Operating Systems / Sistema de Operação

Deadlock

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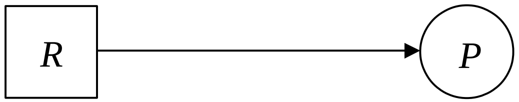
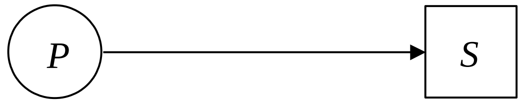
Deadlock

- Generically, a *resource* is something a process needs in order to proceed with its execution
  - *physical components of the computational system* (processor, memory, I/O devices, etc)
  - *common data structures* defined at the operating system level (PCT, communication channels, etc,) or among processes of a given application
- Resources can be:
  - *preemptable* – if they can be withdraw from the processes that hold them
    - ex: processor, memory regions used by a process address space
  - *non-preemptable* – if they can only be released by the processes that hold them
    - ex: a file, a shared memory region that requires exclusive access for its manipulation
- For this discussion, only non-preemptable resources are relevant

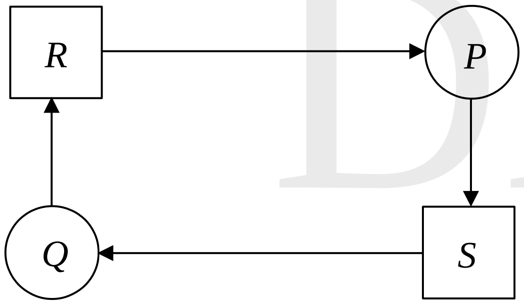
Deadlock



process P holds resource R in its possession



process P requests resource S



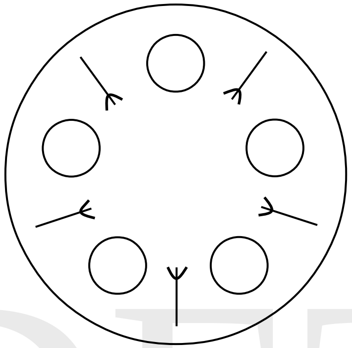
typical deadlock situation
(*the simplest one*)

- What are the conditions for the occurrence of deadlock

Necessary conditions for deadlock

- It can be proved that when *deadlock* occurs 4 conditions are necessarely observed:
  - *mutual exclusion* – only one process may use a resource at a time
    - if another process requests it, it must wait until it is released
  - *hold and wait* – a process must be holding at least one resource, while waiting for another that is being held by another process
  - *no preemption* - resources are non-preemptable
    - only the process holding a resource can release it, after completing its task
  - *circular wait* - a set of waiting processes must exist such that each one is waiting for resources held by other processes in the set

