



Operating Systems

Deadlocks-Part1

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Slides are based on the slides of the main **textbook**.

Silberschatz

<https://www.os-book.com/OS10/slide-dir/index.html>



Outline

- Liveness
- System Model
- Deadlock Characterization
- Methods for Handling Deadlocks
- Deadlock Prevention
- Deadlock Avoidance

Chapter Objectives

- Illustrate how deadlock can occur when mutex locks are used
- Define the four necessary conditions that characterize deadlock
- Identify a deadlock situation in a resource allocation graph
- Evaluate the four different approaches for preventing deadlocks
- Apply the banker's algorithm for deadlock avoidance

Liveness

- Processes may have to wait ***indefinitely*** while trying to acquire a synchronization tool such as a mutex lock or semaphore.
- Waiting indefinitely ***violates*** the ***progress*** and ***bounded-waiting*** criteria.

Liveness (cont.)

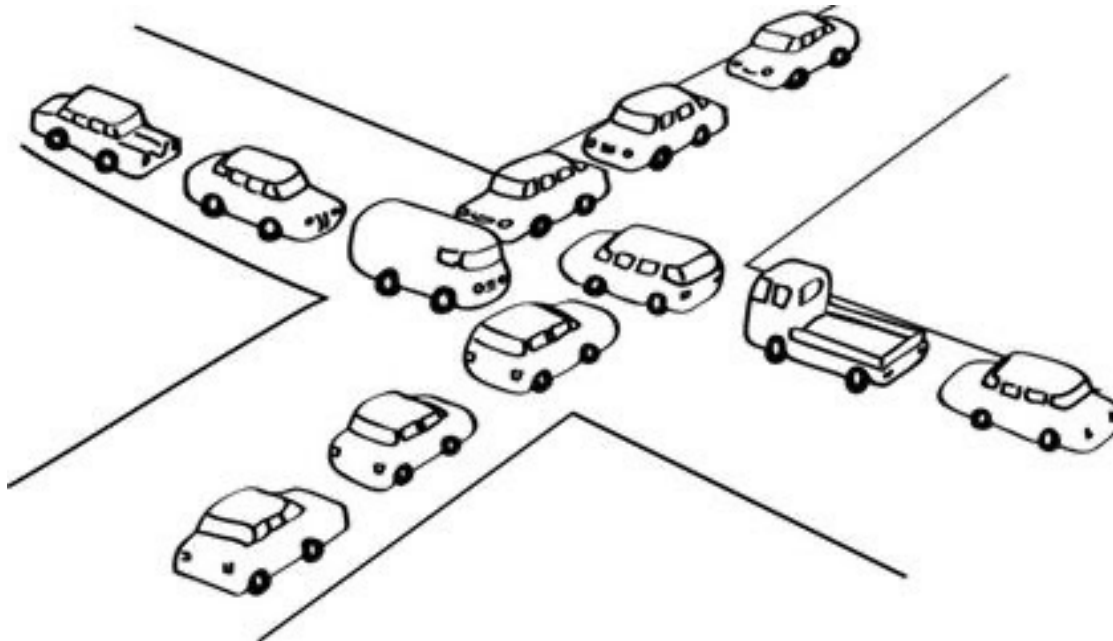
- **Liveness** refers to a set of properties that a system must satisfy to ensure processes make progress.



- ***Indefinite waiting*** is an example of a ***liveness failure***.

