Amirkabir University of Technology
(Tehran Polytechnic)

Operating Systems

Deadlocks-Part1

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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.

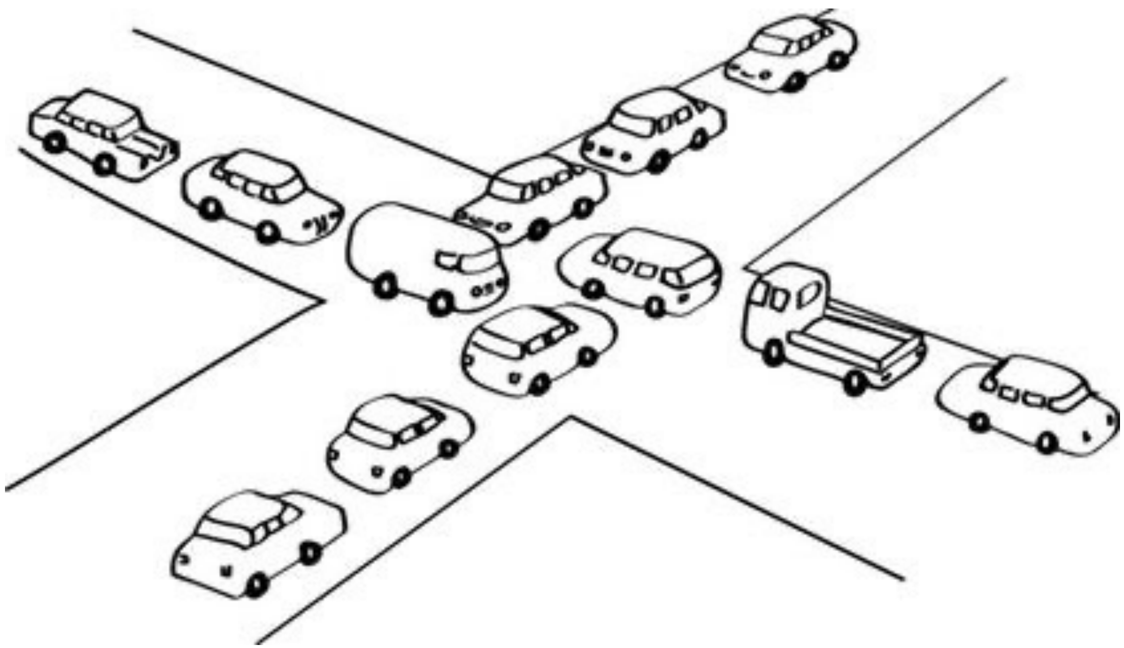
Liveness (cont.)

- **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**

P_0	P_1
`wait(S);`	`wait(Q);`
`wait(Q);`	`wait(S);`
...	...
`signal(S);`	`signal(Q);`
`signal(Q);`	`signal(S);`

P_0 must wait until P_1 executes signal(Q).

P_1 is waiting until P_0 execute signal(S)

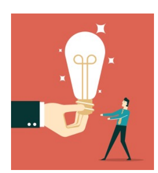
Since these signal() operations will never be executed, P_0 and P_1 are **deadlocked**.

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 $R_1, R_2, \ldots, R_m$
  - *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**:

```
1  wait(s1)
3  wait(s2)
```

  - **P2**:

```
2  wait(s2)
4  wait(s1)
```

Deadlock Characterization

Deadlock can arise if ***four conditions hold simultaneously***.

