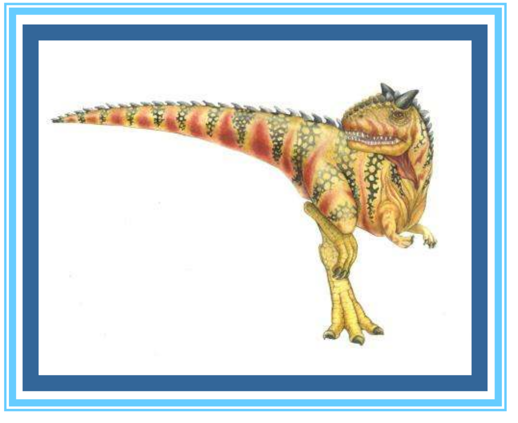
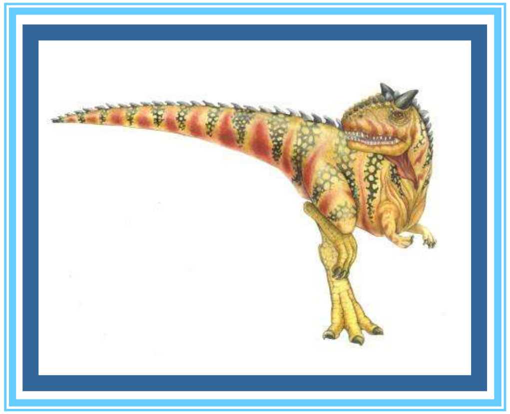
Chapter 7: Deadlocks



Chapter 7: Deadlocks



Chapter 7: Deadlocks

- System Model
- Deadlock Characterization
- Methods for Handling Deadlocks
- Deadlock Prevention
- Deadlock Avoidance
- Deadlock Detection
- Recovery from Deadlock

Chapter Objectives

- To develop a description of deadlocks, which prevent sets of concurrent processes from completing their tasks
- To present a number of different methods for preventing or avoiding deadlocks in a computer system

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**

her Kaynak bu 3 aşamadan geçer

Deadlock Characterization

Deadlock can arise if four conditions hold simultaneously.

- **Mutual exclusion**: only one process at a time can use a resource Bir kaynak en fazla bir Process tarafından kullanılması.
- **Hold and wait**: a process holding at least one resource is waiting to acquire additional resources held by other processes P_1 elinde kaynak var P_2 nin elindeki kaynağı bekliyor. Ancak P_2 de P_1 deki kaynağı beklediği için Hold and wait olmuş olur.
- **No preemption**: a resource can be released only voluntarily by the process holding it, after that process has completed its task Processesin kendine ayrılan kaynakları geri iade etmemesi.
  (Preemptive scheduling istisna)
- **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. Hold and wait gibi ama döngüsel.

Note: Deadlock'un oluşması için bu 4 durum sağlanmak (aynı anda) zorunda. aralarında AND ilişkisi var.

Deadlock with Mutex Locks

- Deadlocks can occur via system calls, locking, etc.
- See example box in text page 318 for mutex deadlock

Kernel içinde Deadlock oluşabiliyor.

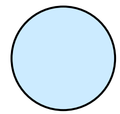
Resource-Allocation Graph

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

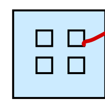
- V is partitioned into two types:
  - $P = \{P_1, P_2, \ldots, P_n\}$, the set consisting of all the processes in the system Pn process
  - $R = \{R_1, R_2, \ldots, R_m\}$, the set consisting of all resource types in the system m kaynak.
- **request edge** – directed edge $P_i \rightarrow R_j$ Processten kaynağa edge → Request
- **assignment edge** – directed edge $R_j \rightarrow P_i$ Kaynaktan processe edge → assign

Resource-Allocation Graph (Cont.)

- Process

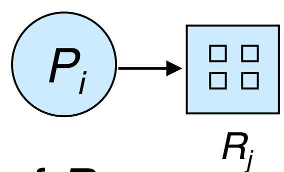


- Resource Type with 4 instances

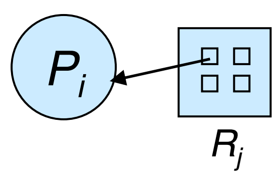


4 kopya var kaynaktan.