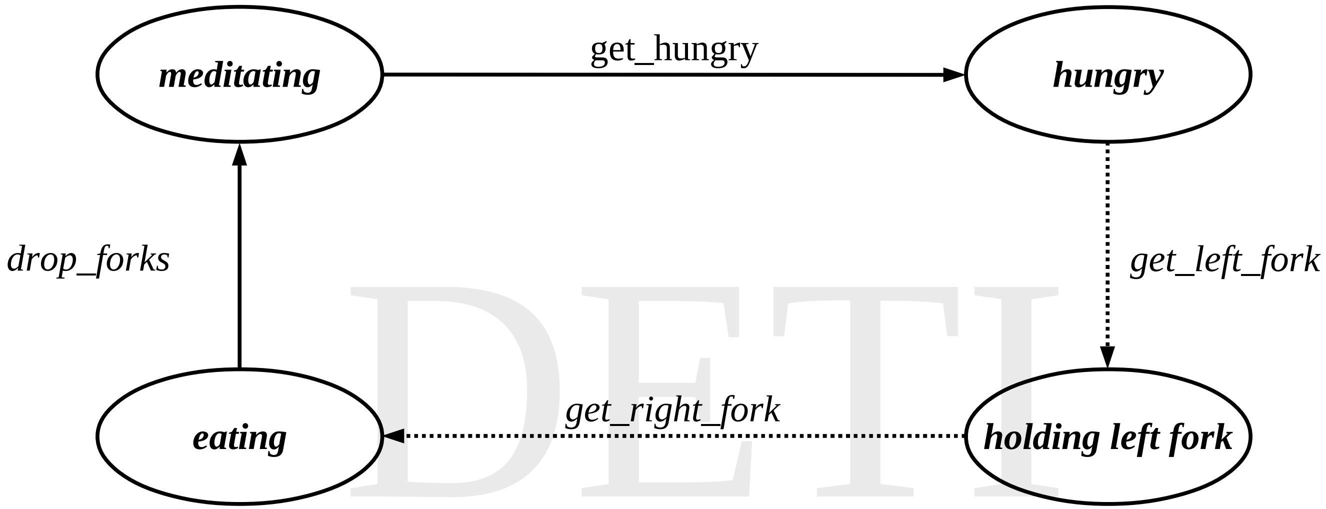
Necessary conditions for deadlock



Problem statement

- 5 philosophers are seated around a table, with food in from of them
  - To eat, every philosopher needs two forks, the ones at her left and right sides
  - Every philosopher alternates periods in which she medidates with periods in which she eats
- Modelling every philosopher as a different process or thread and the forks as resources, design a solution for the problem

Necessary conditions for deadlock



- This is a possible solution for the dining-philosopher problem
  - when a philosopher gets hungry, she first gets the left fork and then holds it while waits for the right one
- This solution can suffer from deadlock
  - Try to identify the four necessary conditions

Necessary conditions for deadlock

```
enum PHILO_STATE {MEDITATING, HUNGRY, HOLDING, EATING};
enum FORK_STATE {DROPPED, TAKEN};

typedef struct TablePlace
{
        int philo_state;
        int fork_state;
        cond fork_available;
} TablePlace;

typedef struct Table
{
        mutex locker;
        int nplaces;
        TablePlace place[0];
} Table;

int set_table(unsigned int n, FILE *logp);
int get_hungry(unsigned int f);
int get_left_fork(unsigned int f);
int get_right_fork(unsigned int f);
int drop_forks(unsigned int f);
```

- Let's look at an implementations of this solution!

Necessary conditions for deadlock

- This solution works some times
  - But, it can suffer from deadlock
- The four necessary conditions for the occurrence of deadlock are satisfied
  - *mutual exclusion* – the forks are not sharable
  - *hold and wait* – each philosopher while waiting to acquire the right fork holds the left one
  - *no preemption* – each philosopher keeps the forks until she finishes eating
  - *circular wait* – if every philosopher can acquire the left fork, there is a chain in which every philosopher waits for a fork in possession of another philosopher

Deadlock prevention

deadlock ⇒ *mutual exclusion* **and**
hold and wait **and**
no preemption **and**
circular wait

- that is equivalent to

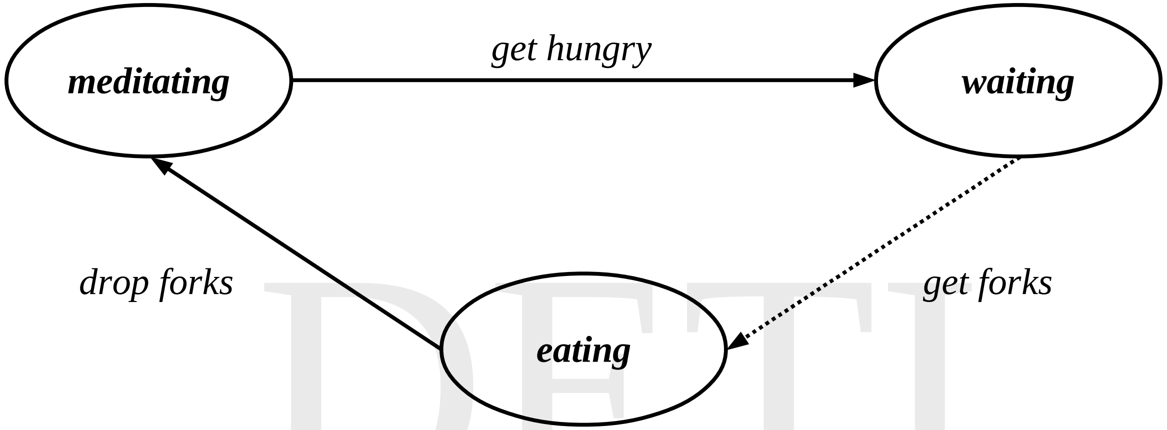
not *mutual exclusion* **or**
not *hold and wait* **or**
not *no preemtion* **or**
not *circular wait* ⇒ **not** *deadlock*

