CISC 7310X
C10a Deadlock and Resource Allocation Graph

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Acknowledgement

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Outline

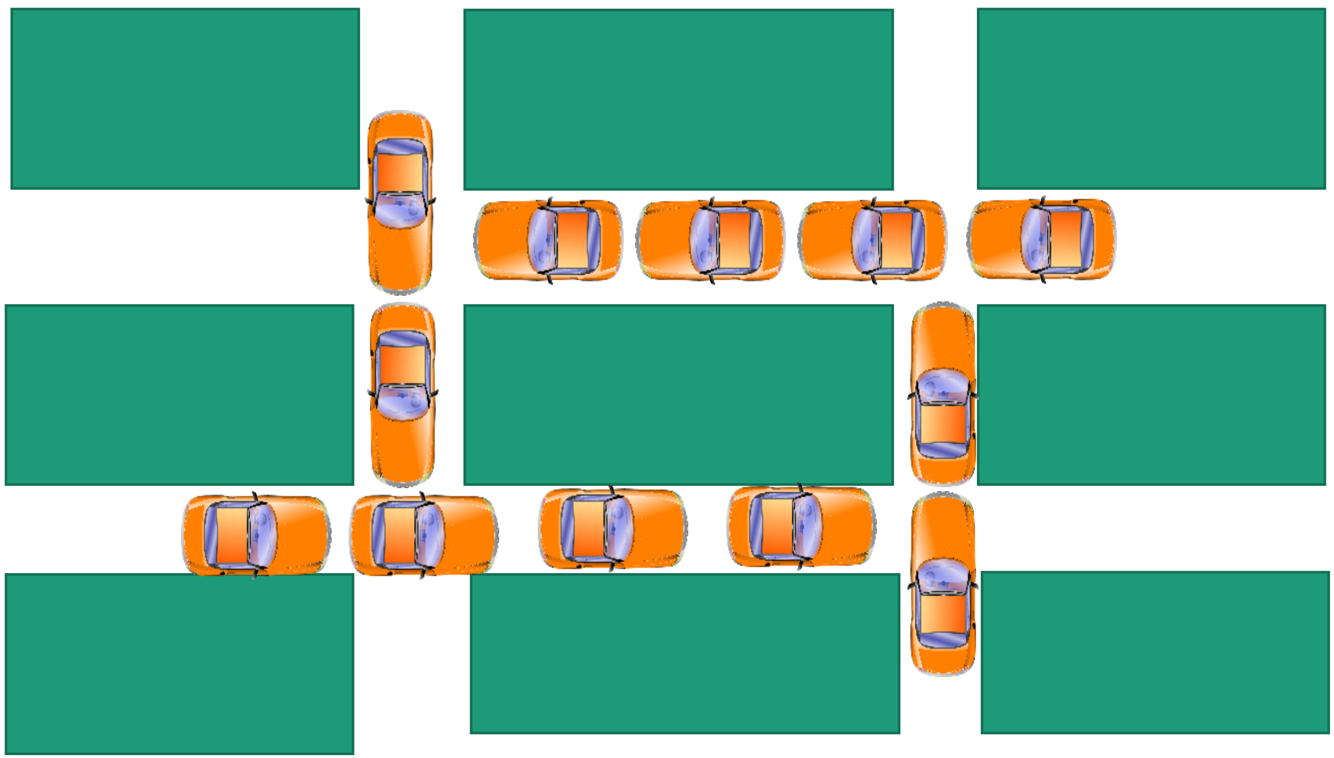
- System Model
- Deadlock Characterization (Necessary Conditions)
- Resource Allocation Graph
- Deadlock in Multithreaded Applications
- Overview of Methods for Handling Deadlocks

- Deadlock Prevention
- Deadlock Avoidance
- Deadlock Detection
- Recovery from Deadlock

Problem when Sharing Resources

- A proposed legislature in the history by Kansas (Botkin and Harlow, 1953)
  - "When two trains approach each other at a crossing, both shall come to a full stop and neither shall start up again until the other has gone."

This can also happen …



System Model

- System consists of resources
- Resource types R1, R2, . . ., Rm
  - Examples
    - CPU cycles, memory space, I/O devices
- Each resource type Ri has Wi instances.
- A set of processes, and each process utilizes a resource as follows:
  - request
  - use
  - release

Deadlock

- Every process in the set is waiting for an event to be triggered by another in the set (request or release resource)

Deadlock Characterization

- Deadlock can arise if four conditions hold simultaneously. (the 4 necessary conditions for deadlocks)
- **Mutual exclusion**: only one process at a time can use a resource
- **Hold and wait**: a process holding at least one resource is waiting to acquire additional resources held by other processes
- **No preemption**: a resource can be released only voluntarily by the process holding it, after that process has completed its task
- **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.

Questions?

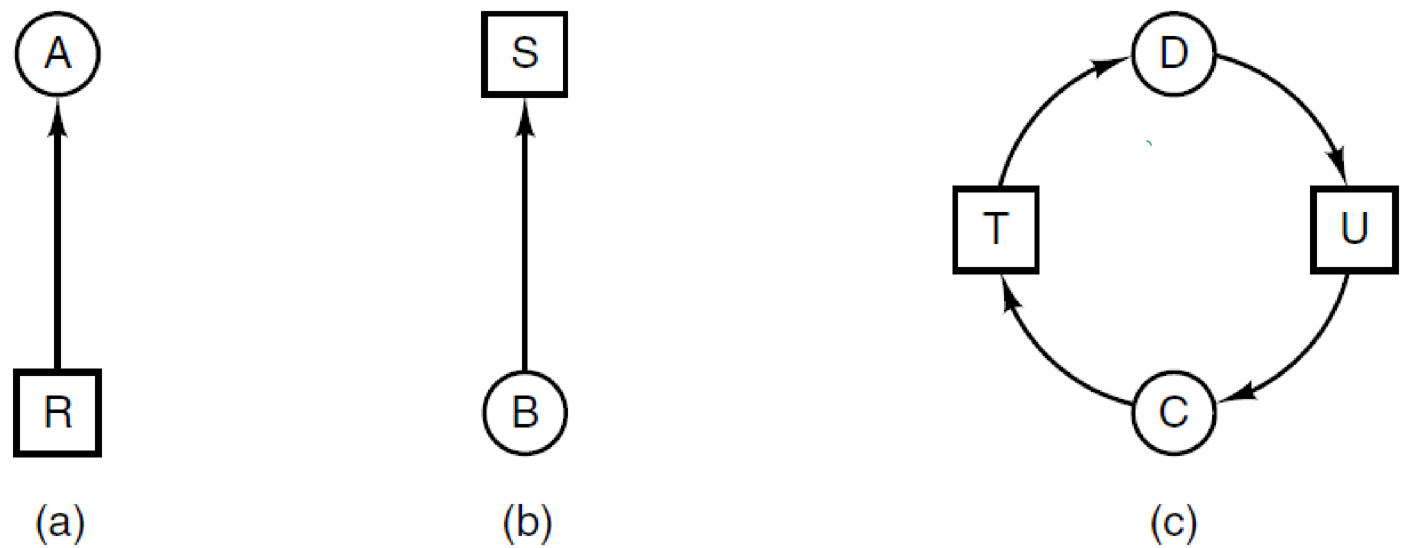
- Concept of deadlock
- Necessary conditions of deadlock

