Deadlock

2023/24 COMP3230B

Contents

- What is deadlock?
- Four necessary conditions of deadlock
- Deadlock prevention
- Deadlock avoidance
- Detection and recovery

Related Learning Outcome

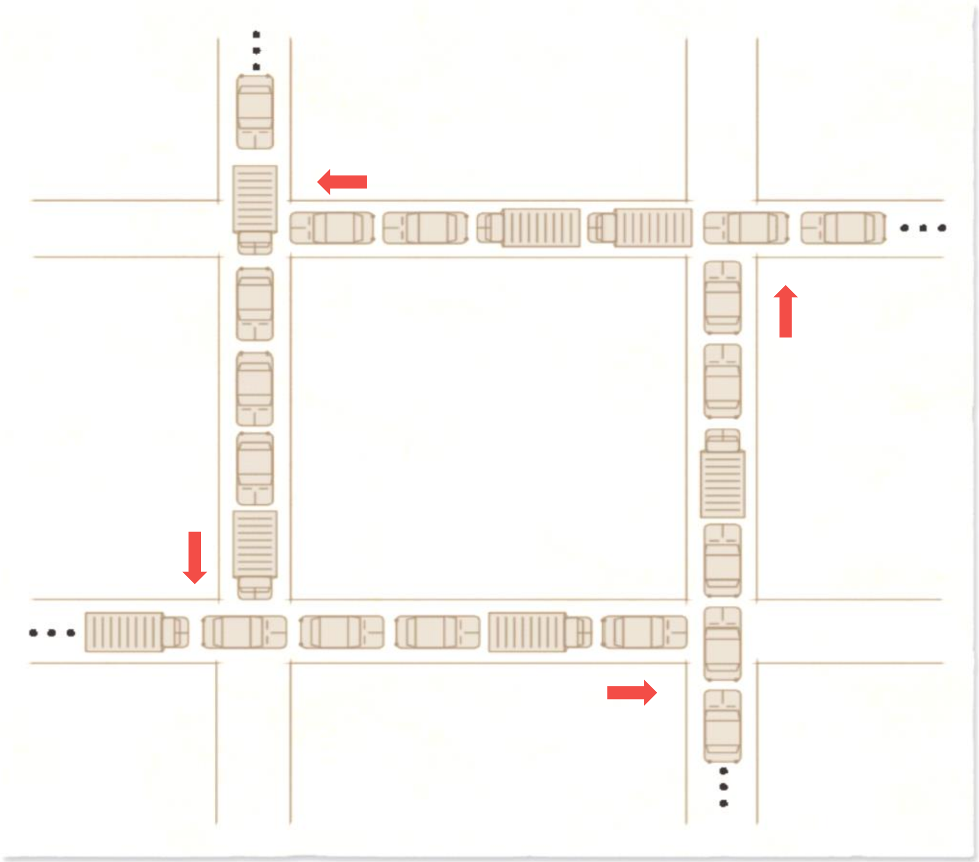
- ILO 2c - explain the underlying causes of deadlock issues and describe the principles and techniques used by OS to support concurrency control

Readings & References

- Required Reading
  - Chapter 32 – **Common Concurrency Problems**
    - http://pages.cs.wisc.edu/~remzi/OSTEP/threads-bugs.pdf

Deadlock Problem in Real Life

It's a system-wide tangle of resource requests, but the system is in a state that all requests cannot be fulfilled, and **the whole system** comes in a standstill.



The Deadlock Problem

- A set of threads each holding some system resources and block waiting to acquire another system resource held by another thread in the set.

- Example
  - System has 2 disk drives.
  - T1 and T2 each holds one disk drive and each needs another one.

- Example
  - Two binary semaphores A and B

```
T0            T1
wait (A);     wait(B)
wait (B);     wait(A)
```

Why do Deadlocks occur?

- In previous examples, if we detect the situations, probably deadlock would not happen

- Unfortunately, sometimes we cannot see how threads use their locks
  - e.g., in large code bases with complex dependencies
  - e.g., in programs with **external library functions**, as with encapsulation that hides the details of implementation

```
Vector vec1, vec2;

    Thread1                      Thread2
       :                            :
       :                            :
vec1.AddAll(vec2);           vec2.AddAll(vec1);
       :                            :
                                    :
```

To avoid race condition, AddAll() probably needs to lock both Vectors before performing the computation.