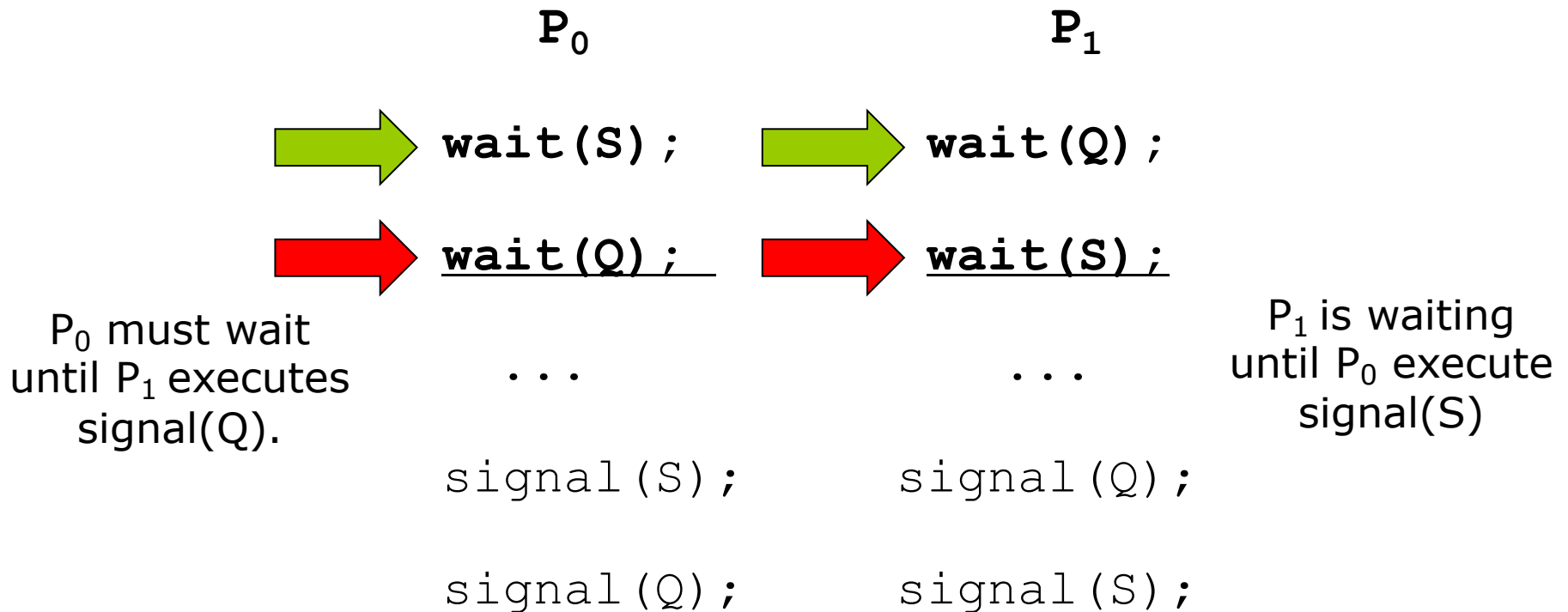
Deadlock

two or more processes are ***waiting indefinitely*** for an event that can be caused ***by only one of the waiting processes***.



Liveness (cont.)

- Let S and Q be two semaphores initialized to 1



Since these `signal()` operations will never be executed, P_0 and P_1 are **deadlocked**.

Other Forms of Deadlock

- **Starvation** – indefinite blocking
 - A process may never be removed from the semaphore queue in which it is suspended.

- **Priority Inversion** – Scheduling problem when lower-priority process holds a lock needed by higher-priority process.
 - We do not cover this.

System Model

- System consists of resources
- Resource types R_1, R_2, \dots, R_m
 - *CPU cycles, memory space, I/O devices*
- Each resource type R_i has W_i instances.
- Each process utilizes a resource as follows:

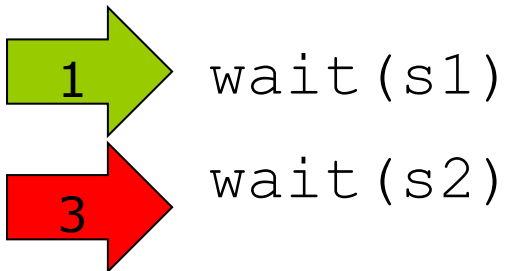
- **request**
- **use**
- **release**



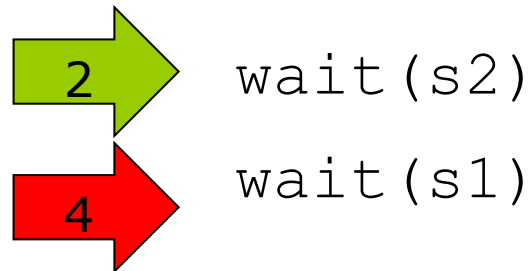
Deadlock with Semaphores

- Data:
 - A semaphore **S1** initialized to 1
 - A semaphore **S2** initialized to 1
- Two processes P1 and P2