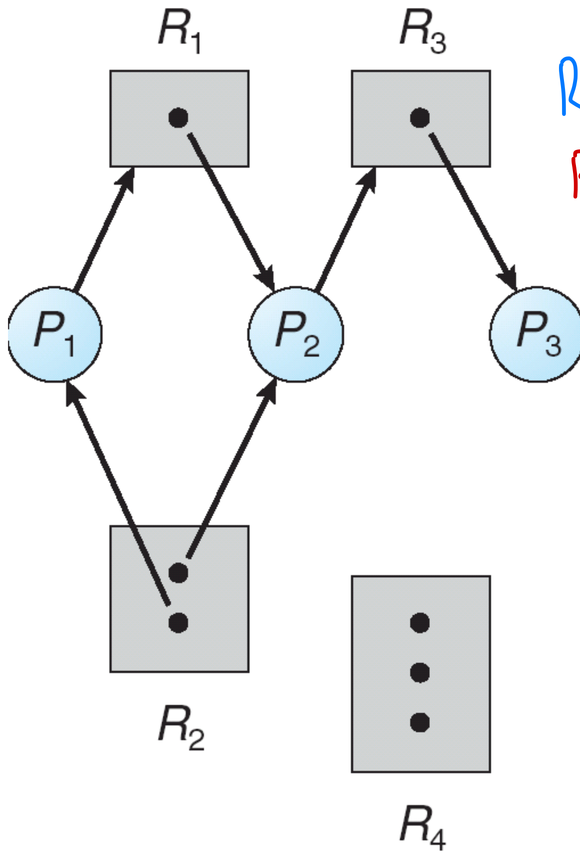
- P_i requests instance of R_j



- P_i is holding an instance of R_j



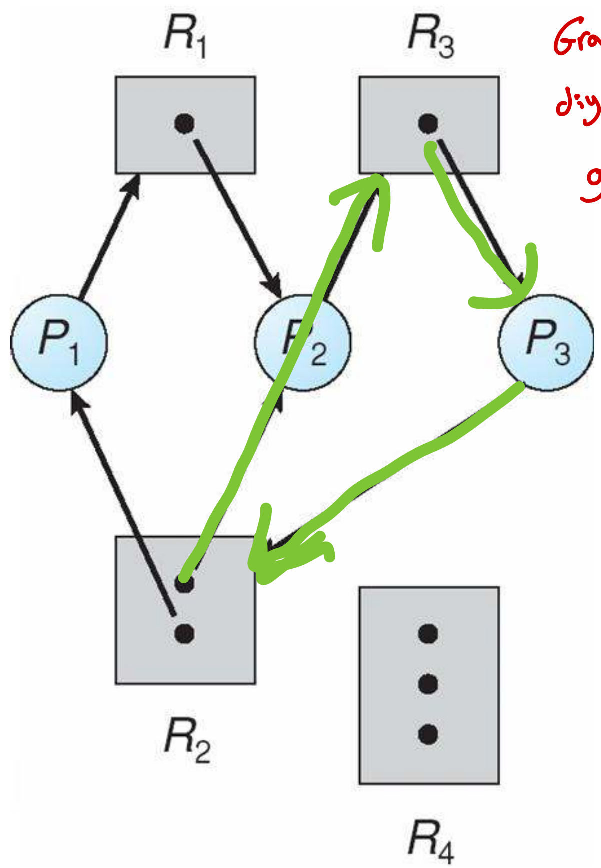
Example of a Resource Allocation Graph



Resource allocation grafta:

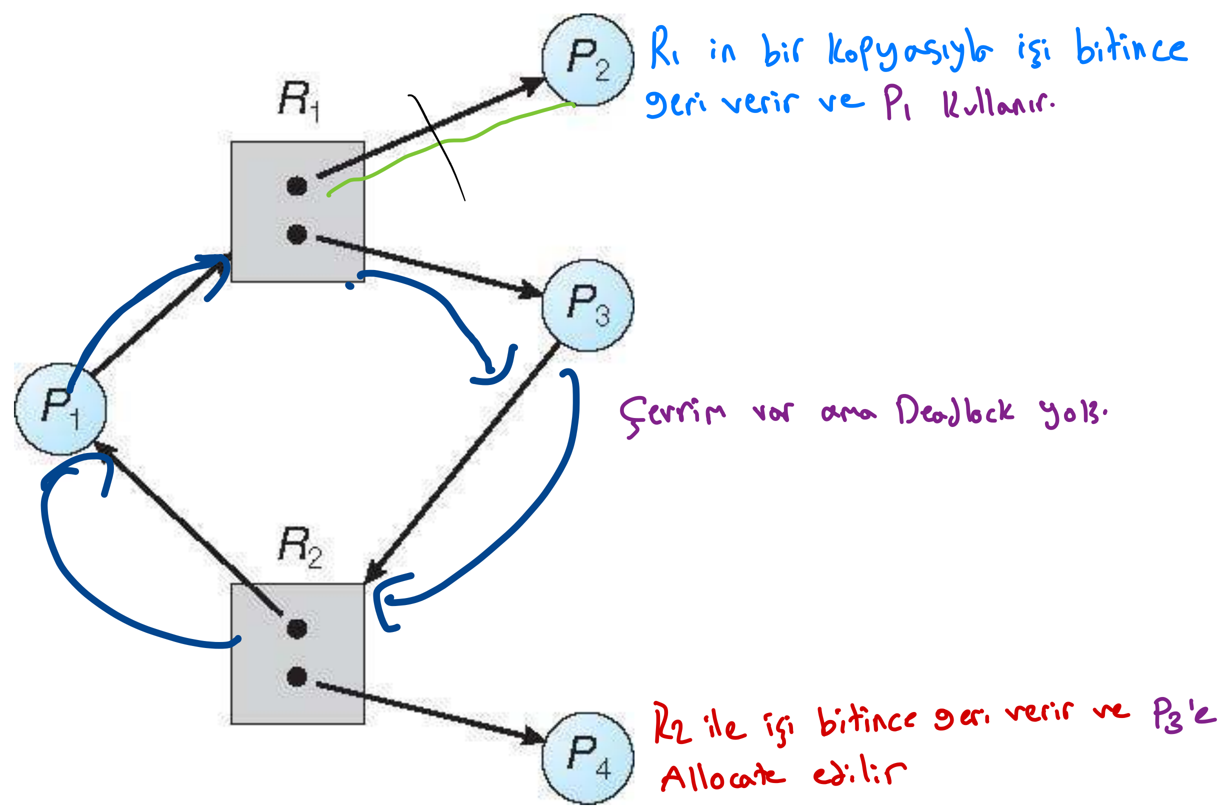
Prosessler ve kaynaklar arasında bir Döngü oluşturamıyorsak Deadlock Bulunmuyor sonucuna varırız.