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 (drawn in <u>ovals</u>)
  - $R = \{R_1, R_2, \ldots, R_m\}$, the set consisting of all resource types in the system (drawn in <u>rectangles</u>)
- **request edge** – directed edge $P_i \rightarrow R_j$
  - P_i requests or waits for R_j
- **assignment edge** – directed edge $R_j \rightarrow P_i$
  - *R_j is assigned to or is held by P_i*

Resource-Allocation Graph: Example 1

- Can you describe the graphs in English? (Hint: oval: process; rectangle: resource; arrow: Resource → Process, Process → Resource, i.e., is being held/assigned to or requests by/waiting for)



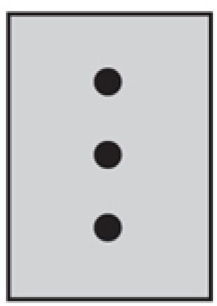
- Resource allocation graphs. (a) Holding a resource. (b) Requesting a resource. (c) Deadlock. [Figure 6-3 in Tanenbaum & Bos, 2014]

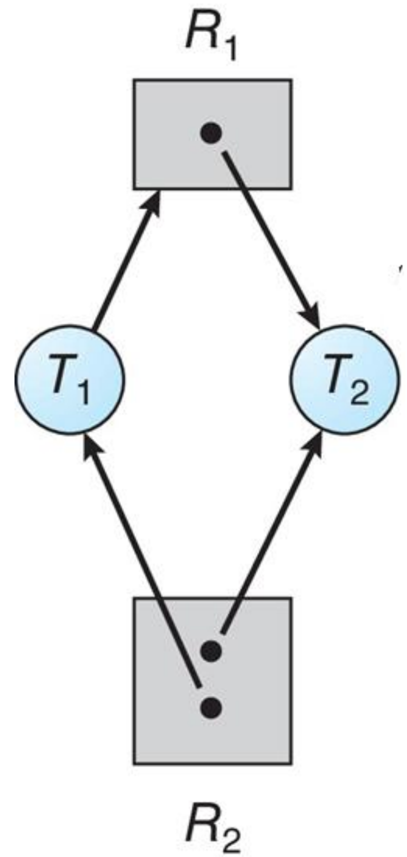
Questions?

- Concept of resource allocation graph
- Examples of simple resource allocation graph
  - Each type of resources has only a single instance
- What if a type of resource has multiple instances?

Resource with Multiple Instances

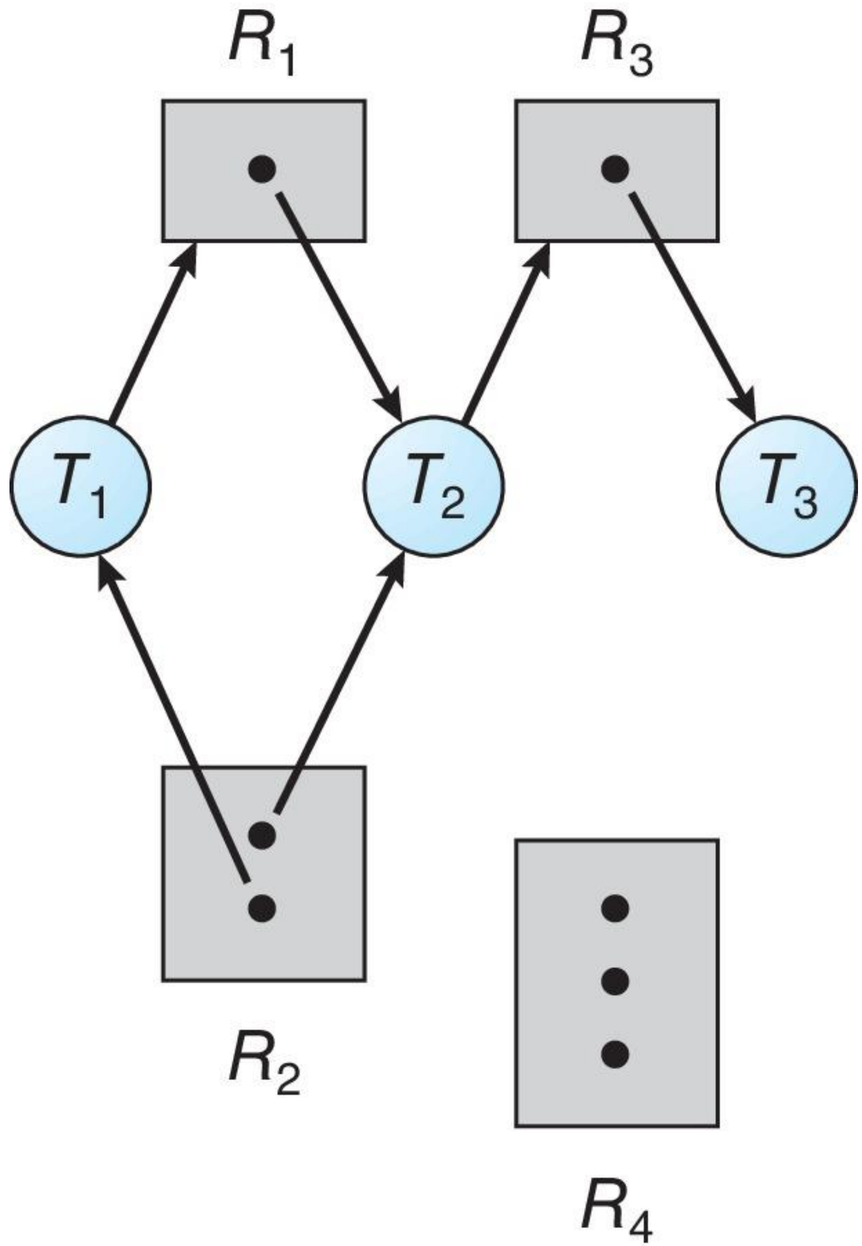
- A type of resource may have multiple instances
- Notations