■ **P1:**



■ **P2:**



Deadlock Characterization

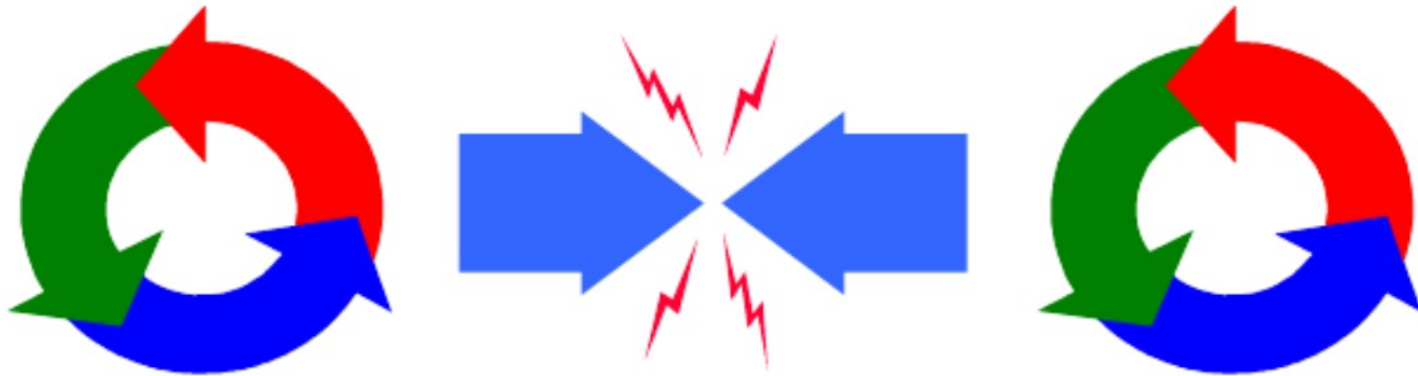
Deadlock can arise if *four conditions hold simultaneously*.

1. Mutual exclusion
2. Hold and wait
3. No preemption
4. Circular wait

“The circular-wait condition implies the hold-and-wait condition, so the four conditions are not completely independent. We shall see in Section 8.5, however, that it is useful to consider each condition separately.” ref: page 321 of source book

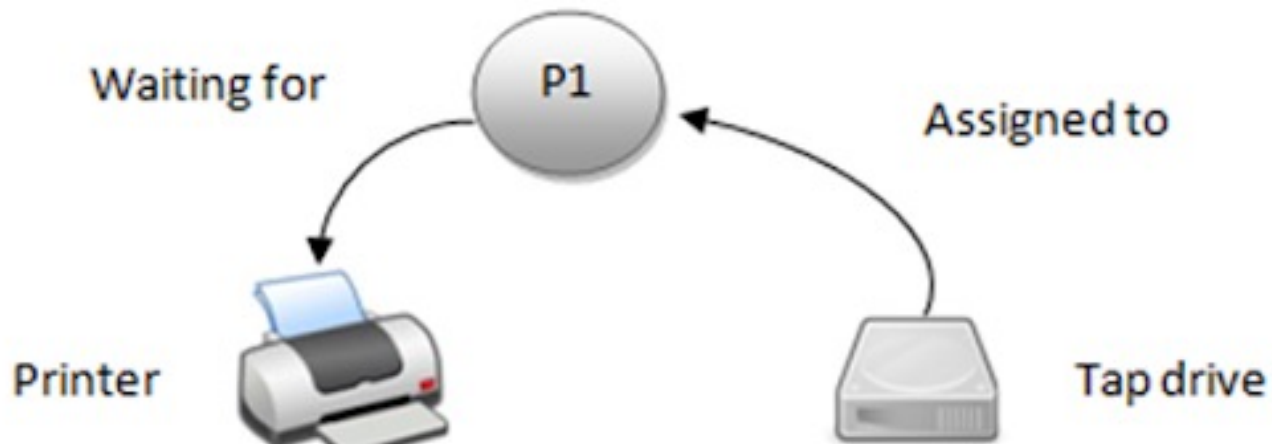
1-Mutual Exclusion

- Only one process at a time can use a resource.



