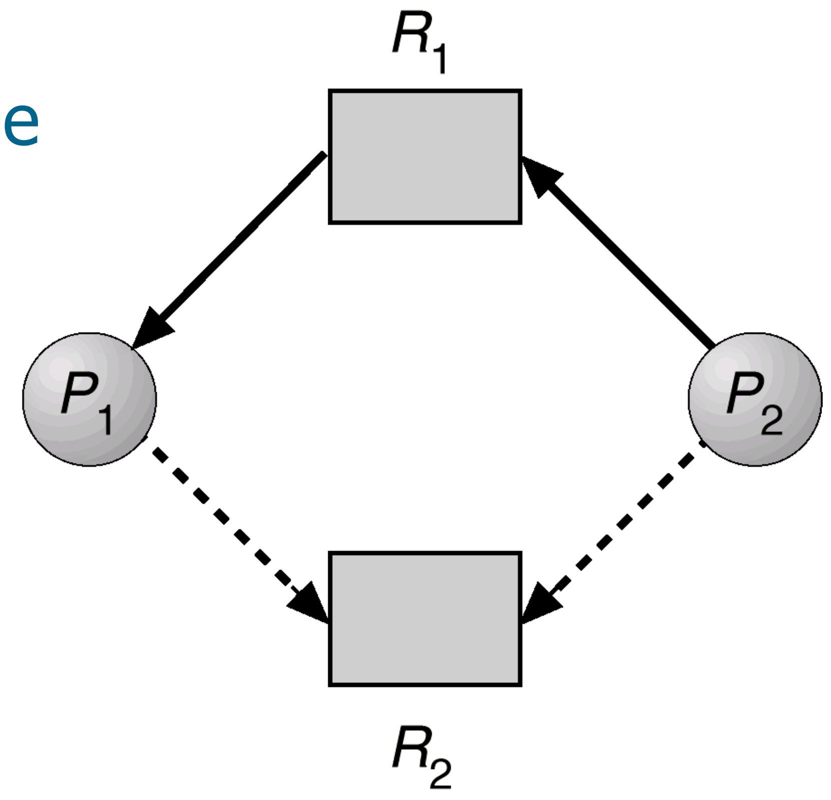
Modeling

- A **resource allocation graph** can be sometime simplified in a **wait-for graph** by
  - deleting the resource vertices
  - creating the edges between the remaining vertices
- Use and consideration similar to the resource allocation graph



Modeling

- Sometimes it is useful to extend the resource-allocation graph to a **claim graph** by
  - adding a claim edge: $P_i \dashrightarrow R_j$, indicates that process P_j **can ask resource R_j in the future**
  - A claim arc is represented by dashed line



Detection and recovery techniques

- The system is allowed to enter in a deadlock state, to then intervene.
- Algorithm in two steps
  - **Deadlock detection (of deadlock condition)**
    - The system performs a deadlock detection algorithm
  - **Recovery from deadlock**
    - If deadlock has been detected, a recovery action is performed