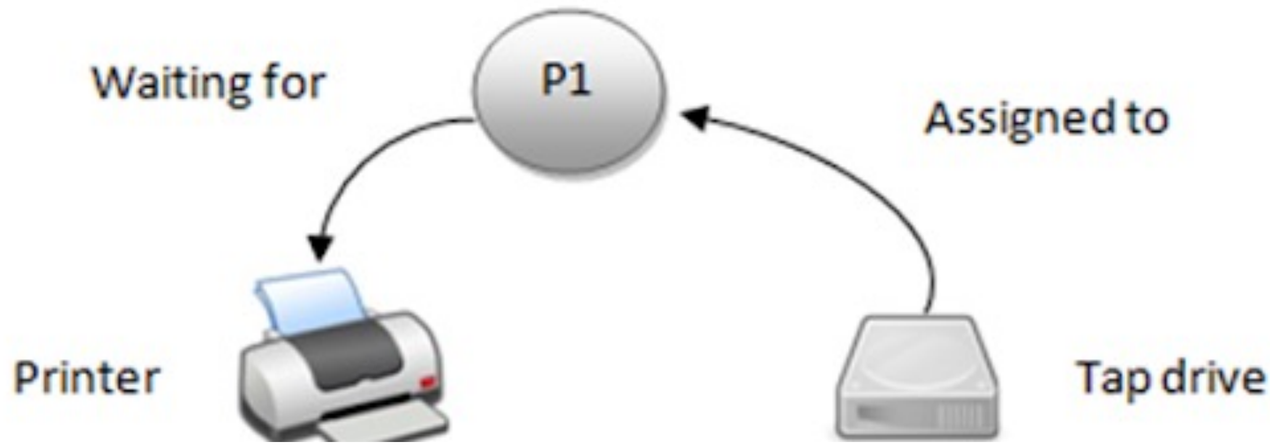
1. **Mutual exclusion**
2. **Hold and wait**
3. **No preemption**
4. **Circular wait**