2-Hold and Wait

- A process *holding at least one resource* is *waiting to acquire additional resources* held by other processes.



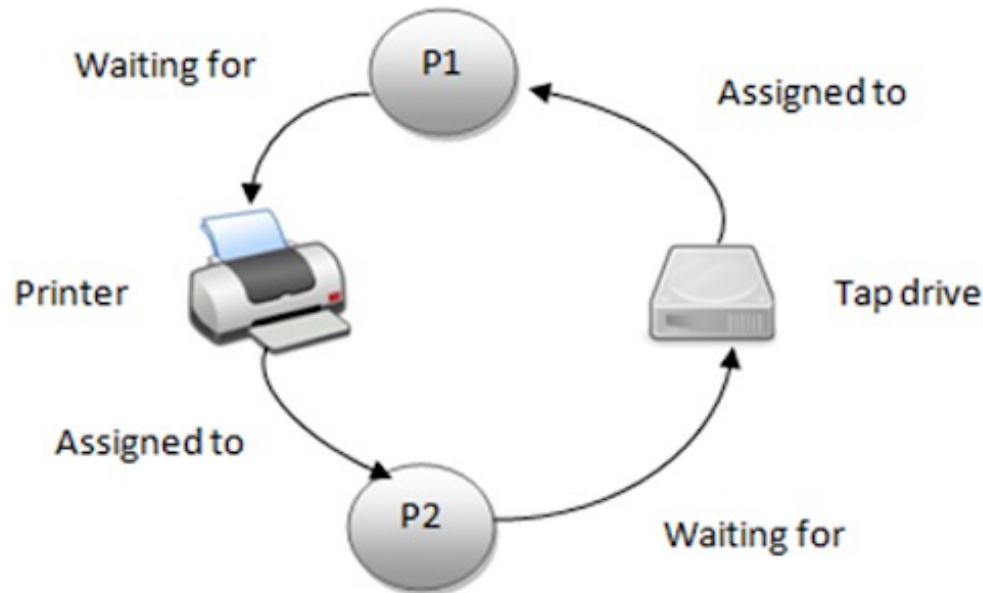
3-No Preemption

- A resource can be released only ***voluntarily*** by the process holding it, after that process has completed its task.



4-Circular Wait

- There exists a set $\{P_0, P_1, \dots, P_n\}$ of waiting processes such that:
 - P_0 is waiting for a resource that is held by P_1 ,
 - P_1 is waiting for a resource that is held by P_2, \dots ,
 - P_{n-1} is waiting for a resource that is held by P_n ,
 - and P_n is waiting for a resource that is held by P_0 .



Resource-Allocation Graph

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

- V is partitioned into two types:
 - $P = \{P_1, P_2, \dots, P_n\}$,
 - ▶ The set consisting of all the ***processes*** in the system.
 - $R = \{R_1, R_2, \dots, R_m\}$,
 - ▶ The set consisting of all ***resource types*** in the system.