Resource Allocation Graph: Example 2

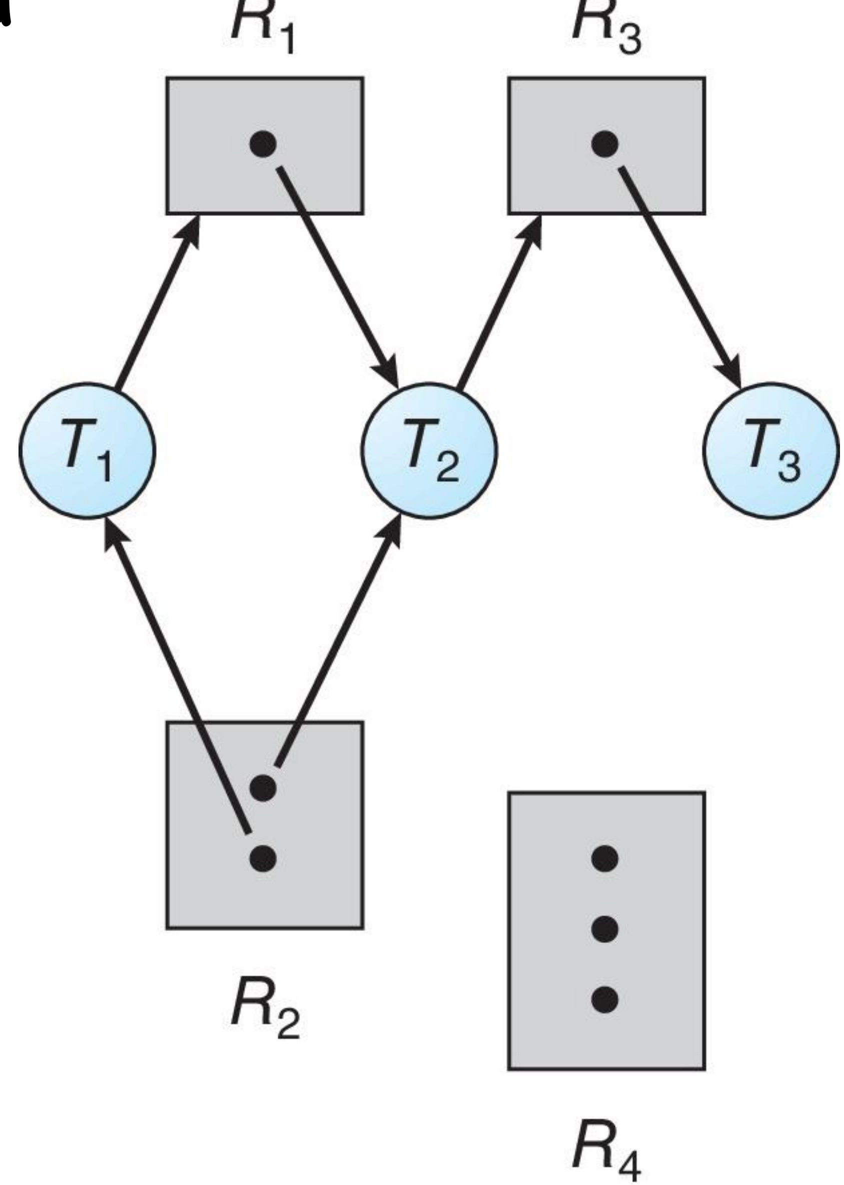
- Can you draw the resource allocation graph for the following scenario?
  - One instance of R1
  - Two instances of R2
  - One instance of R3
  - Three instance of R4
  - T1 holds one instance of R2 and is waiting for an instance of R1
  - T2 holds one instance of R1, one instance of R2, and is waiting for an instance of R3
  - T3 is holds one instance of R3