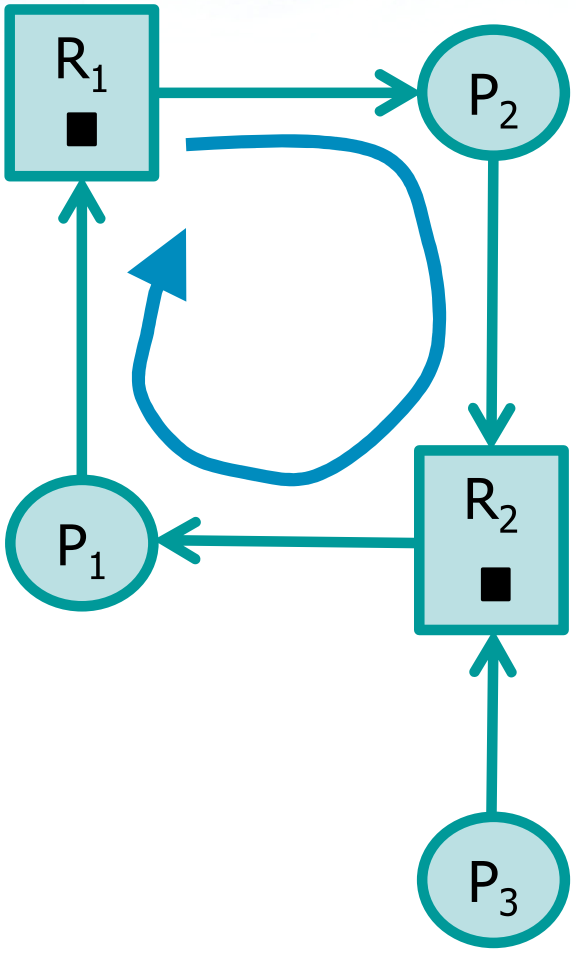
Detection: strategies

- Given an allocation graph, deadlock can be detected by checking for cycles
  - If the graph contains no cycles, then there is no deadlock
  - If the graph contains one or more cycles then
    - Deadlock exist if each type of resource has a **single instance**
    - Deadlock is possible if the are **several instances** per resource type
      - The presence of cycles is necessary but not sufficient condition in the case of multiple instances per resource type