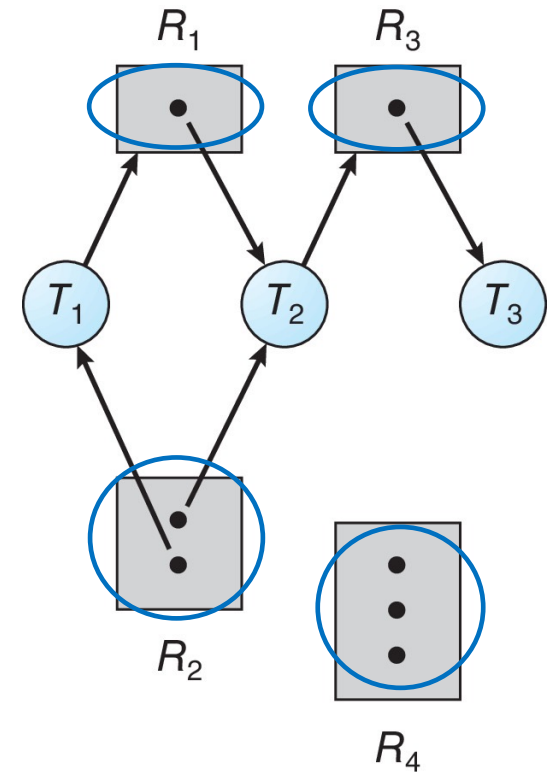
Resource-Allocation Graph

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

- **Request edge** – directed edge $P_i \rightarrow R_j$
- **Assignment edge** – directed edge $R_j \rightarrow P_i$

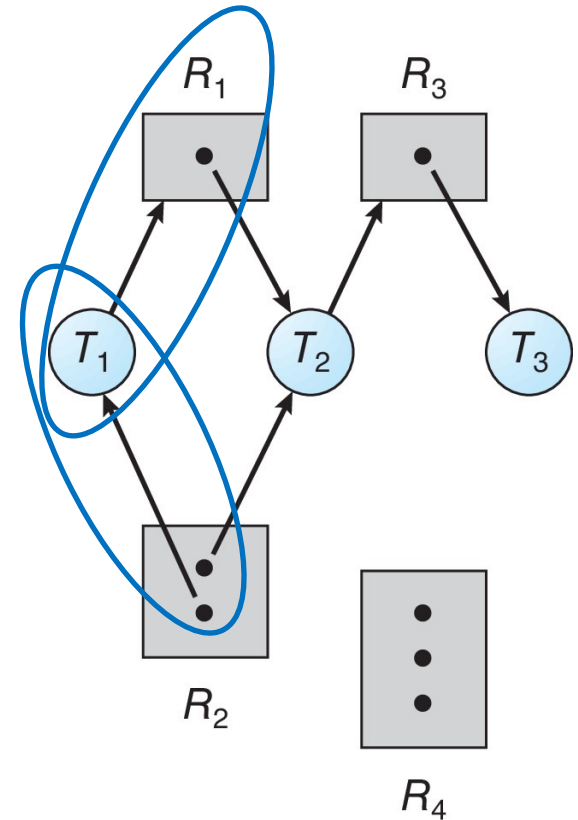
Resource Allocation Graph Example

- One instance of R_1
- Two instances of R_2
- One instance of R_3
- Three instance of R_4