1-Mutual Exclusion

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

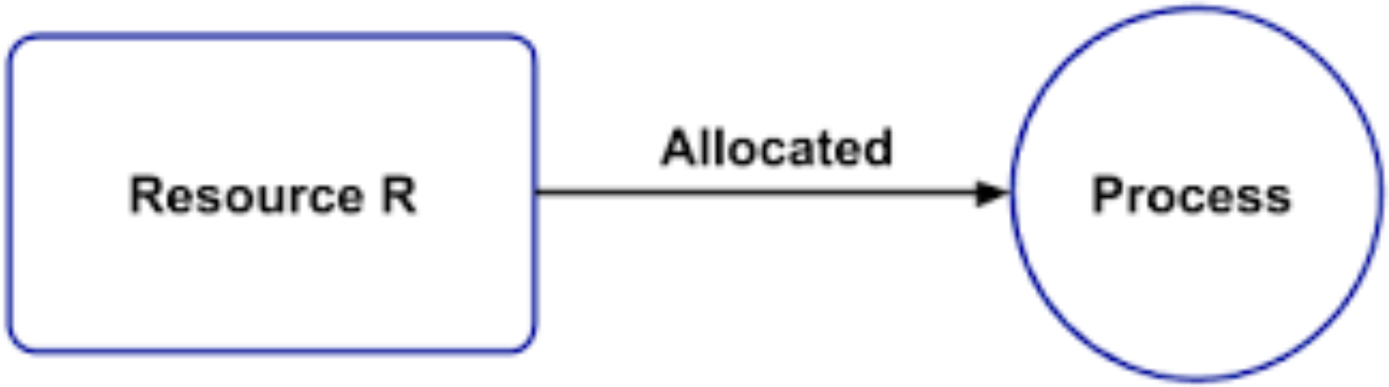
2-Hold and Wait

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



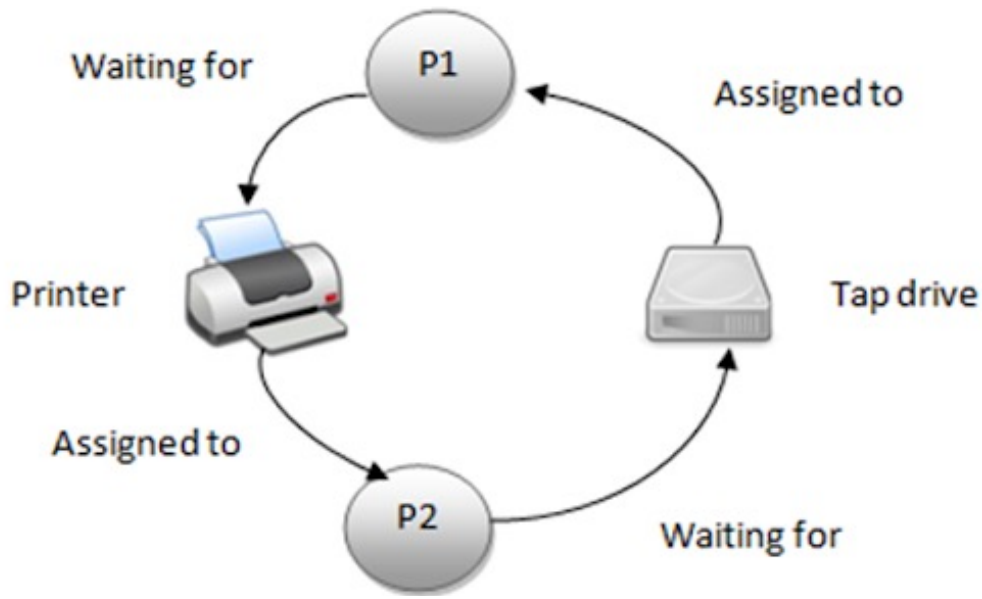
3-No Preemption

- 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 $\{P_0, P_1, \ldots, P_n\}$ 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, …,
  - 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:
  - $P = \{P_1, P_2, \ldots, P_n\}$,
    - The set consisting of all the ***processes*** in the system.
  - $R = \{R_1, R_2, \ldots, R_m\}$,
    - The set consisting of all ***resource types*** in the system.

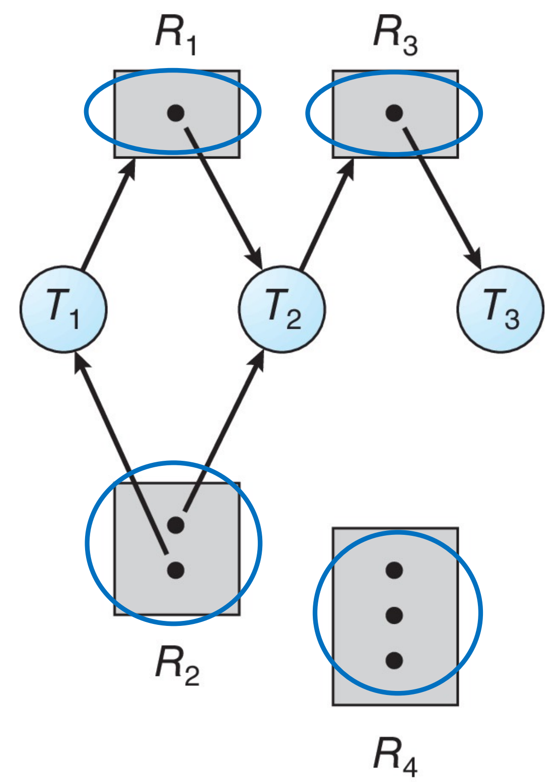
Resource-Allocation Graph

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

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

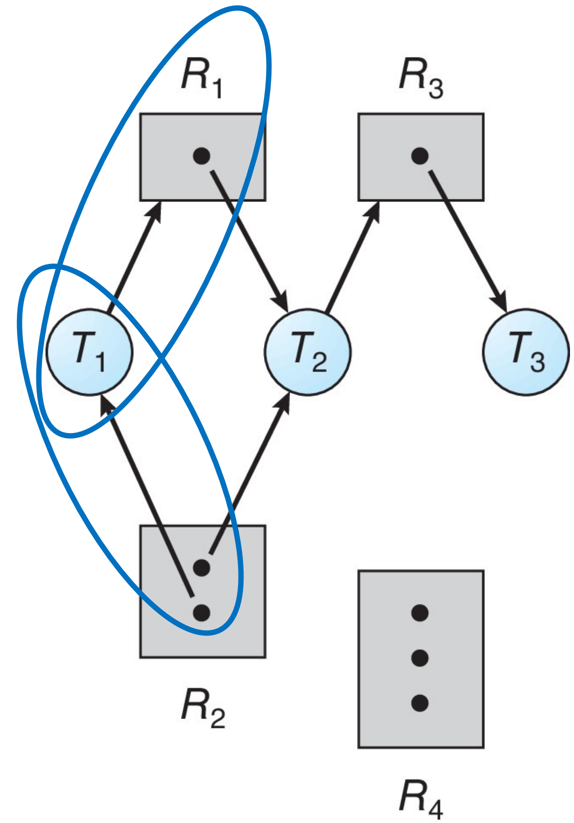
Resource Allocation Graph Example

- One instance of R1
- Two instances of R2
- One instance of R3
- Three instance of R4