Resource Allocation Graph With A Deadlock



Grafta çevrimin olması Kesin Deadlock oluştuğu diyemez ama yüksek ihtimalle olabilir anlamına gelir.

Graph With A Cycle But No Deadlock



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 Kaynağın kopyaları yoksa Deadlock var.
  - if several instances per resource type, possibility of deadlock Kaynakların kopyası varsa bir ihtimalle var.

Methods for Handling Deadlocks

Bir takım Kaynak ve Process.

- Ensure that the system will ***never*** enter a deadlock state:

  Multiprogramming'i kısıtlar

  - Deadlock prevention engellemek. Kaynakları kısıtlı kullanıyoz bazen Kaynak boşta Kalabilir.
  - Deadlock avoidence Kaçınmak. Bütün Kaynakları kullanıyoz ama her adımda Deadlock oluşur mu sorusuna

    Yanlış hesap yaparsak Deadlock oluşabilir. Cevap vermek durumundayız.

- Allow the system to enter a deadlock state and then recover
- Ignore the problem and pretend that deadlocks never occur in the system; used by most operating systems, including UNIX

Deadlock Prevention

Restrain the ways request can be made

- **Mutual Exclusion** – not required for sharable resources (e.g., read-only files); must hold for non-sharable resources
  Processler birbiriyle etkileşmesin. gerçekçi değil.
- **Hold and Wait** – must guarantee that whenever a process requests a resource, it does not hold any other resources
  - Require process to request and be allocated all its resources before it begins execution, or allow process to request resources only when the process has none allocated to it. ihtiyacı olan bütün kaynakları ya hep al ya hiç alma.
  - Low resource utilization; starvation possible ne kadar bekleyecek? starvation

Kaynak ayırdık ama biz belki 1 saat sonra kullanacağız?

ör) birşey hesapla sonra yazıcıyla yazdır. hesaplamak 1 saat sürse yazıcıyı başka kaynaklar kullanamayacaklar.

Diğer processler bu sefer biz bekleyecek.

Deadlock Prevention (Cont.)

- **No Preemption** – Bir processesin kaynağını izni olmadan elinden alınması
  işlemci bunu sorunsuz yapabilir yapısı gereği
  - If a process that is holding some resources requests another resource that cannot be immediately allocated to it, then all resources currently being held are released
  - Preempted resources are added to the list of resources for which the process is waiting
  - Process will be restarted only when it can regain its old resources, as well as the new ones that it is requesting
- **Circular Wait** – impose a total ordering of all resource types, and require that each process requests resources in an increasing order of enumeration

Kaynakları numaralandır. Processler kaynakları artan bi şekilde istemesi lazım R_5 sonra R_2 X
ama process başlanadan hangi sırayla hangi kaynaklara ihtiyacı olduğunu bilmesi lazım. online-interactive sistemlerde bu imkansızdır. R_1 sonra R_3 ✓

Deadlock Example

```
/* 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);
}
```

Deadlock Example with Lock Ordering

```
void transaction(Account from, Account to, double amount)
{
   mutex lock1, lock2;
   lock1 = get_lock(from);
   lock2 = get_lock(to);
   acquire(lock1);
      acquire(lock2);
         withdraw(from, amount);
         deposit(to, amount);
      release(lock2);
   release(lock1);
}
```