R1
R3
T1
T2
T3
R2
R4

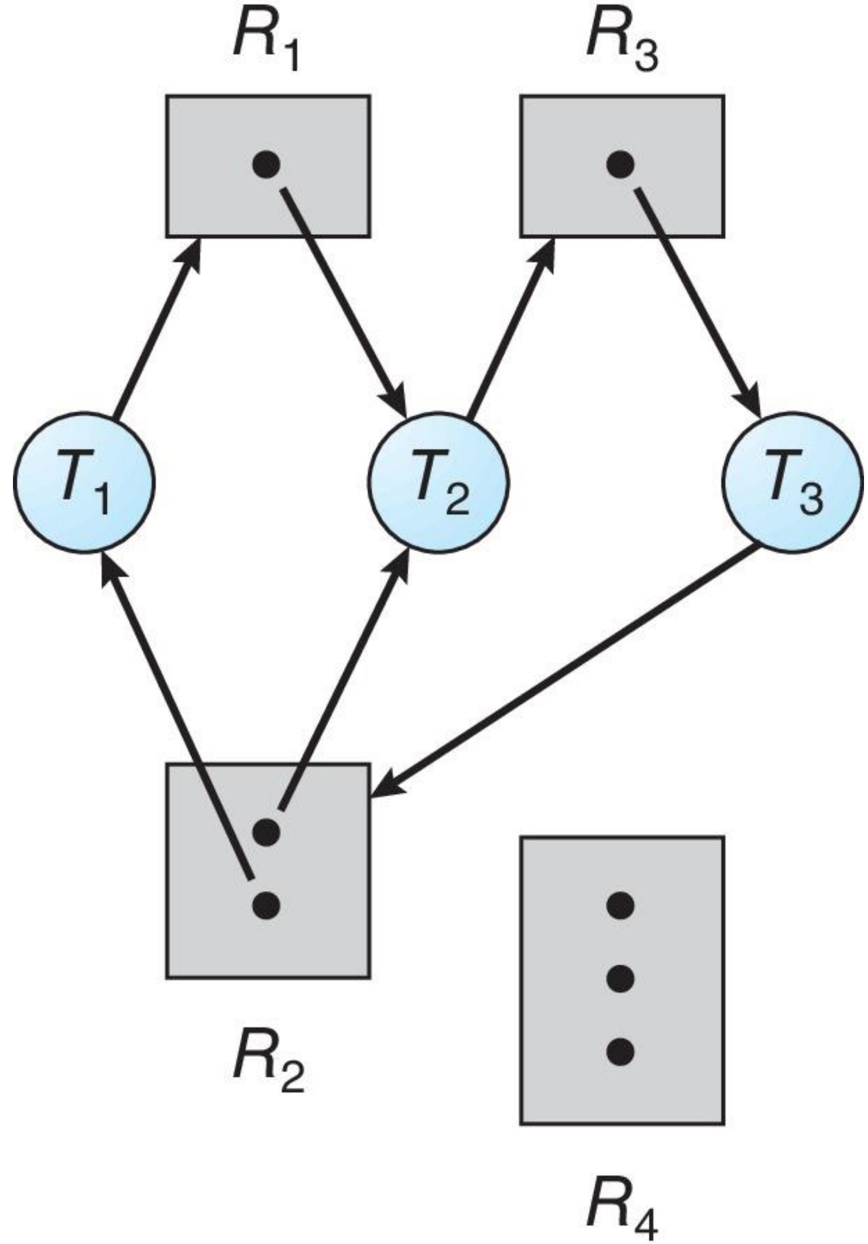
Is There a Dead Lock?

- Mutual exclusion?
- Hold and wait?
- No preemption?
- Circular wait?



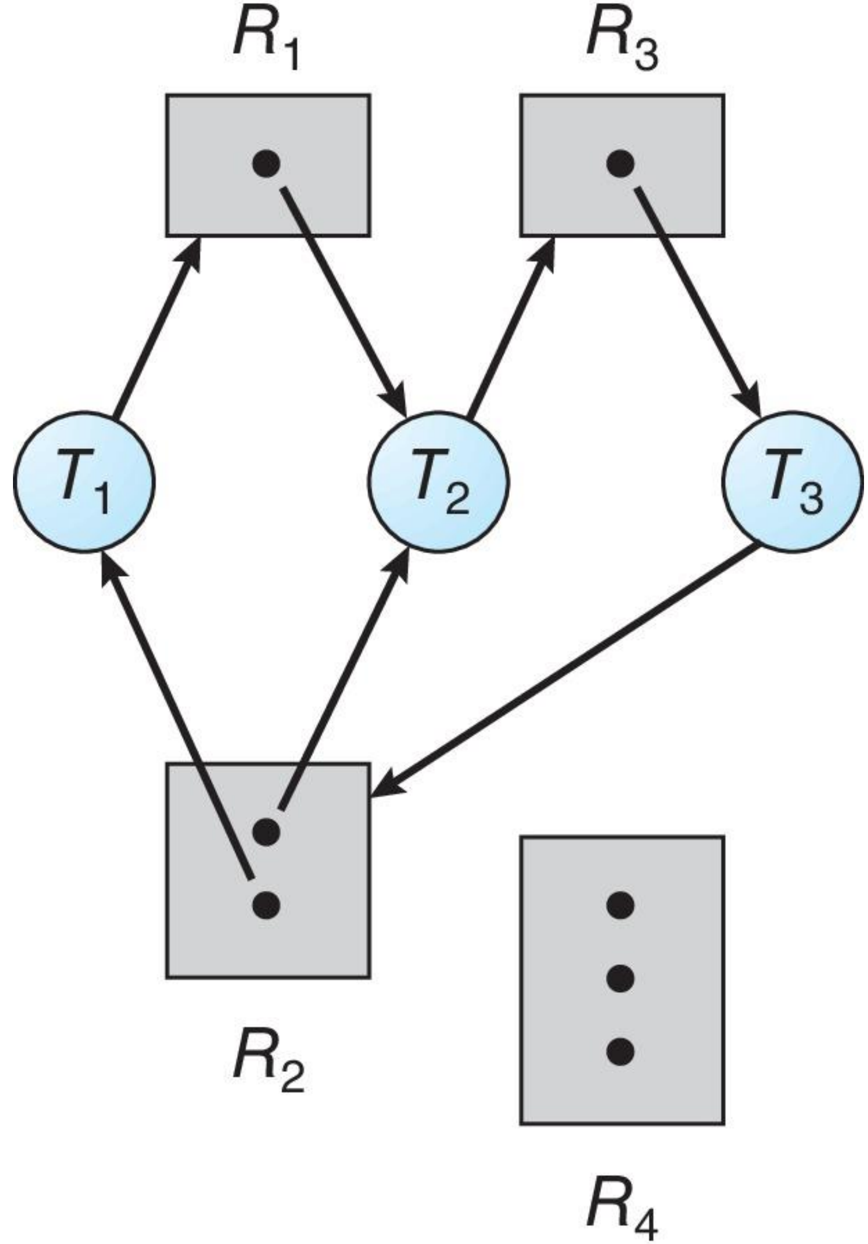
Resource Allocation Graph: Example 3

- Can you draw the resource allocation graph for the following scenario?
  - One instance of R1
  - Two instances of R2
  - One instance of R3
  - Three instance of R4
  - 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, and is waiting for an instance of R2*


