



Sistemas de Operação / Fundamentos de Sistemas Operativos

Deadlock

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Deadlock

Introduction

- 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 topic, only non-preemptable resources are relevant

Deadlock

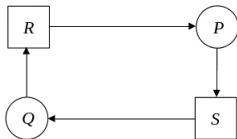
Illustrating deadlock



process P holds resource R in its possession



process P requests resource S



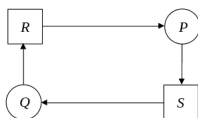
*typical deadlock situation
(the simplest one)*

- P needs S to proceed, which is on possession of Q
- Q needs R to proceed, which is on possession of P
- What are the conditions for the occurrence of deadlock?

Deadlock

Necessary conditions for deadlock

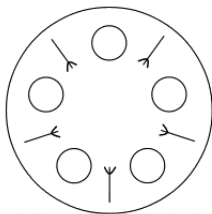
- It can be proved that when deadlock occurs 4 conditions are necessarily observed:
 - **mutual exclusion** – only one process may use a resource at a time
 - if another process requests it, it must wait until it is released
 - **hold and wait** – a process must be holding at least one resource, while 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
 - there are loops in the graph



*typical deadlock situation
(the simplest one)*

Deadlock

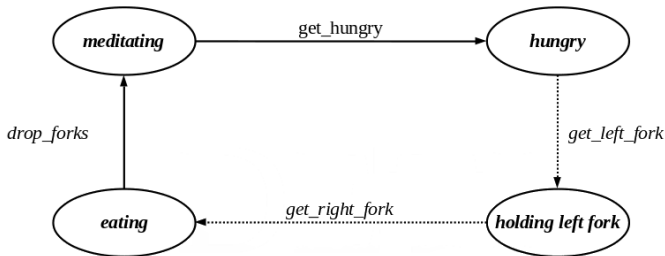
Illustrating with the philosopher dinner problem



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

Philosopher dinner

Solution 1 – state diagram



- This is a possible solution for the dining-philosopher problem
 - when a philosopher gets hungry, he/she first gets the left fork and then holds it while waits for the right one
- Let's look at an implementations of this solution!