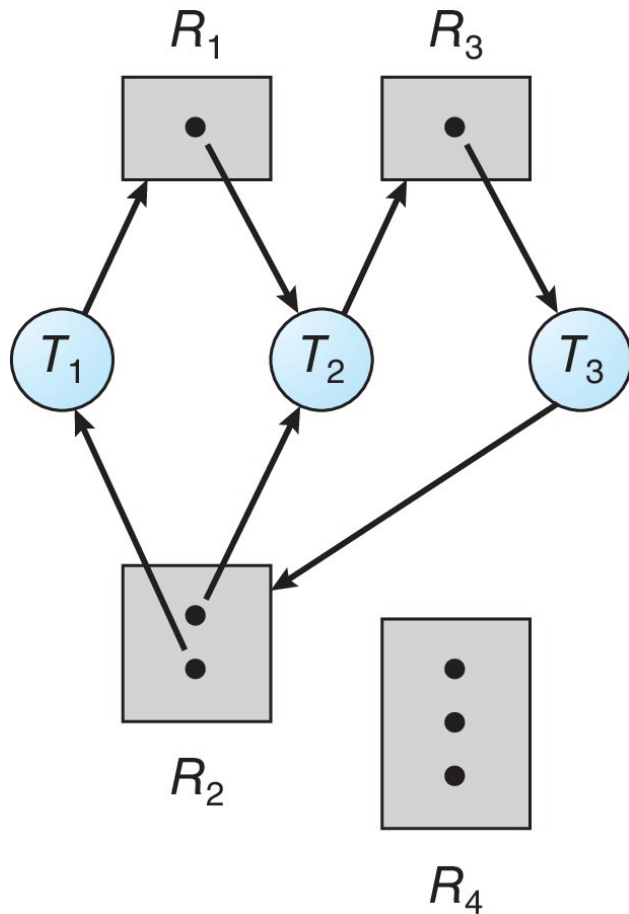


Resource Allocation Graph Example

- T1 holds one instance of R2 and is waiting for an instance of R1
- T2 holds one instance of R1, one instance of R2, and is waiting for an instance of R3.
- T3 holds one instance of R3



Resource Allocation Graph with a Deadlock



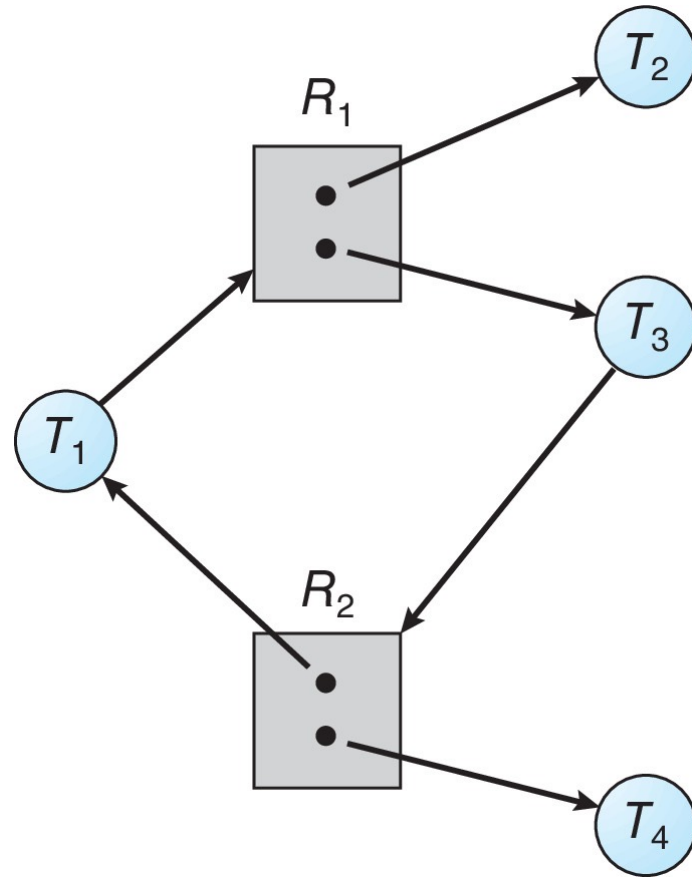
$T_1 \rightarrow R_1 \rightarrow T_2 \rightarrow R_3 \rightarrow T_3 \rightarrow R_2 \rightarrow T_1$

$T_2 \rightarrow R_3 \rightarrow T_3 \rightarrow R_2 \rightarrow T_2$

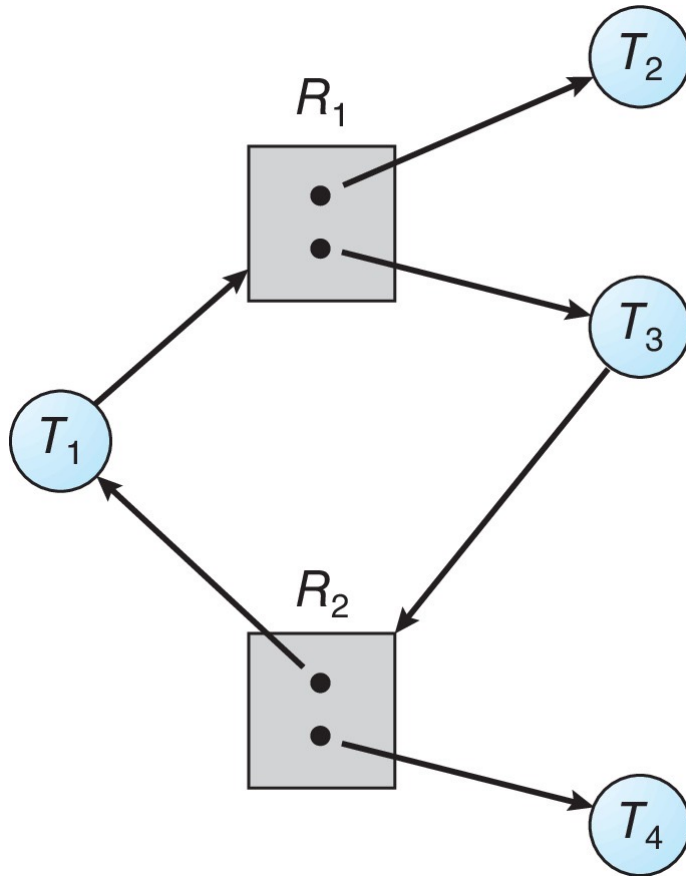
Threads T_1 , T_2 , and T_3 are deadlocked.