Transactions 1 and 2 execute concurrently. Transaction 1 transfers $25 from account A to account B, and Transaction 2 transfers $50 from account B to account A

Deadlock Avoidance

Requires that the system has some additional ***a priori*** information available

- Simplest and most useful model requires that each process declare the ***maximum number*** of resources of each type that it may need her Process her Kaynaktan en fazla ne kadar kullanır onu sor. Kaynak istek sayısı Kaynak sayısı geçmezse Safe state'teyiz.
- The deadlock-avoidance algorithm dynamically examines the resource-allocation state to ensure that there can never be a circular-wait condition
- Resource-allocation *state* is defined by the number of available and allocated resources, and the maximum demands of the processes

Kaynaklar isteme sırasında mevcut duruma göre bu kaynak tahsisatı sistemi Safe durumunda olur mu diye kontrol eder ve sistemi Safe durumunda tutmaya çalışır.

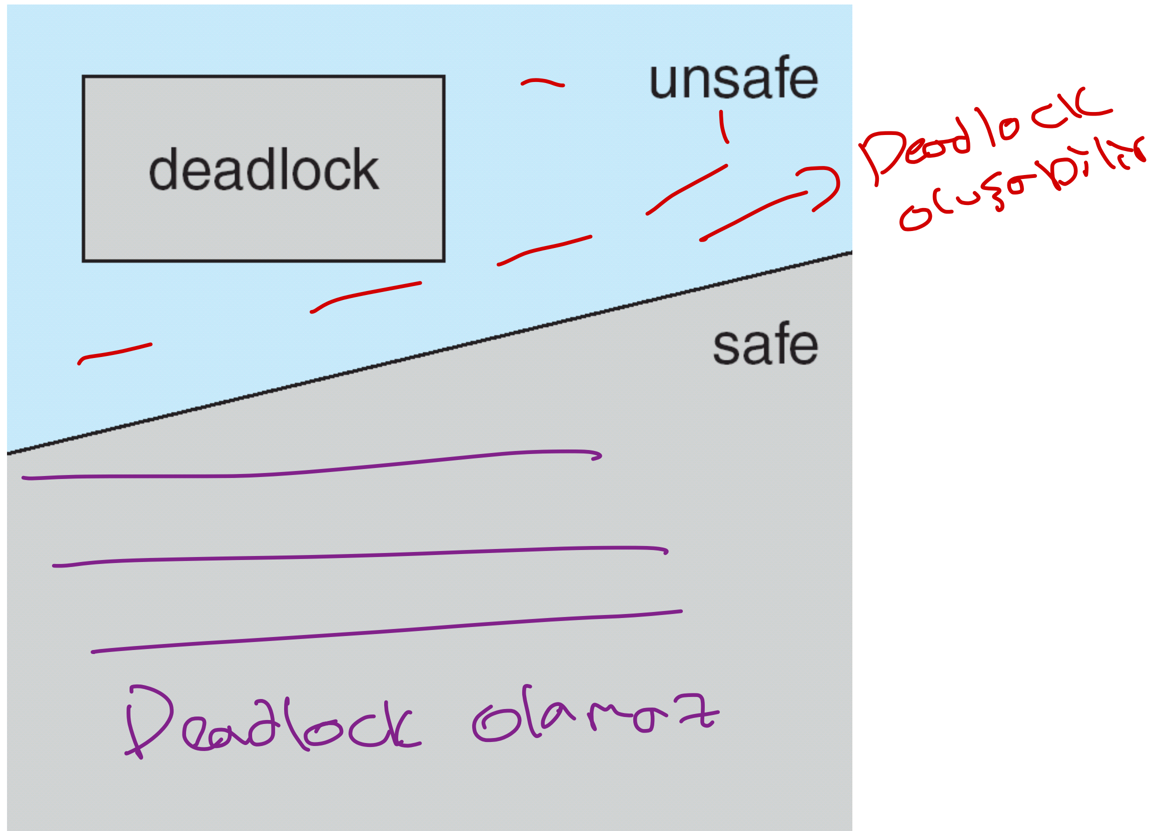
Safe State

- When a process requests an available resource, system must decide if immediate allocation leaves the system in a safe state
- System is in **safe state** if there exists a sequence $<P_1, P_2, \ldots, P_n>$ of ALL the processes in the systems such that for each P_i, the resources that P_i can still request can be satisfied by currently available resources + resources held by all the P_j, with $j < I$
- That is:
  - If P_i resource needs are not immediately available, then P_i can wait until all P_j have finished
  - When P_j is finished, P_i can obtain needed resources, execute, return allocated resources, and terminate
  - When P_i terminates, P_{i+1} can obtain its needed resources, and so on

Basic Facts

- If a system is in safe state $\Rightarrow$ no deadlocks
- If a system is in unsafe state $\Rightarrow$ possibility of deadlock
- Avoidance $\Rightarrow$ ensure that a system will never enter an unsafe state.