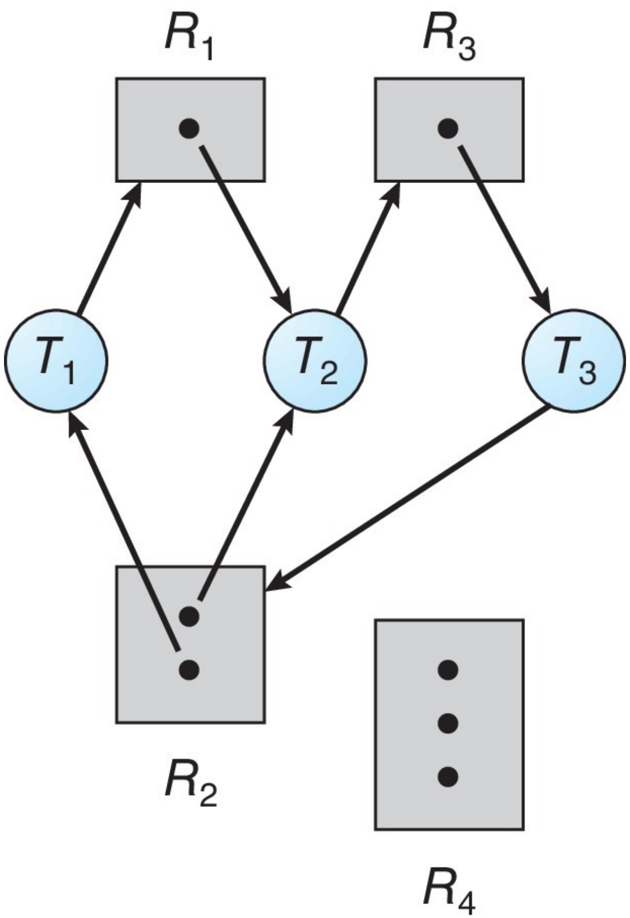


Resource Allocation Graph Example

- 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 is holds one instance of R3



Resource Allocation Graph with a Deadlock



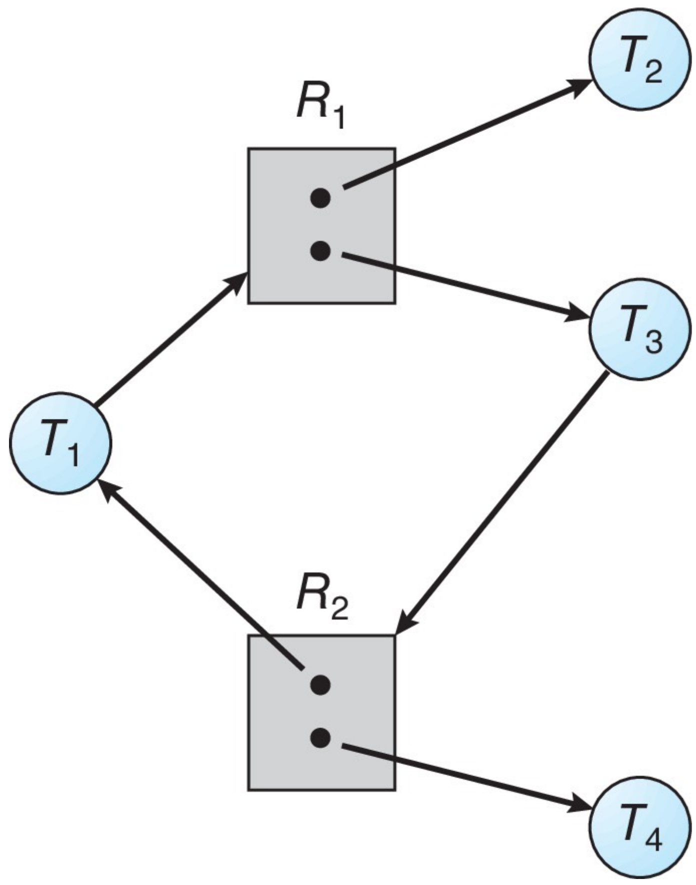
$T_1 \rightarrow R_1 \rightarrow T_2 \rightarrow R_3 \rightarrow T_3 \rightarrow R_2 \rightarrow T_1$