- So, if in the solution of a concurrent problem at least one of the necessary condition does not hold, there is no deadlock
- This is called *deadlock prevention*

Deadlock prevention

- Denying the *mutual exclusion* condition is only possible if the resources are shareable
  - Otherwise *race conditions* can occur
  - In the dining-philosopher problem, the forks are not shareable
- Thus, in general, only the other conditions are used to implement deadlock prevention
- Denying the *hold-and-wait* condition can be done if a process requests all required resources at once
  - In the dining-philosopher problem, the two forks must be acquired at once
  - In this solution, *starvation* can occur
    - *Aging* mechanisms are often used to solve starvation

Deadlock prevention

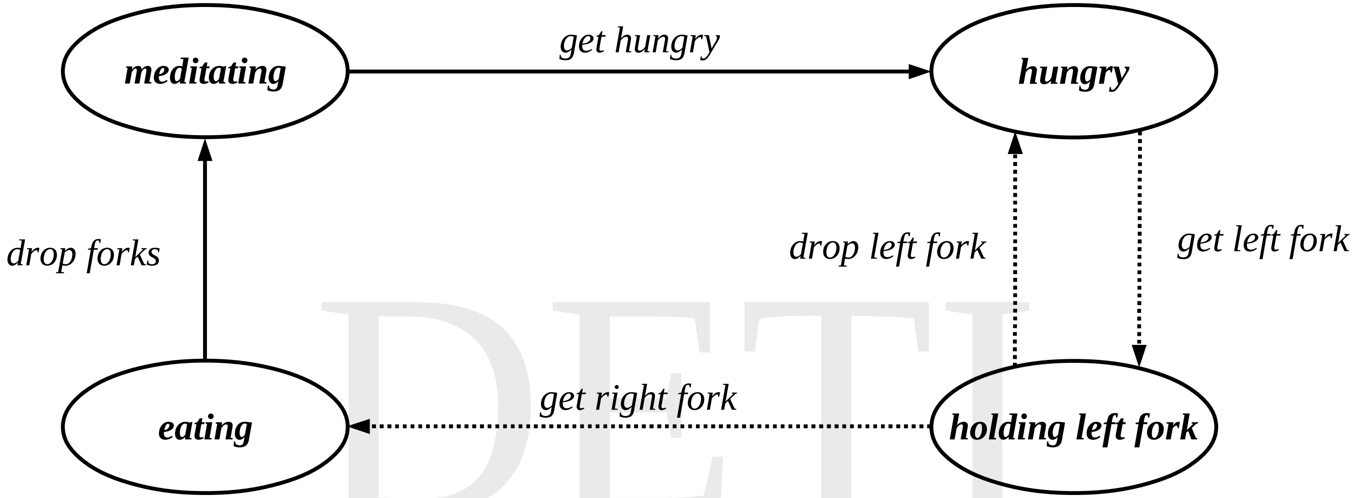


- This solution is equivalent to the one proposed by Dijkstra
- Every philosopher, when want to eat acquire the two forks at the same time
- If they are not available, she/he waits in the waiting state
- Starvation is not avoided

Deadlock prevention

- Denying the *hold and wait* condition can also be done if a process releases the already acquired resources if it fails acquiring the next one
  - Later on she/he can try the acquition again
  - In the dining-philosopher problem, a philosopher must release the left fork if she/he fails acquiring the right one
  - In this solution, *starvation* and *busy waiting* can occur
    - *Aging* mechanisms are often used to solve starvation
    - To avoid busy waiting, the process should block and be waked up when the resource is released