Safe, Unsafe, Deadlock State



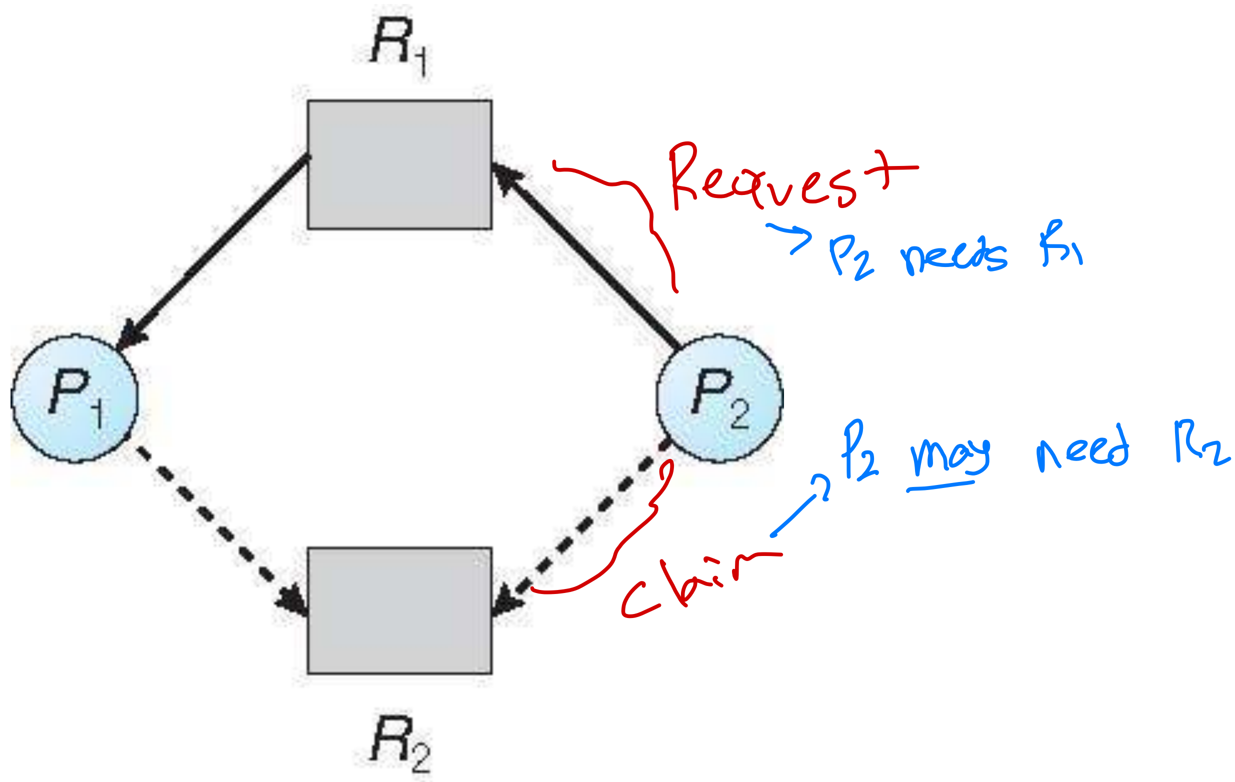
Avoidance Algorithms

- Single instance of a resource type
  - Use a resource-allocation graph
- Multiple instances of a resource type Kaynakların kopyaları var ise
  - Use the banker's algorithm