Philosopher dinner

Solution 1 – code

```
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;

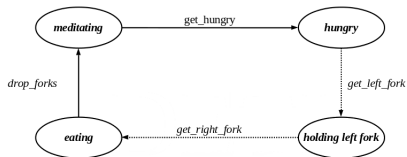
typedef struct Table
{
    mutex locker;
    int nplaces;
    TablePlace place[0];
} Table;

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 execute the code

Philosopher dinner

Solution 1 – deadlock conditions



- This solution works some times, but can suffer from deadlock
- Let's identify the four necessary conditions
 - **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** – only the philosophers can release the fork(s) in their possession
 - **circular wait** – if all philosopher acquire the left fork, there is a chain in which every philosopher waits for a fork in possession of another philosopher

Deadlock prevention

Definition

- From the definition

deadlock \implies
mutual exclusion and
hold and wait and
no preemption and
circular wait

- Which is equivalent to

not mutual exclusion or
not hold and wait or
not no preemption or
not circular wait
 \implies not deadlock

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

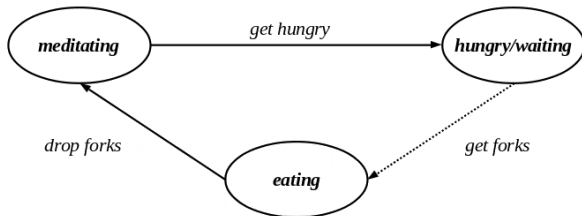
Deadlock prevention

Denying the necessary conditions

- Denying the **mutual exclusion** condition is only possible if 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

Philosopher dinner

Solution 2 – state diagram



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

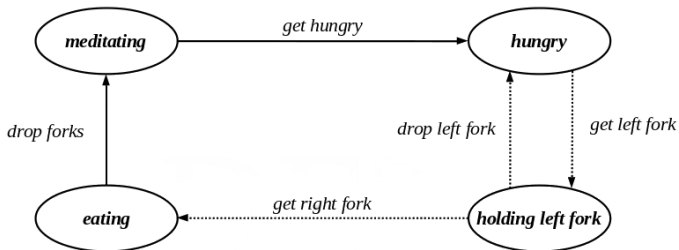
Deadlock prevention

Denying the necessary conditions (2)

- 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 it can try the acquisition 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

Philosopher dinner

Solution 3 – state diagram



- 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

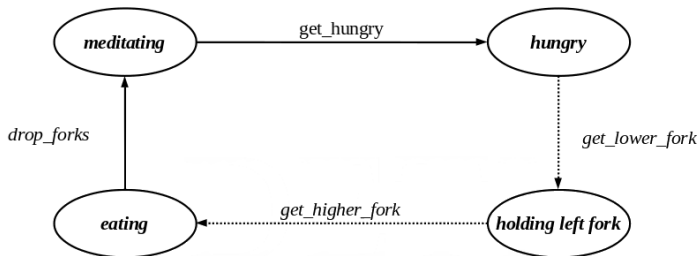
Deadlock prevention

Denying the necessary conditions (3)

- 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
 - Show it!

Philosopher dinner

Solution 4 – state diagram



- Philosophers are numbered from 0 to $N - 1$
- Every fork is assigned an id, equal to the id of the philosopher 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 avoidance

Definition

- **Deadlock avoidance** is less restrictive than deadlock prevention
 - None of the deadlock conditions is denied
 - The resource system is monitored in order to decide what to do in terms of resource allocation
 - Requires **knowledge in advance** of maximum process resource requests
 - The intervening processes have to **declare at start** their needs in terms of resources
- Two possible approaches
 - **Process Initiation Denial**
 - Do not start a process if its demands might lead to deadlock
 - **Resource Allocation Denial**
 - Do not grant an incremental resource request to a process if this allocation might lead to deadlock

Deadlock avoidance

Process initiation denial

- The system prevents a new process to start if its termination can not be guaranteed
- Let
 - $R = (R_1, R_2, \dots, R_n)$ be a vector of the total amount of each resource
 - P be the set of processes competing for resources
 - C_p be a vector of the total amount of each resource declared by process $p \in P$
- A new process q ($q \notin P$) is only started if

$$C_q \leq R - \sum_{p \in P} C_p$$

- It is a quite restrictive approach

Deadlock avoidance

Resource allocation denial

- A new resource is allocated to a process if and only if there is at least one sequence of future allocations that does not result in deadlock
 - In such cases, the system is said to be in a **safe state**
- Let
 - $R = (R_1, R_2, \dots, R_n)$ be a vector of the total amount of each resource
 - $V = (V_1, V_2, \dots, V_n)$ be a vector of the amount of each resource available
 - P be the set of processes competing for resources
 - C_p be a vector of the total amount of each resource declared by process $p \in P$
 - A_p be a vector of the amount of each resource already allocated to process $p \in P$
- A new request of a process q is only granted if, after it, there is a sequence $s(k)$, with $s(k) \in P$ and $k = 1, 2, \dots, |P|$, of processes, such that

$$C_{s(k)} - A_{s(k)} = V + \sum_{m=1}^{k-1} A_{s(m)}$$

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

Deadlock avoidance

Banker's algorithm

		R1	R2	R3	R4
total resources		6	5	7	6
available resources		3	1	1	2
resources declared	P1	3	3	2	2
	P2	1	2	3	4
	P3	1	3	5	0
resources allocated	P1	1	2	2	1
	P2	1	0	3	3
	P3	1	2	1	0
resources requestable	P1	2	1	0	1
	P2	0	2	0	1
	P3	0	1	4	0

- Consider the system state described by the table. Is it a safe state?
 - P2 may still request 2 R2, but only one is available
 - P3 may still request 4 R3, but only one is available
 - All that P1 can still request is available

Deadlock avoidance

Banker's algorithm (2)

		R1	R2	R3	R4
total resources		6	5	7	6
available resources		3	1	1	2
resources declared	P1	3	3	2	2
	P2	1	2	3	4
	P3	1	3	5	0
resources allocated	P1	1	2	2	1
	P2	1	0	3	3
	P3	1	2	1	0
resources requestable	P1	2	1	0	1
	P2	0	2	0	1
	P3	0	1	4	0
new request		—	—	—	—

- Consider the following sequence:
 - P1 requests all the resources it can still; the request is granted; then terminates
 - P2 requests all the resources it can still; the request is granted; then terminates
 - P3 requests all the resources it can still; the request is granted; then terminates

Deadlock avoidance

Banker's algorithm (3)

		R1	R2	R3	R4
total resources		6	5	7	6
available resources		3	1	1	2
resources declared	P1	3	3	2	2
	P2	1	2	3	4
	P3	1	3	5	0
resources allocated	P1	1	2	2	1
	P2	1	0	3	3
	P3	1	2	1	0
resources requestable	P1	2	1	0	1
	P2	0	2	0	1
	P3	0	1	4	0
new request	P3	0	0	2	0

- If P3 requests 2 resources of type R3, the grant is postponed. Why?
 - Because only 1 is available

Deadlock avoidance

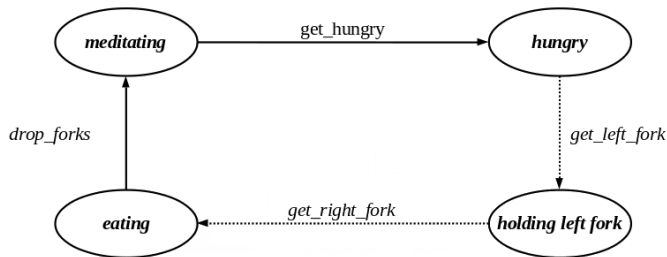
Banker's algorithm (4)

		R1	R2	R3	R4
total resources		6	5	7	6
available resources		3	1	1	2
resources declared	P1	3	3	2	2
	P2	1	2	3	4
	P3	1	3	5	0
resources allocated	P1	1	2	2	1
	P2	1	0	3	3
	P3	1	2	1	0
resources requestable	P1	2	1	0	1
	P2	0	2	0	1
	P3	0	1	4	0
new request	P3	0	1	0	0

- If P3 requests 1 resource of type R2, the grant is also postponed. Why?
 - Because, if the grant is given, the system transitions to an unsafe state. Show it.

Deadlock avoidance

Banker's algorithm - example



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

Deadlock detection

- No deadlock-prevention or deadlock-avoidance is used
 - So, deadlock situations may occur
 - The state of the system should be examined to determine whether a deadlock has occurred
 - A recover from deadlock procedure should exist and be applied
-
- What to do?
 - In a quite naive approach, the problem can simply be ignored
 - Otherwise, the circular chain of processes and resources need to be broken

Deadlock detection

Recover procedure

- How?
 - **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 an easy to implement method

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