Deadlock prevention

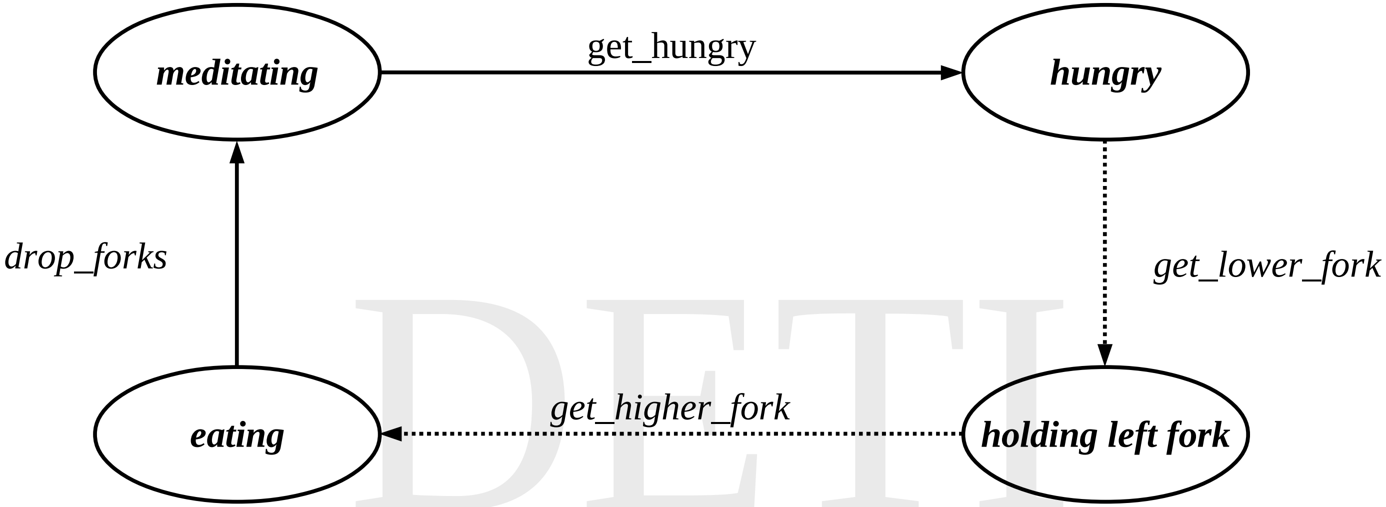


- When a philosopher gets hungry, she/he first acquire the left fork
- Then she/he tries to acquired the right one, releasing the left if she/he fails and returning to the hungry state
- *busy waiting* and starvation were not avoided in this solution

Deadlock prevention

- Denying the *circular wait* condition can be done assigning a different numeric id to every resource and imposing that the acquisition of resources have to be done either in ascending or descending order
  - This way the circular chain is always avoided
  - Starvation is not avoided
  - In the dining-philosopher problem, this can be done imposing that one of the philosophers acquires first the right fork and then the left one

Deadlock prevention



- Philosophers are numbered from 0 to N-1
- Every fork is assigned an id, equal to the id of the philosipher at its right, for instance
- Every philosopher, acquires first the fork with the lower id
- This way, philosophers 0 to N-2 acquire first the left fork, while philosopher N-1 acquires first the right one

Deadlock prevention

- Deadlock prevention policies are in general quite restrictive, not efficient and hard to apply in many situations
  - *denying mutual exclusion* – can only be applied to shareable resources
  - *denying hold and wait* – requires the a priori knowledge of all the necessary resources and always consider the worst case (all resources simultaneously)
  - *denying no preemption* – imposing the release and re-acquisition of resources; can introduce long delays in processing the task
  - *denying circular wait* – can introduce a bad use of resources

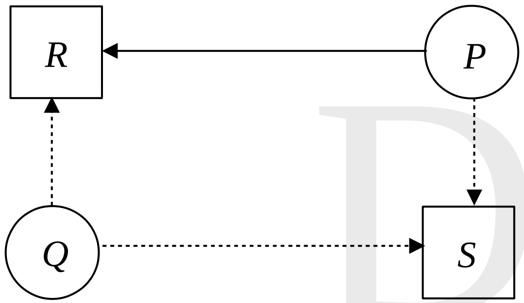
Deadlock avoidance

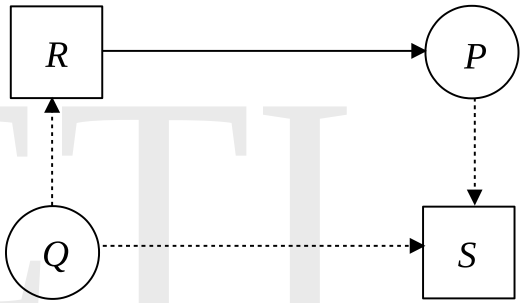
- *Deadlock avoidance* is less restrictive than deadlock prevention
  - None of the necessary conditions is denied
  - Instead, the system is monitored continuosly and a resource request is only granted if the system does not enter an unsafe state in consequence
- A state is said to be safe if there is a sequence of assignments of resources such that all intervening processes do terminate (no deadlock)
    - Otherwise it is assumed to be unsafe
- drawbacks:
  - the list of all resources must be known in advance
  - so, the intervening processes have to declare at start their needs in terms of resources
- Note that unsafe does not mean deadlock
  - worst case conditions are considered