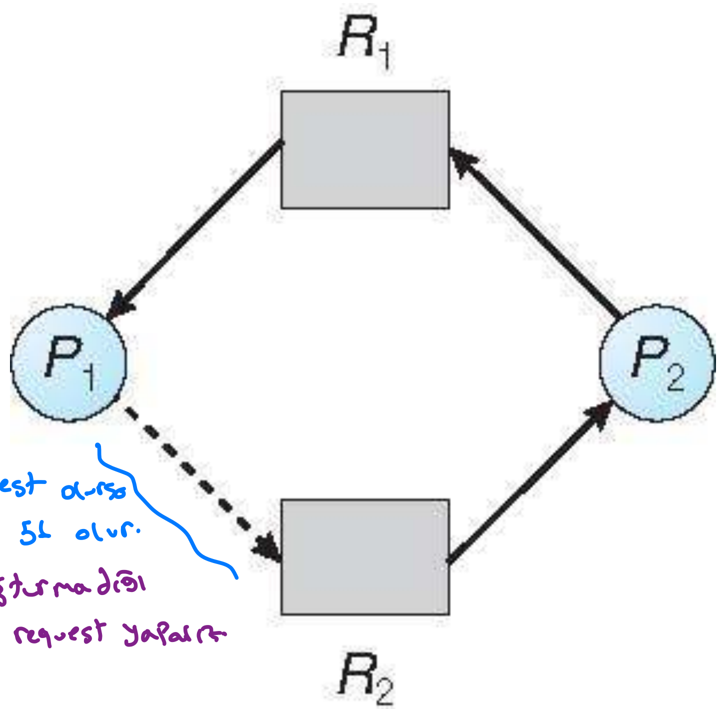
Resource-Allocation Graph Scheme

- **Claim edge** $P_i \rightarrow R_j$ indicated that process P_j may request resource R_j; represented by a dashed line
- Claim edge converts to request edge when a process requests a resource
- Request edge converted to an assignment edge when the resource is allocated to the process
- When a resource is released by a process, assignment edge reconverts to a claim edge
- Resources must be claimed *a priori* in the system

Resource-Allocation Graph



Unsafe State In Resource-Allocation Graph



Request olursa
ortalık 5L olur.

Döngü oluşturmadığı
Durumda bunu request yapabilir

Resource-Allocation Graph Algorithm

- Suppose that process P_i requests a resource R_j
- The request can be granted only if converting the request edge to an assignment edge does not result in the formation of a cycle in the resource allocation graph

Banker's Algorithm

- Multiple instances
- Each process must a priori claim maximum use yine max ne kadar lazım onu söyler
- When a process requests a resource it may have to wait
- When a process gets all its resources it must return them in a finite amount of time

kaynakları makul bir zamanda geri döndermeli

Data Structures for the Banker's Algorithm

Let n = number of processes, and m = number of resources types.

her kaynağın kaç kopyası var bilgisini tutan dizi.

- **Available**: Vector of length m. If available $[j] = k$, there are k instances of resource type R_j available

Processx kaynak matrisi bir process bir kaynağın en fazla kaç kopyasını kullanır onu tutar.

- **Max**: $n \times m$ matrix. If $Max\,[i,j] = k$, then process P_i may request at most k instances of resource type R_j

yukarıyla aynı ama ne kadar tahsis edildiğini gösteriyor.

- **Allocation**: $n \times m$ matrix. If Allocation$[i,j] = k$ then P_i is currently allocated k instances of R_j

bir processin bir kaynaktan ihtiyacı kalan kaynak sayısı.

- **Need**: $n \times m$ matrix. If $Need[i,j] = k$, then P_i may need k more instances of R_j to complete its task

$$Need\,[i,j] = Max[i,j] - Allocation\,[i,j]$$

Safety Algorithm

1. Let ***Work*** and ***Finish*** be vectors of length m and n, respectively. Initialize:

   Work = Available

   ***Finish* [*i*] = *false* for *i* = 0, 1, …, *n*- 1**

2. Find an ***i*** such that both:

   (a) ***Finish* [*i*] = *false***

   (b) $\boldsymbol{Need_i \leq Work}$

   If no such ***i*** exists, go to step 4

3. $\boldsymbol{Work = Work + Allocation_i}$
   Finish*[*i*] = *true
   go to step 2

4. If ***Finish* [*i*] == *true*** for all ***i***, then the system is in a safe state

Resource-Request Algorithm for Process P_i

$\boldsymbol{Request_i}$ = request vector for process $\boldsymbol{P_i}$. If $\boldsymbol{Request_i[j] = k}$ then process $\boldsymbol{P_i}$ wants $\boldsymbol{k}$ instances of resource type $\boldsymbol{R_j}$

Kalan hakkından az istiyor. Problem yok.

1. If $\boldsymbol{Request_i \le Need_i}$ go to step 2. Otherwise, raise error condition, since process has exceeded its maximum claim

isteği kadar kaynak mevcutsa devam. yoksa beklemek zorunda.

2. If $\boldsymbol{Request_i \le Available}$, go to step 3. Otherwise $\boldsymbol{P_i}$ must wait, since resources are not available
3. Pretend to allocate requested resources to $\boldsymbol{P_i}$ by modifying the state as follows:

$$\boldsymbol{Available = Available - Request_i;}$$ ← Kalan kaynak sayısını azalt

$$\boldsymbol{Allocation_i = Allocation_i + Request_i;}$$ ← Process'e ayrılan kaynak sayısı arttır.

$$\boldsymbol{Need_i = Need_i - Request_i;}$$ ← Process'in kalan ihtiyaç sayısını azalt

- If safe ⇒ the resources are allocated to $\boldsymbol{P_i}$
- If unsafe ⇒ $\boldsymbol{P_i}$ must wait, and the old resource-allocation state is restored

eğer Değerler beni unsafe state'e sokuyorsa son değişiklikler revert edilir.