R1
R3
T1
T2
T3
R2
R4

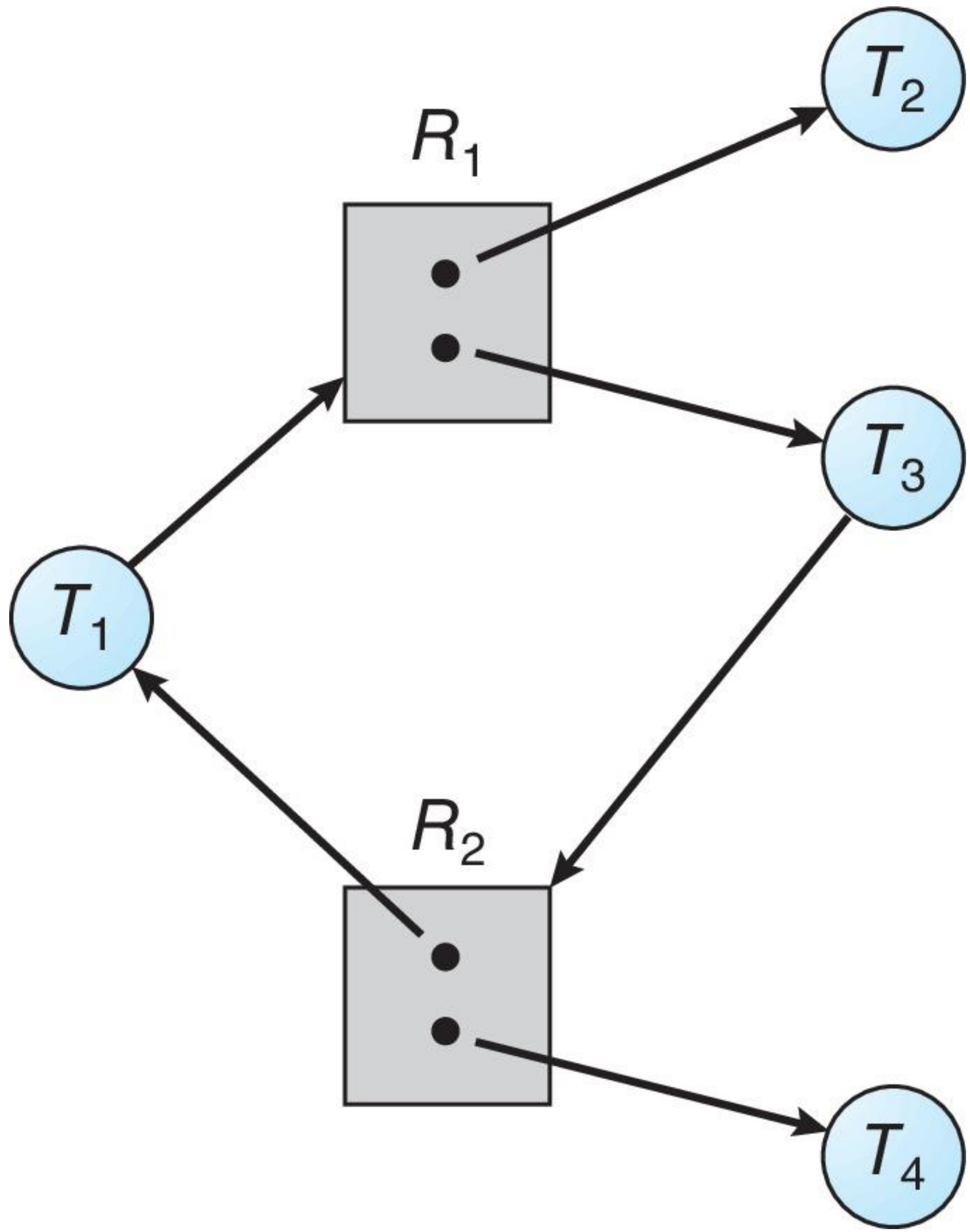
Is There a Dead Lock?

- Mutual exclusion?
- Hold and wait?
- No preemption?
- Circular wait?