Deadlock avoidance

- In case there is a single instance per resource type:
  - Use resource allocation graph algorithm

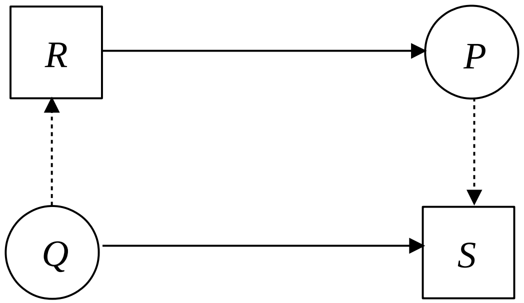
P requests R

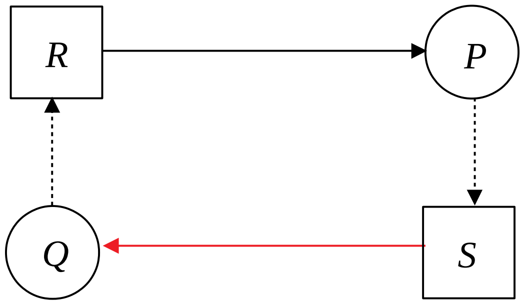




request is granted

Q requests S





Request is denied because a cycle is formed

Deadlock avoidance

- In case there are multiple instances per resource type
- Let

  NTR_i – be the total no. of resources of type i (with $i = 0,1,...,N-1$)

  $R_{i,j}$ – be the no. of resources of type i requered by process j

  (with i = 0,1,...,N-1, j = 0,1,...,M-1)

- The system can prevent a new process M to start if its termination can not be guaranteed
  - It is only launched if $$\forall_i: \; R_{i,M} \leqslant NTR_i - \sum_{j=0}^{M-1} R_{i,j}$$

Deadlock avoidance

- Let

  NTR_i – be the total no. of resources of type i (with $i = 0,1,...,N-1$)

  $R_{i,j}$ – be the no. of resources of type i requered by process j

  (with i = 0,1,...,N-1, j = 0,1,...,M-1)

  $A_{i,j}$ – be the no. of resources of type i assigned to process j

  (with i = 0,1,...,N-1, j = 0,1,...,M-1)

- A new resource of type i is only assigned to a process if and only if there is a sequence $s(k) = f(i,j)$ such that

$$\forall_k \ \forall_i \ : \ R_{i,s(k)} - A_{i,s(k)} \leqslant NTR_i - \sum_{j \geqslant k}^{M-1} A_{i,s(j)}$$

- This approach is called the ***banker's algotithm***

Banker's algorithm

		A	B	C	D
	total	6	5	7	6
	free	3	1	1	2
maximum	p1	3	3	2	2
	p2	1	2	3	4
	p3	1	3	5	0
granted	p1	1	2	2	1
	p2	1	0	3	3
	p3	1	2	1	0
needed	p1	2	1	0	1
	p2	0	2	0	1
	p3	0	1	4	0
new Grant	p1	0	0	0	0
	p2	0	0	0	0
	p3	0	0	0	0

- Is this a safe state?

Banker's algorithm

		A	B	C	D
	total	6	5	7	6
	free	3	1	1	2
maximum	p1	3	3	2	2
	p2	1	2	3	4
	p3	1	3	5	0
granted	p1	1	2	2	1
	p2	1	0	3	3
	p3	1	2	1	0
needed	p1	2	1	0	1
	p2	0	2	0	1
	p3	0	1	4	0
new Grant	p1	0	0	0	0
	p2	0	0	0	0
	p3	0	0	0	0