For multiple instances see the Banker's Algorithm

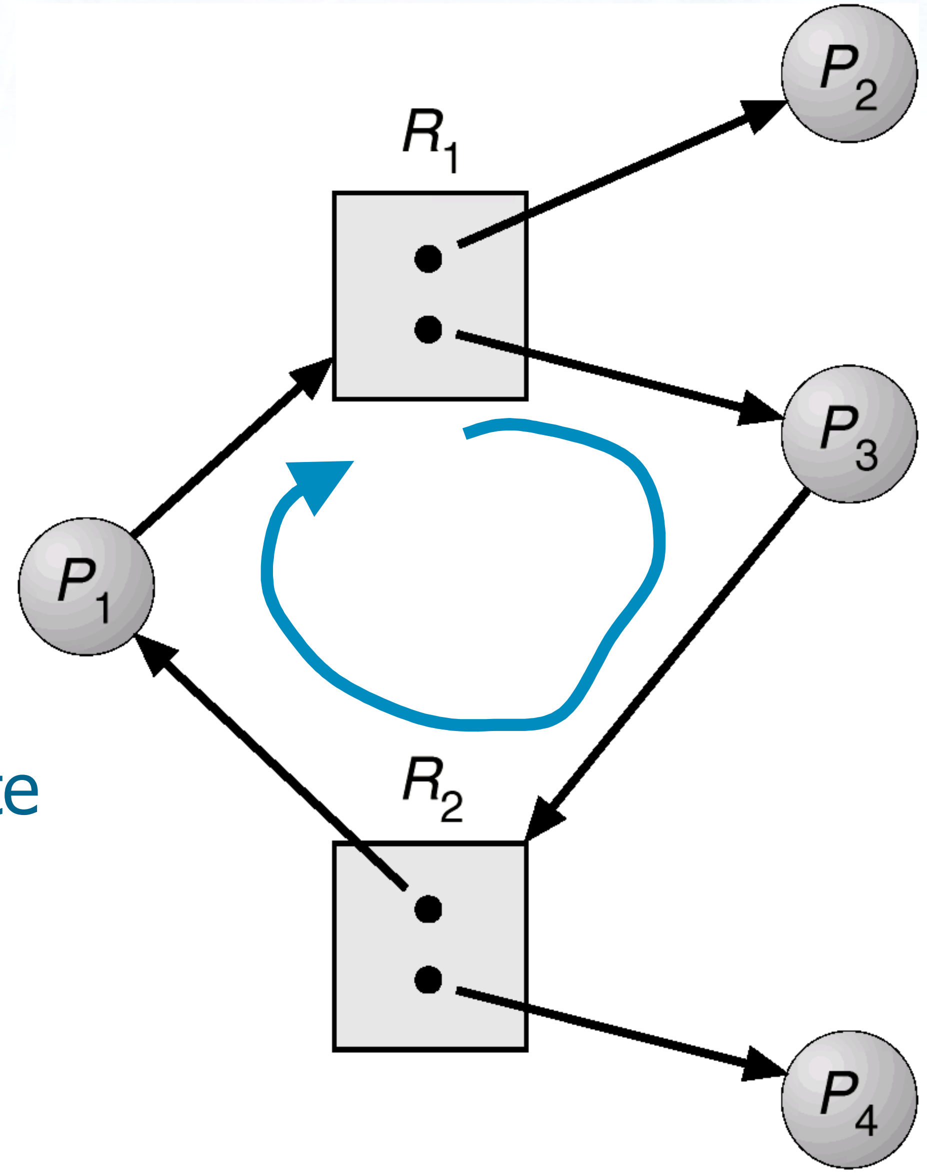
Example

- Processes
  - P_1, P_2, P_3
- Resources
  - R_1 and R_2 with a single instance
- A cycle exists
- Deadlock
  - P_1 waits for P_2
  - P_2 waits for P_1