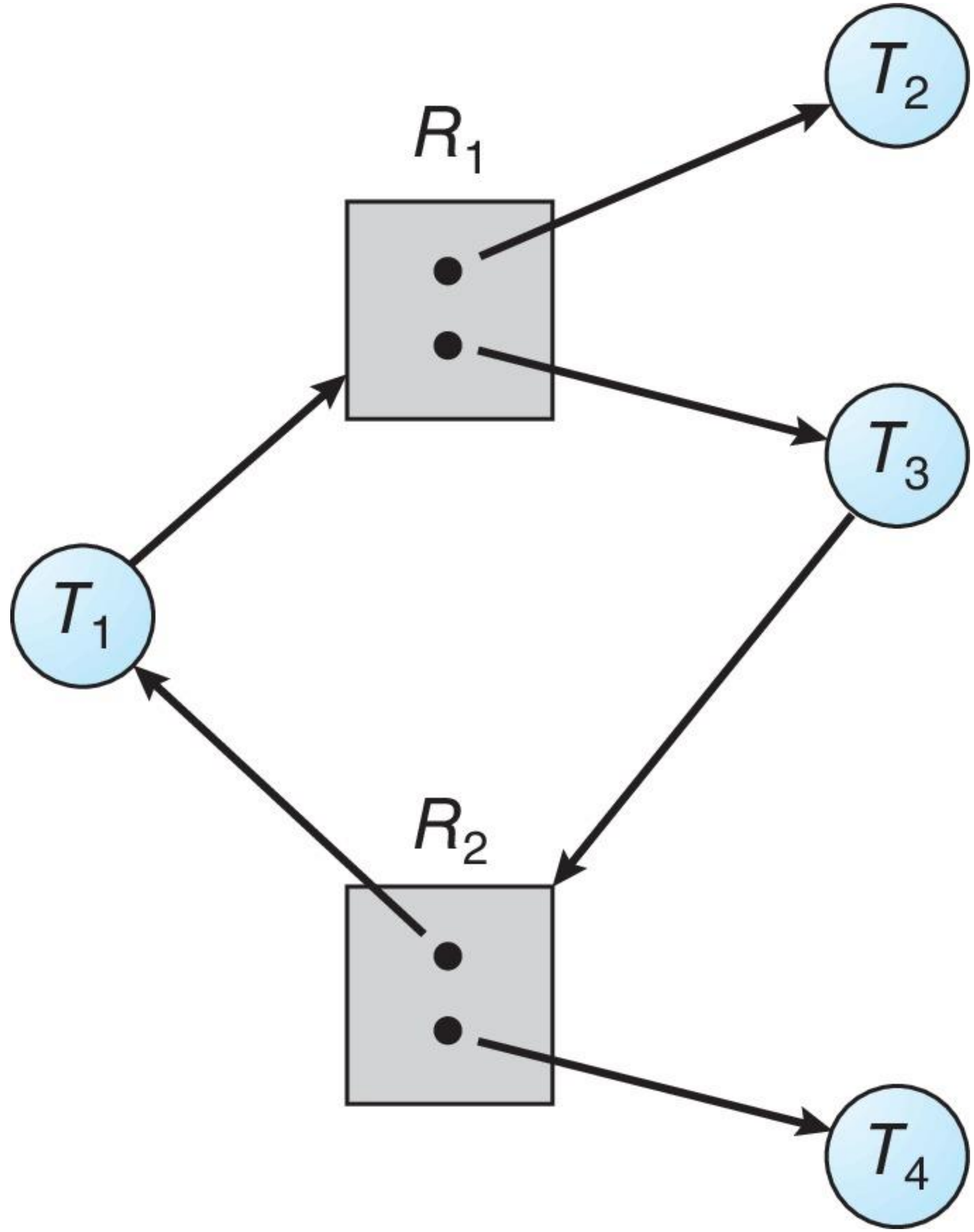
Resource Allocation Graph: Example 4

- Can you draw the resource allocation graph for the following scenario?
  - Two instances of R1
  - Two instances of R2
  - T1 holds one instance of R2 and is waiting for an instance of R1
  - T2 holds one instance of R1
  - T3 holds one instance of R1 and is waiting for an instance of R2
  - T4 is waiting for an instance of R2


R1
T2
T3
T1
R2
T4

Is There a Dead Lock?

- Mutual exclusion?
- Hold and wait?
- No preemption?
- Circular wait?



Determine Existence of Deadlocks

- 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

Resource Allocation Graph: Example 5

- What's the resource allocation graph?
  - 2 processes, P1 and P2 share two 2 CD-RW drives (D1, D2)
  - P1 is using D1, P2 is using D2
  - P1 requests D2 before releasing D1; P2 requests D1 before releasing D2
- Is there a deadlock?

Questions?

- Resource allocation graph
- Determine existence of deadlock using resource allocation graph

Resource-Allocation Graph and Scheduling: Example

- Three processes: A, B, C
- Three resources: R, S, T
- Each process requests and release schedule in the sequence below:

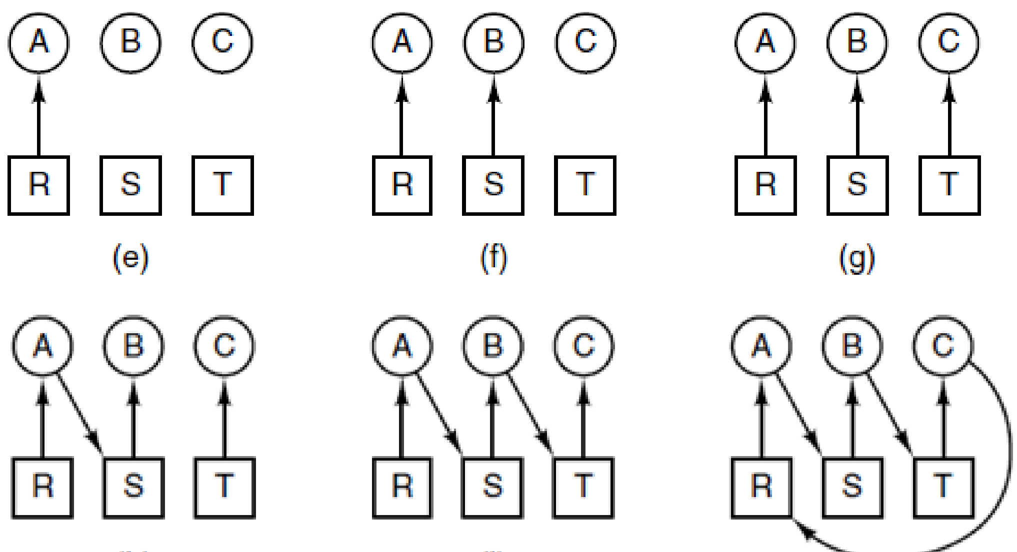
A	B	C
Request R	Request S	Request T
Request S	Request T	Request R
Release R	Release S	Release T
Release S	Release T	Release R
(a)	(b)	(c)

Schedule with Deadlock

A	B	C
Request R	Request S	Request T
Request S	Request T	Request R
Release R	Release S	Release T
Release S	Release T	Release R
(a)	(b)	(c)

1. A requests R
2. B requests S
3. C requests T
4. A requests S
5. B requests T
6. C requests R
   deadlock

(d)



(e) (f) (g) (h) (i) (j)