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

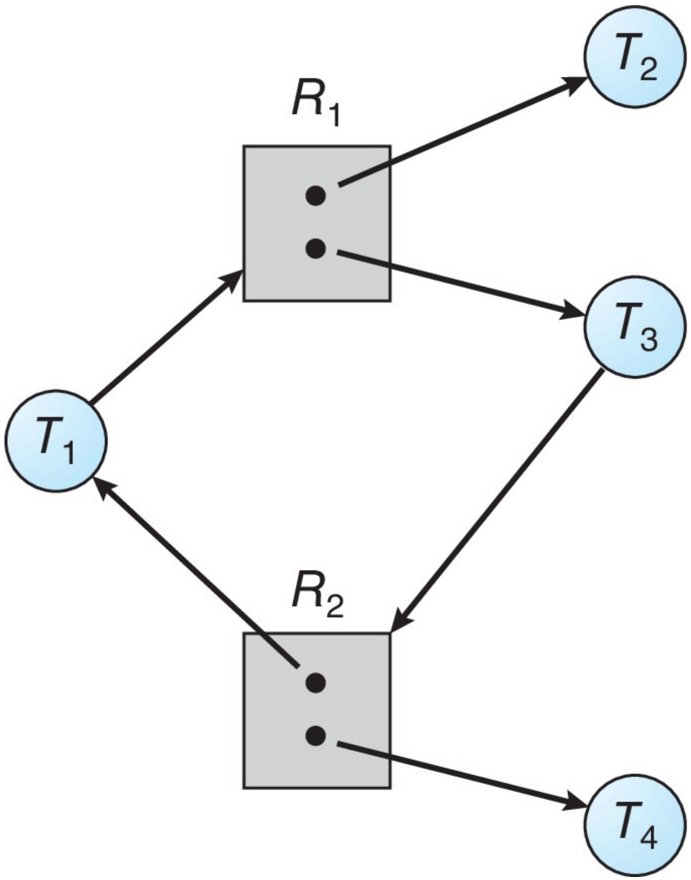
Threads T1, T2, and T3 are deadlocked.

- Thread $\mathbf{T_2}$ is waiting for the resource $\mathbf{R_3}$, which is held by thread $\mathbf{T_3}$.
- Thread $\mathbf{T_3}$ is waiting for either thread $\mathbf{T_1}$ or thread $\mathbf{T_2}$ to release resource $\mathbf{R_2}$.
- In addition, thread T1 is waiting for thread $\mathbf{T_2}$ to release resource $\mathbf{R_1}$.

Is there a Deadlock?



Graph with a Cycle But no Deadlock

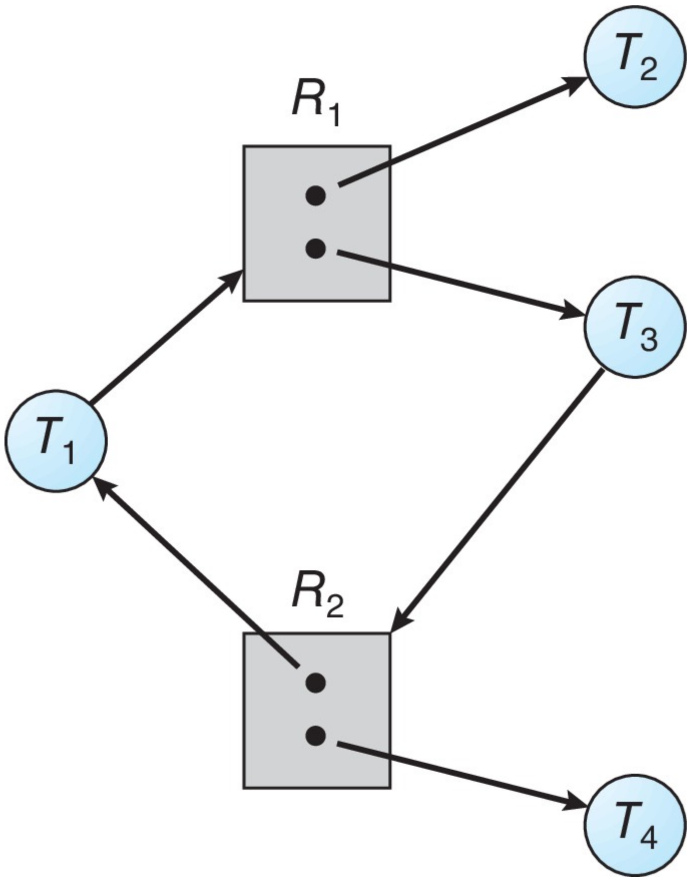


$T_1 \rightarrow R_1 \rightarrow T_3 \rightarrow R_2 \rightarrow T_1$

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 T4 **may release** its instance of resource type R2. That resource can then be allocated to T3, breaking the cycle.