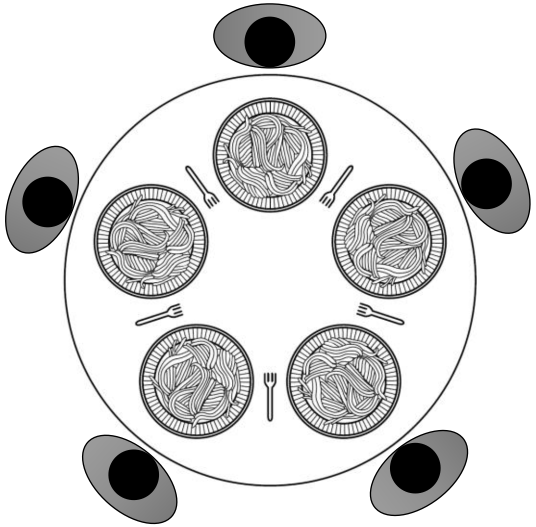
Classical Synchronization Problem

- Dining Philosophers
  - Five philosophers sit around a circular table. Each leads a simple life alternating between thinking and eating spaghetti. In front of each philosopher is a dish of spaghetti that is constantly replenished by a dedicated wait staff. There are exactly five forks on the table, one between each adjacent pair of philosophers. Eating spaghetti (in the most proper manner) requires that a philosopher uses both adjacent forks (simultaneously). Develop a concurrent program free of deadlock and indefinite postponement that models the activities of the philosophers.

Dining Philosophers

"The problem is famous because it is fun and somewhat intellectually interesting; however, its practical utility is low."

The key challenge is to show that your solution is without deadlock, no philosopher is being starved, and concurrency is high



```
philosopher

while (true) {
        think();
        eat();
}


eat() {
        pickupLeftFork();
        pickupRightFork();
        eatingSpaghetti();
        putdownRightFork();
        putdownLeftFork();
}
```

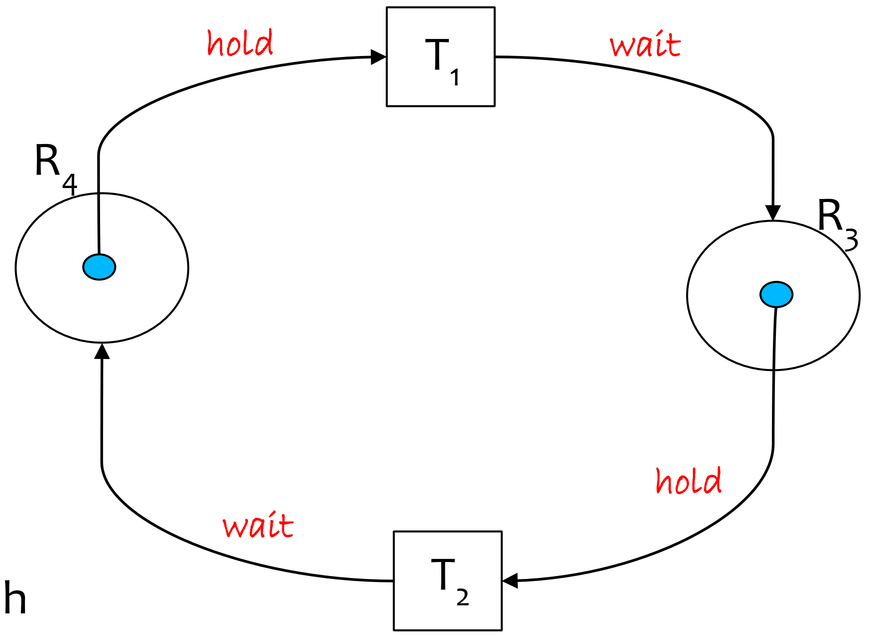
Is this solution working?