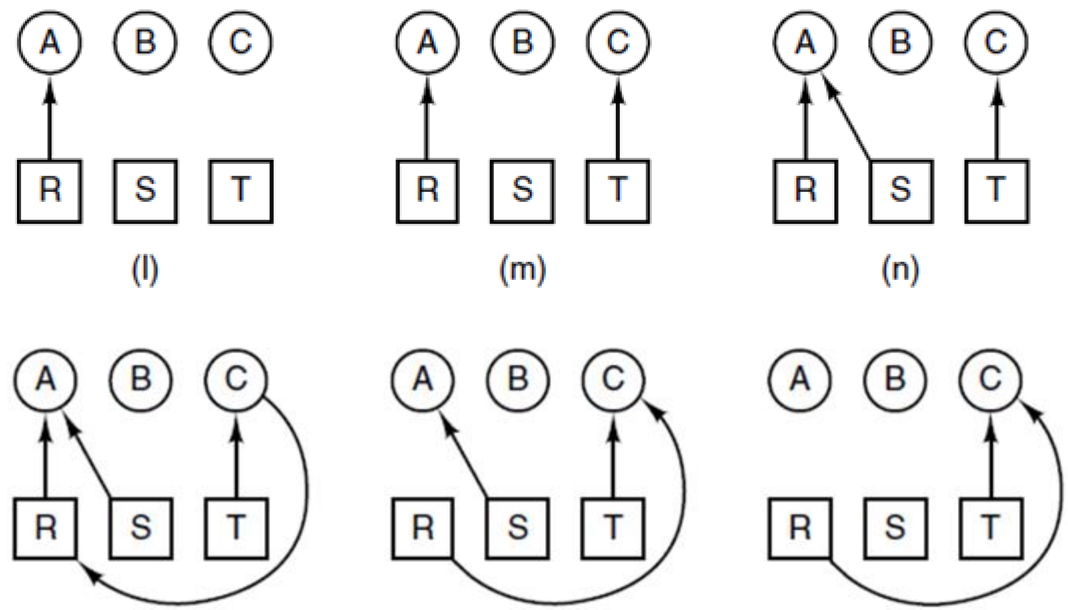
Schedule without Deadlock

A	B	C
Request R	Request S	Request T
Request S	Request T	Request R
Release R	Release S	Release T
Release S	Release T	Release R
(a)	(b)	(c)

1. A requests R
2. C requests T
3. A requests S
4. C requests R
5. A releases R
6. A releases S

no deadlock

(k)



(l) (m) (n) (o) (p) (q)

Semaphores or Mutexes are Resources

- Access non-preemptive resource with semaphore (request, use, release)
    - down/signal/P; up/wait/V

```
typedef int semaphore;
semaphore resource_1;


void process_A(void) {
        down(&resource_1);
        use_resource_1( );
        up(&resource_1);
}
```

(a)

```
typedef int semaphore;
semaphore resource_1;
semaphore resource_2;

void process_A(void) {
        down(&resource_1);
        down(&resource_2);
        use_both_resources( );
        up(&resource_2);
        up(&resource_1);
}
```

(b)

- [Figure 6-1 in Tanenbaum & Bos, 2014]

Deadlock in Multithreaded Application

- Two mutex locks are created an initialized:

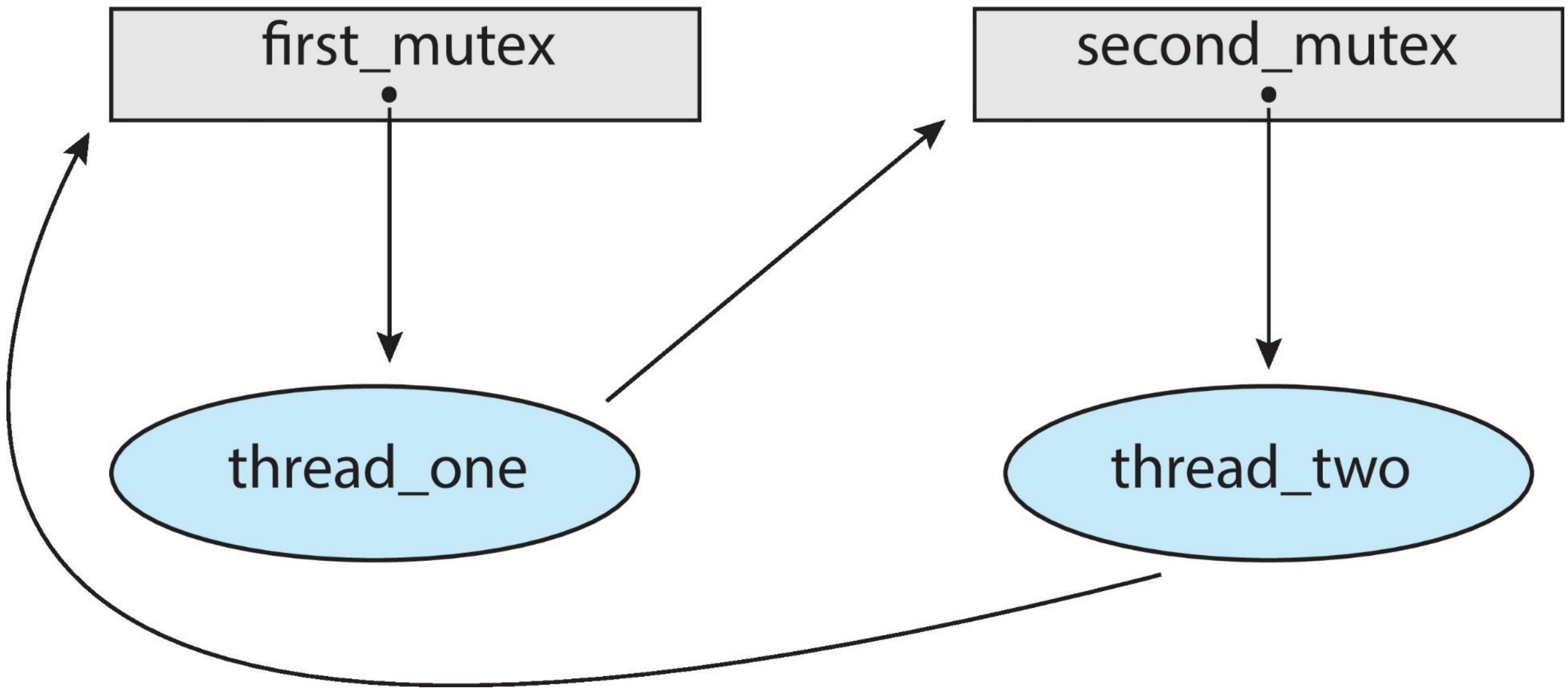
```
pthread_mutex_t first_mutex;
pthread_mutex_t second_mutex;

pthread_mutex_init(&first_mutex,NULL);
pthread_mutex_init(&second_mutex,NULL);
```

```
/* thread_one runs in this function */
void *do_work_one(void *param)
{
   pthread_mutex_lock(&first_mutex);
   pthread_mutex_lock(&second_mutex);
   /**
    * Do some work
    */
   pthread_mutex_unlock(&second_mutex);
   pthread_mutex_unlock(&first_mutex);

   pthread_exit(0);
}

/* thread_two runs in this function */
void *do_work_two(void *param)
{
   pthread_mutex_lock(&second_mutex);
   pthread_mutex_lock(&first_mutex);
   /**
    * Do some work
    */
   pthread_mutex_unlock(&first_mutex);
   pthread_mutex_unlock(&second_mutex);

   pthread_exit(0);
}
```

Is Deadlock Possible in the Example?