Example of Banker's Algorithm

- 5 processes P_0 through P_4;

  3 resource types:

  A (10 instances), *B* (5instances), and *C* (7 instances)

- Snapshot at time T_0:

	Allocation	*Max*	*Available*
	A B C	*A B C*	*A B C*
~~P_0~~	~~0 1 0~~	~~7 5 3~~	3 3 2
~~P_1~~	~~2 0 0~~	~~3 2 2~~	5 3 2
	+3 3 2		
P_2	3 0 2	9 0 2	7 4 3
~~P_3~~	~~2 1 1~~	~~2 2 2~~	7 4 5
~~P_4~~	~~0 0 2~~	~~4 3 3~~	7 5 3

herhangi birini hiç bir şekilde doyuramıyorsak

Deadlock vardır.

Example (Cont.)

- The content of the matrix ***Need*** is defined to be ***Max – Allocation***

	Need
	A B C
P_0	7 4 3
P_1	1 2 2
P_2	6 0 0
P_3	0 1 1
P_4	4 3 1

- The system is in a safe state since the sequence $< P_1, P_3, P_4, P_2, P_0>$ satisfies safety criteria

Example: P_1 Request (1,0,2)

- Check that Request ≤ Available (that is, $(1,0,2) \le (3,3,2) \Rightarrow$ true

	Allocation	*Need*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	7 4 3	2 3 0
P_1	3 0 2	0 2 0	5 3 2
P_2	3 0 2	6 0 0	7 4 3
P_3	2 1 1	0 1 1	7 4 5
P_4	0 0 2	4 3 1	7 5 5

- Executing safety algorithm shows that sequence < P_1, P_3, P_4, P_0, P_2> satisfies safety requirement
- Can request for (3,3,0) by P_4 be granted?
- Can request for (0,2,0) by P_0 be granted?

Deadlock Detection

- Allow system to enter deadlock state
- Detection algorithm
- Recovery scheme

Single Instance of Each Resource Type

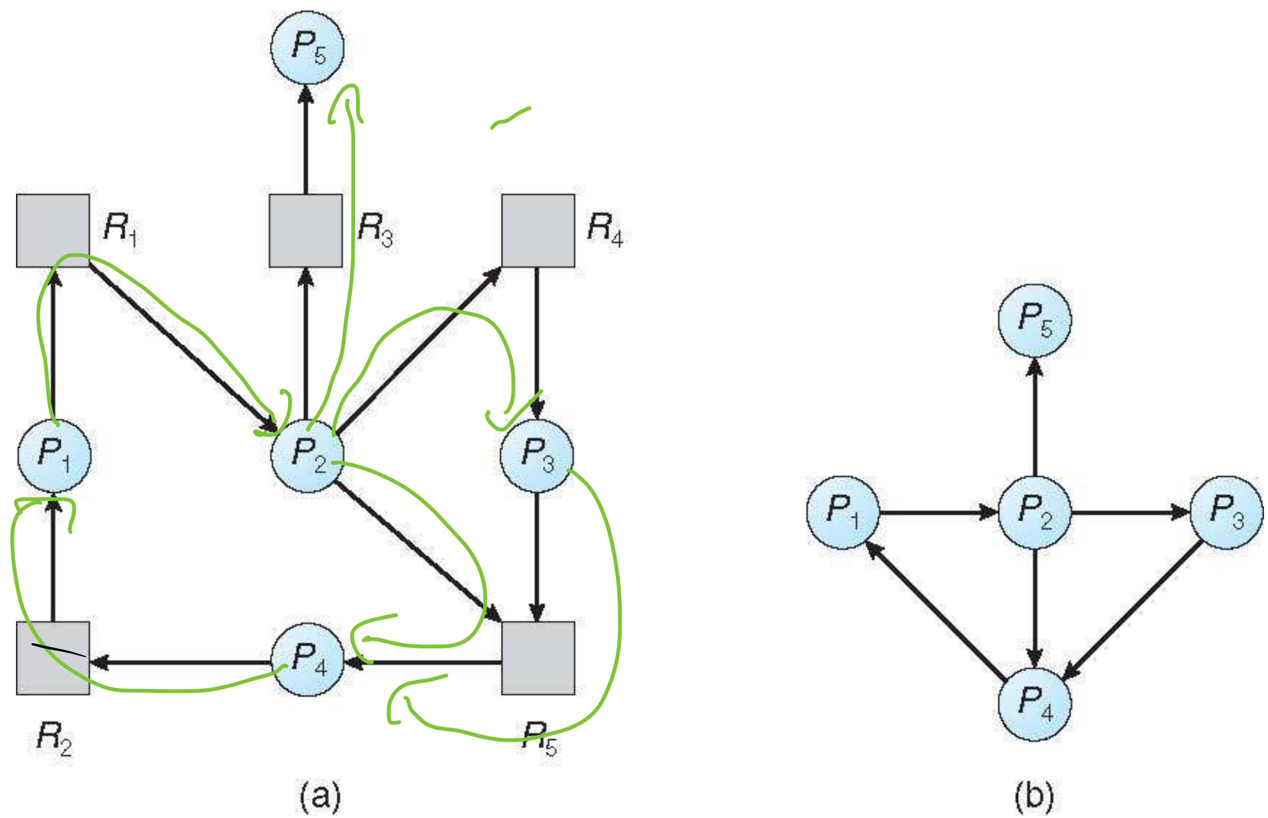
- Maintain **wait-for** graph → resource allocation graf'ın Dönüştürülmüş hali.
  - Nodes are processes → hangi process hangi processi bekliyor. Kaynak yok.
  - $P_i \rightarrow P_j$ if P_i is waiting for P_j