- Thread T_2 is waiting for the resource R_3 , which is held by thread T_3 .
- Thread T_3 is waiting for either thread T_1 or thread T_2 to release resource R_2 .
- In addition, thread T_1 is waiting for thread T_2 to release resource R_1 .

Is there a Deadlock?



Graph with a Cycle But no Deadlock

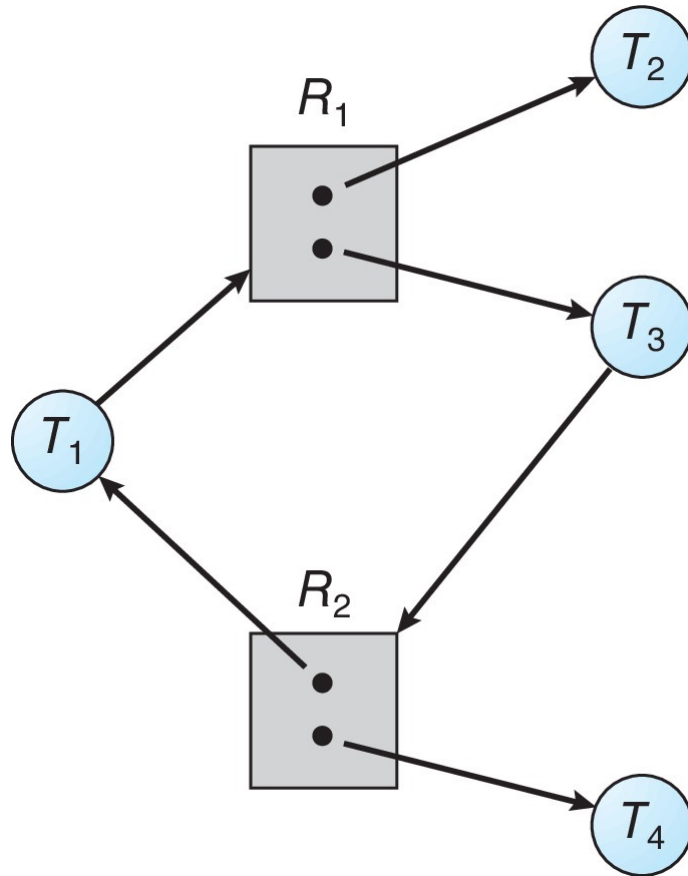


$T_1 \rightarrow R_1 \rightarrow T_3 \rightarrow R_2 \rightarrow T_1$

Which condition is not satisfied?

1. Mutual exclusion
2. Hold and wait
3. No preemption
4. Circular wait

Graph with a Cycle But no Deadlock



$$T_1 \rightarrow R_1 \rightarrow T_3 \rightarrow R_2 \rightarrow T_1$$

There is no deadlock. Observe that thread T_4 **may release** its instance of resource type R_2 . That resource can then be allocated to T_3 , breaking the cycle.