Basic Facts

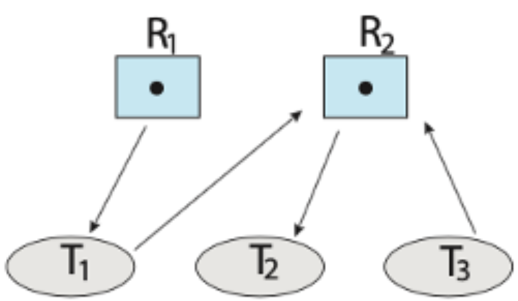
- If graph contains no cycles $\Rightarrow$ no deadlock
- If graph contains a cycle $\Rightarrow$
  - if only one instance per resource type**, then deadlock**
  - if several instances per resource type, **possibility of deadlock**

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

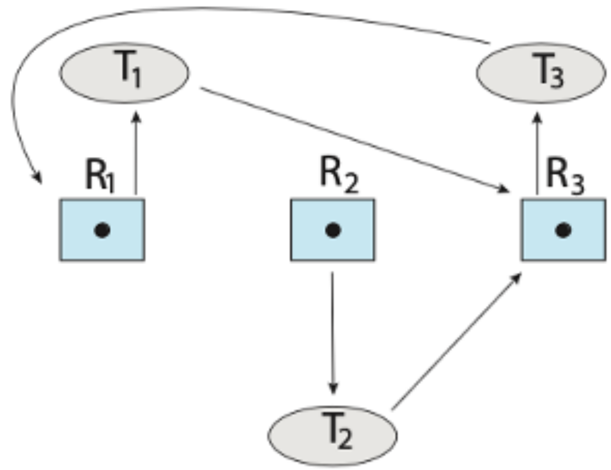
If the graph **does contain a cycle** $\rightarrow$ **a deadlock may or may not exist**.

Example Exam Question

(a)

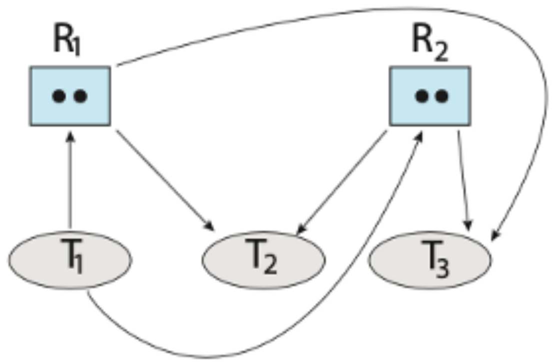


(b)



Example Exam Question (cont.)

(c)



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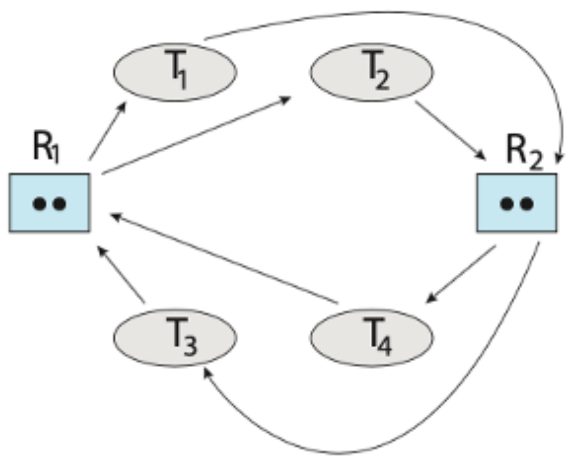
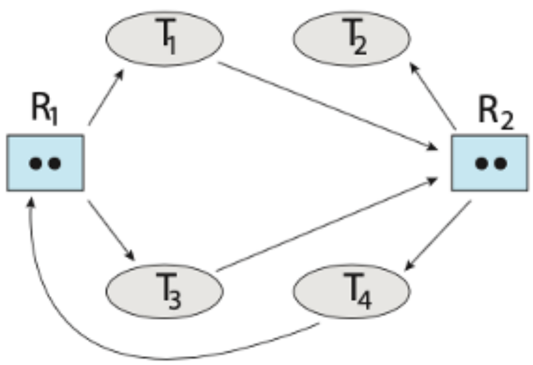


Example Exam Question

(e)



(f)