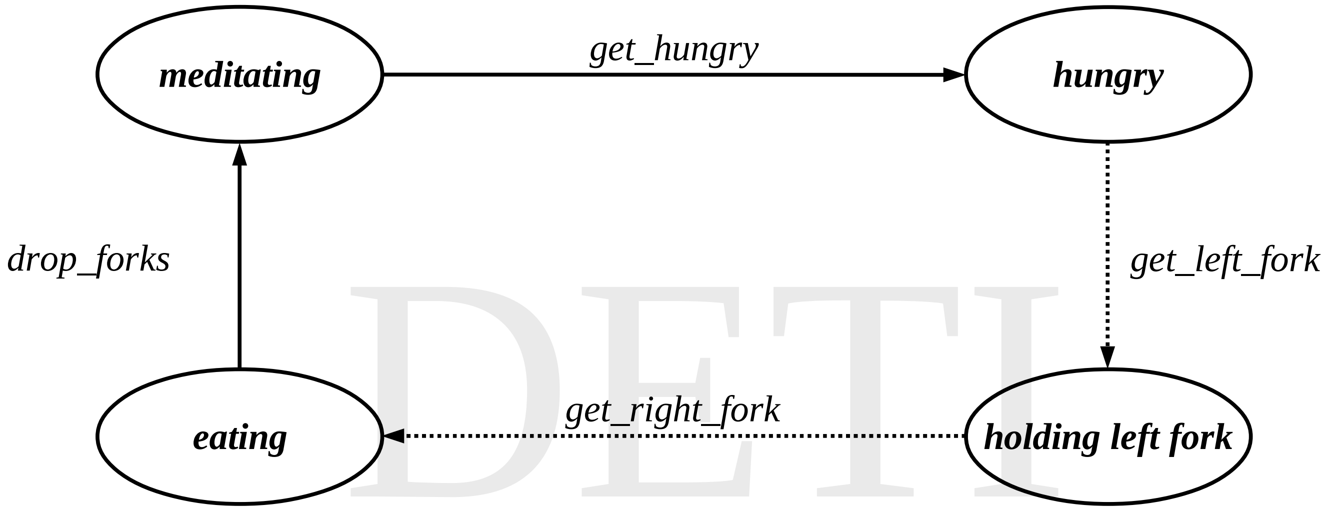
- If p3 requests 2 resources of type C, the grant is postponed
  - Because only 1 is available
- If p3 requests 1 resource of type B, the grant is also postponed
  - Why?

Banker's algorithm

		A	B	C	D
	total	6	5	7	6
	free	3	0	1	2
maximum	p1	3	3	2	2
	p2	1	2	3	4
	p3	1	3	5	0
granted	p1	1	2	2	1
	p2	1	0	3	3
	p3	1	2	1	0
needed	p1	2	1	0	1
	p2	0	2	0	1
	p3	0	0	4	0
new Grant	p1	0	0	0	0
	p2	0	0	0	0
	p3	0	1	0	0

- If p3 requests 1 resource of type B, the grant is postponed
  - Because, even if there is one available, the system in case the grant is done enters an unsafe state

Banker's algorithm



- Every philosopher first gets the left fork and then gets the right one
- However, in a specific situation the request of the left fork can be denied
  - What situation? Why?

Deadlock detection

- No deadlock-prevention or deadlock-avoidance is used
  - So, deadlock situations may occur
- In these cases
  - The state of the system should be examined to determine whether a deadlock has occurred
  - In such a case, a recover procedure from deadlock should exist and be applied

- In a more naive approach
  - The problem can simply be ignored

Deadlock detection

- If deadlock has occurred, the circular chain of processes and resources need to be broken
- This can be done:
  - *release resources from a process* – if it is possible
    - The process is suspended until the resource can be returned back
    - Efficient but requires the possibility of saving the process state
  - *rollback* – if the states of execution of the different processes is periodically saved
    - A resource is released from a process, whose state of execution is rolled back to the time the resource was assigned to it
  - *kill processes* –
    - Radical but easy to implement method

Bibliography

Operating Systems Concepts, Silberschatz, Galvin, Gagne, John Wiley & Sons, 9th Ed

- Chapter 7: *Deadlocks* (sections 7.1 to 7.6)

Modern Operating Systems; Tanenbaum & Bos; Prentice-Hall International Editions, 4rd Ed

- Chapter 6: *Deadlocks* (sections 6.1 to 6.6)

Operating Systems, Stallings, Prentice-Hall International Editions, 7th Ed

- Chapter 6: *Concurrency: deadlock and starvation* (sections 6.1 to 6.7)