Basic Facts

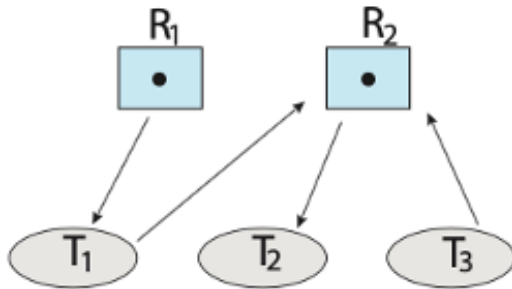
- If graph contains no cycles \Rightarrow no deadlock
- If graph contains a cycle \Rightarrow
 - if only one instance per resource type, **then deadlock**
 - if several instances per resource type, **possibility of deadlock**

if the graph contains **no cycles** \rightarrow **no thread in the system is deadlocked**

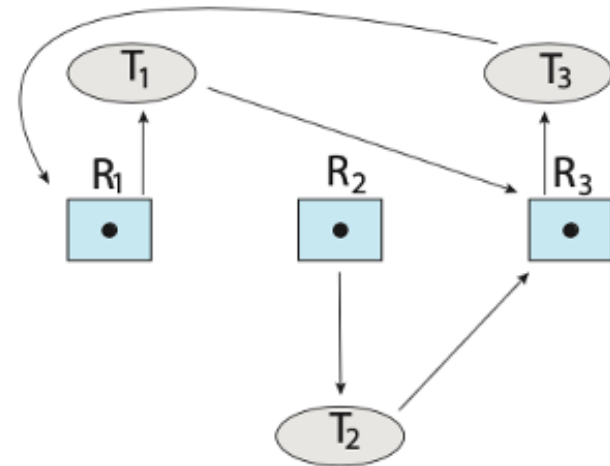
If the graph **does contain a cycle** \rightarrow **a deadlock may or may not exist.**

Example Exam Question

(a)

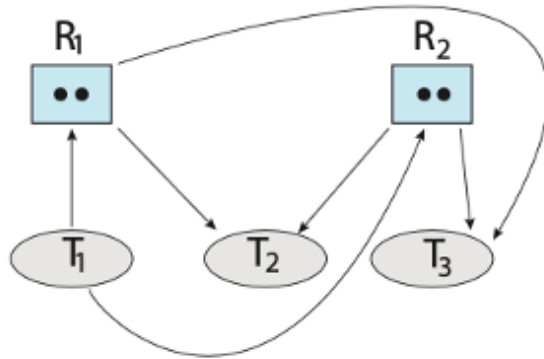


(b)

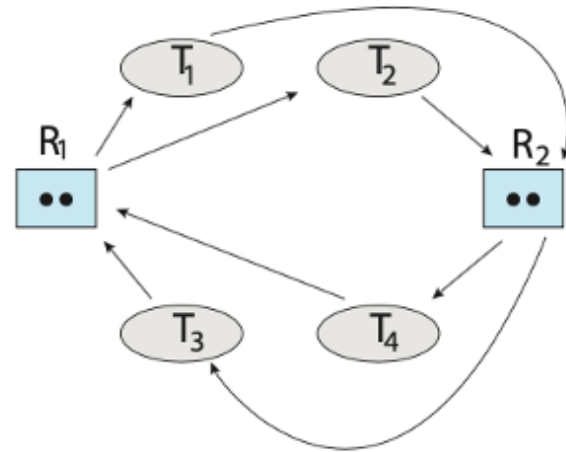


Example Exam Question (cont.)

(c)

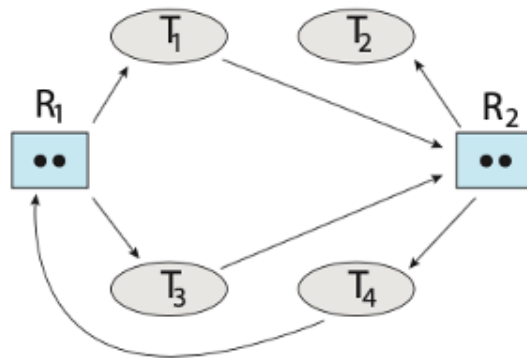


(d)



Example Exam Question

(e)



(f)