- Periodically invoke an algorithm that searches for a cycle in the graph. If there is a cycle, there exists a deadlock

  wait-in grafında Döngü var ise mutlaka Döngü vardır.

- An algorithm to detect a cycle in a graph requires an order of n^2 operations, where n is the number of vertices in the graph

Resource-Allocation Graph and Wait-for Graph



Resource-Allocation Graph Corresponding wait-for graph

Several Instances of a Resource Type

- **Available***:* A vector of length ***m*** indicates the number of available resources of each type
- **Allocation***:* An ***n* x *m*** matrix defines the number of resources of each type currently allocated to each process
- **Request***:* An ***n* x *m*** matrix indicates the current request of each process. If ***Request* [*i*][*j*] = *k***, then process P_i is requesting ***k*** more instances of resource type R_j.

Detection Algorithm

1. Let ***Work*** and ***Finish*** be vectors of length ***m*** and ***n***, respectively Initialize:

   (a) ***Work* = *Available***

   (b) For ***i* = 1,2, …, *n***, if $\boldsymbol{Allocation_i \neq 0}$, then ***Finish*[i] = *false***; otherwise, ***Finish*[i] = *true***

2. Find an index ***i*** such that both:

   (a) ***Finish*[*i*] == *false***

   (b) $\boldsymbol{Request_i \leq Work}$

   If no such ***i*** exists, go to step 4

Detection Algorithm (Cont.)

3. $\boldsymbol{Work} = \boldsymbol{Work} + \boldsymbol{Allocation_i}$
   Finish*[*i*] = *true
   go to step 2

4. If ***Finish[i] == false***, for some ***i***, $1 \leq \boldsymbol{i} \leq \boldsymbol{n}$, then the system is in deadlock state. Moreover, if ***Finish*[*i*] == *false***, then $\boldsymbol{P_i}$ is deadlocked

Algorithm requires an order of $O(m \times n^2)$ operations to detect whether the system is in deadlocked state

Example of Detection Algorithm

- Five processes P_0 through P_4; three resource types A (7 instances), B (2 instances), and C (6 instances)

- Snapshot at time T_0:

	Allocation	*Request*	*Available*
	A B C	*A B C*	*A B C*
P_0	0 1 0	0 0 0	0 0 0
P_1	2 0 0	2 0 2	
P_2	3 0 3	0 0 0	
P_3	2 1 1	1 0 0	
P_4	0 0 2	0 0 2	

- Sequence <P_0, P_2, P_3, P_1, P_4> will result in ***Finish[i] = true*** for all ***i***

Example (Cont.)

- P_2 requests an additional instance of type C

	Request
	A B C
P_0	0 0 0
P_1	2 0 2
P_2	0 0 1
P_3	1 0 0
P_4	0 0 2

- State of system?
  - Can reclaim resources held by process P_0, but insufficient resources to fulfill other processes; requests
  - Deadlock exists, consisting of processes P_1, P_2, P_3, and P_4

Detection-Algorithm Usage

- When, and how often, to invoke depends on:
  - How often a deadlock is likely to occur?
  - How many processes will need to be rolled back?
    - one for each disjoint cycle
- If detection algorithm is invoked arbitrarily, there may be many cycles in the resource graph and so we would not be able to tell which of the many deadlocked processes "caused" the deadlock.

Recovery from Deadlock: Process Termination

- Abort all deadlocked processes

- Abort one process at a time until the deadlock cycle is eliminated

- In which order should we choose to abort?
  1. Priority of the process
  2. How long process has computed, and how much longer to completion
  3. Resources the process has used
  4. Resources process needs to complete
  5. How many processes will need to be terminated
  6. Is process interactive or batch?

Recovery from Deadlock: Resource Preemption

- **Selecting a victim** – minimize cost
- **Rollback** – return to some safe state, restart process for that state
- **Starvation** – same process may always be picked as victim, include number of rollback in cost factor

End of Chapter 7