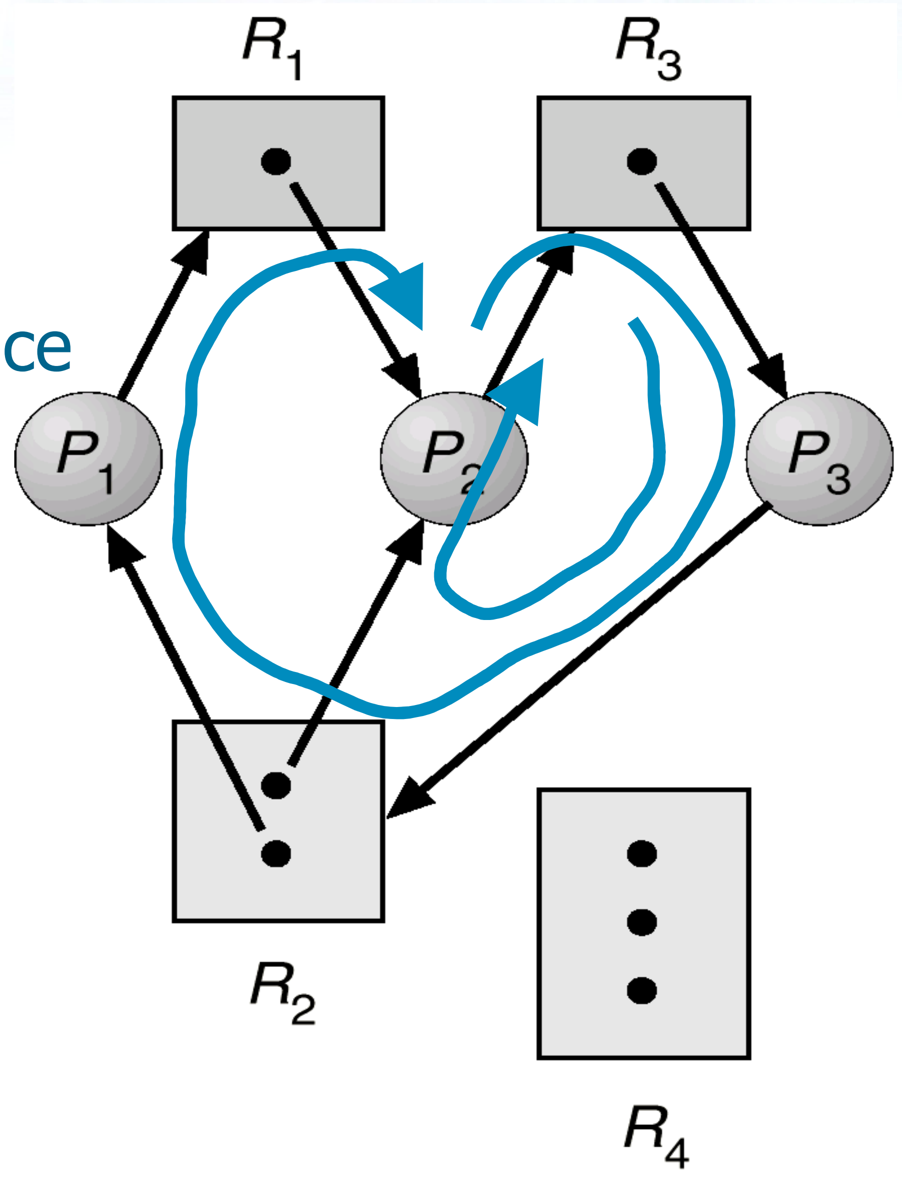
Example

- Processes
  - P_1, P_2, P_3, P_4
- Resources
  - R_1 and R_2 with two instances
- A cycle exists
- No deadlock
  - P_2 and P_4 can terminate
  - P_1 can acquire R_1 and terminate
  - P_3 can acquire R_2 and terminate



Example

- Processes
  - P_1, P_2, P_3
- Resources
  - R_1 and R_3 with an instance
  - R_2 with two instances
  - R_4 with three instances
- Two cycles exist
- Deadlock
  - P_1 waits for R_1
  - P_2 waits for R_3
  - P_3 waits for R_2



Detection: costs

- The detection phase has the high computational cost
  - An algorithm to detect a cycle in a graph is required
    - The presence of cycles can be verified by a visit in depth
    - A graph is acyclic if a visit in depth does not meet arcs labeled "backward" directed to gray vertices
      - If you reach a gray vertex, i.e., you cross a backward arc, you have a cycle
    - The computational cost of this operation is equal to
      - $\Theta(|V|+|E|)$ for representations with adjacency list
      - $\Theta(|V|^2)$ for representations with adjacency matrix

Detection: costs

- When detection is performed?
  - Every time a process makes a request not immediately satisfied
  - At fixed time intervals, e.g., every 30 minutes
  - At variable intervals of time, e.g., when the CPU usage falls below a given threshold

Recovery

- Different strategies are possible for deadlock recovery
  - Act on the vertex of allocation graphs
  - Act on the arches of allocation graph

Recovery

Strategy	Description
Terminate all deadlocked processes	• **Complexity**: **low**, but easy to cause inconsistencies on databases • **Cost**: **much higher than it might be** strictly **necessary**
Terminate a process at a time among the ones in deadlock	• **Complexity**: **high**, since it is necessary to select the victims with objective criteria (priority, current and future execution time, number of held resources, etc.) • **Cost**: **high**, after each termination must re-check the deadlock condition
Preempt the resources of a deadlocked process at a time	• **Complexity**: rollback is necessary to return the selected process to a safe state • **Cost**: the victim process selection must aim at minimizing the preemption cost

Recovery

Strategy	Description
Remove **holding** arcs (i.e., specific resources)	• **Complexity**: rollback is necessary to return the selected process to a safe state. The arc must be properly selected. • **Cost**: the victim process selection must aim at minimizing the preemption cost. • Same as preemption strategy.
Remove **waiting** arcs	• **Complexity**: The arc must be properly selected. • **Cost**: the victim must manage only the failure of a resource request (e.g., a malloc that returns with an error message).

Best strategy

Conclusions

- Detection and recovery operations are
  - logically complex
  - computationally expensive
- In any case, if a process requires many resources, starvation may occur
  - The same process is repeatedly chosen as the victim, incurring repeated rollbacks
    - To avoid starvation the victim selection algorithm should take into account the number of a process rollbacks