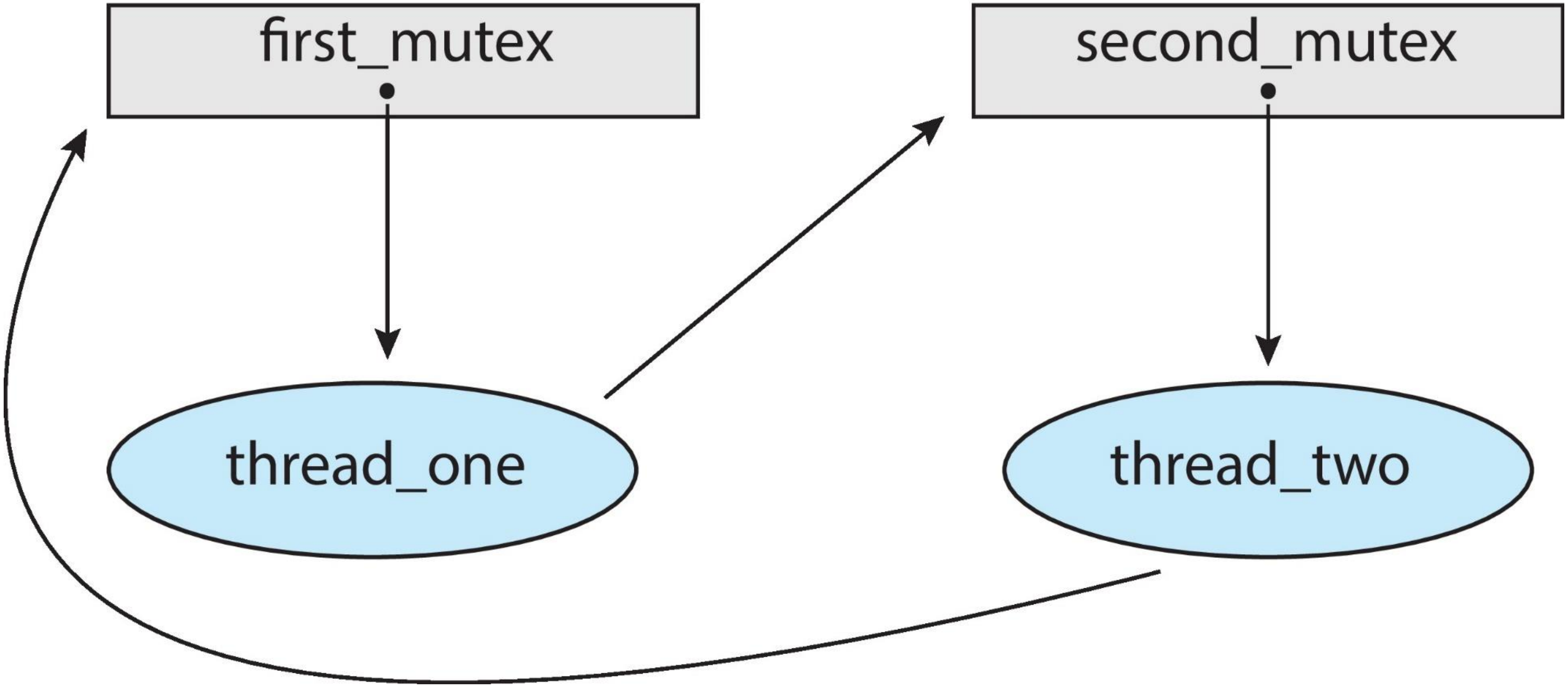
- Deadlock is possible.
- If thread 1 acquires **`first_mutex`** and thread 2 acquires **`second_mutex`**, Thread 1 then waits for **`second_mutex`** and thread 2 waits for **`first_mutex`**.
- Can be illustrated with a **resource allocation graph**:

Illustration using Resource Allocation Graph



Resource-Allocation Graph: Example 6

- Describe the following resource allocation graph?



Resource Allocation is Subtle

Deadlock free

```
typedef int semaphore;
    semaphore resource_1;
    semaphore resource_2;

    void process_A(void) {
        down(&resource_1);
        down(&resource_2);
        use_both_resources( );
        up(&resource_2);
        up(&resource_1);
    }

    void process_B(void) {
        down(&resource_1);
        down(&resource_2);
        use_both_resources( );
        up(&resource_2);
        up(&resource_1);
    }
```

(a)

Deadlock

```
semaphore resource_1;
semaphore resource_2;

void process_A(void) {
    down(&resource_1);
    down(&resource_2);
    use_both_resources( );
    up(&resource_2);
    up(&resource_1);
}

void process_B(void) {
    down(&resource_2);
    down(&resource_1);
    use_both_resources( );
    up(&resource_1);
    up(&resource_2);
}
```

(b)

- [Figure 6-2 in Tanenbaum & Bos, 2014]

Remarks

- Whether the deadlock happens or not depends on the result of a race (or scheduling)
  - Difficult to debug because it only happens sporadically
- Difference between deadlock free and deadlocked code is subtle in coding style

Questions?

- Synchronization tools are resources
- Subtle to write deadlock-free code, and difficult to debug

Methods for Handling Deadlocks

- Ensure that the system will ***never*** enter a deadlock state:
  - Deadlock prevention (by structurally negating one of the four required conditions)
  - Deadlock avoidance (by carefully allocating resources)
- Allow the system to enter a deadlock state and then recover
  - Deadlock detection and recovery (Let deadlocks occur, detect them, and then take action)
- Ignore the problem and pretend that deadlocks never occur in the system.
  - The **Ostrich algorithm**

The Ostrich Algorithm

The deadlock in my system
happens once in a blue moon …

Questions?

- System Model
- Deadlock in Multithreaded Applications
- Deadlock Characterization and Resource Allocation Graph
- Methods for Handling Deadlocks
- The Ostrich Algorithm