Necessary Conditions for Deadlock

- Four conditions must be hold for a deadlock to occur; if any of these are not met, deadlock CANNOT occur
  - ***Mutual exclusion condition***
    - Allow only one thread to have exclusive access to a resource
  - Wait-for condition (***hold-and-wait condition***)
    - A thread may hold some resources while awaiting assignment of additional resources
  - ***No-preemption condition***
    - No resource can be forcibly removed from a thread that holding it
  - ***Circular-wait condition***
    - Two or more threads are locked in a “circular chain” in which each thread is waiting for one or more resources that the next thread in the chain is holding

Circular-Wait Condition

- Thread T1 has been allocated resource R4 that is being requested by thread T2 that has been allocated resource R3 that is being requested by T1

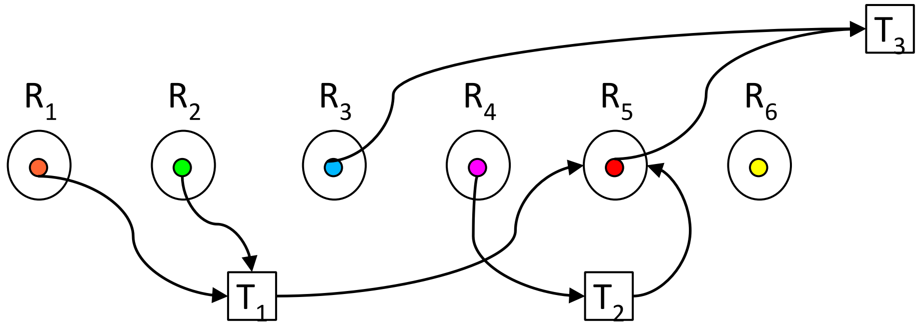


Resource-allocation graph

Deadlock Prevention

- By using restrictive policy in allocation of resources to remove any one of the four necessary conditions, deadlock cannot happen

- Prevent Circular-wait condition
  - **Imposes a total ordering** of all resource types, and requires that each threads **requests resources in** an increasing **order** of enumeration
  - Disadvantage:
    - Not all programs using resources in that order, but you are required to hold resources of smaller labels before granting resources of larger labels; this may lead to poor resource utilization



Deadlock Prevention

- Prevent Hold-and-wait condition
  - At start, thread gets all needed resources all at once or nothing
  - So the hold-and-wait condition is never satisfied
  - Disadvantages:
    - Low resource utilization
    - Starvation possible
      - a process requests many resources may have to wait for a longer time as this strategy favors waiting processes with small resource needs

- The Mutual Exclusion condition
  - Sharable resources, if allow non-mutually exclusive access, do not result in deadlock
    - Unfortunately, most sharable resources don’t support or work properly under non-mutual exclusive access

Deadlock Prevention

- Denying No-preemption condition
  - If a process that is holding some resources requests another resource but not immediately available, must **release all holding resources**
  - Process will be restarted only when it can regain its old resources, as well as the new ones that it is requesting
  - Disadvantages:
    - This can lead to substantial overhead
      - when a process releases resources, it may lose all of its work to that point; or it may have to undone all previous work before going to restart
    - possibility of starvation

Deadlock Avoidance

- Does not preventively remove one of the conditions for deadlock; instead, the system tries to avoid deadlock if it knows ahead of time all the resources requests associated **with each** of the threads

- Avoidance **requires some global knowledge** of which locks/resources various threads might grab during their execution
- Subsequently schedules the threads in a way as to guarantee no deadlock can occur

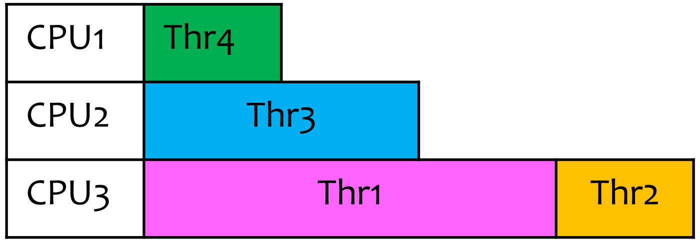
- Two approaches
  - Avoidance by scheduling
  - Banker's algorithm

Avoidance by Scheduling

- Given the resources needs of different concurrent threads, the system looks at their dependency and use it as a guideline in scheduling the threads to avoid deadlock

- Example

	Thr1	Thr2	Thr3	Thr4
R1	need	need	no	no
R2	need	need	need	no



  - If the system allows Thr1 & Thr2 to execute concurrently by different CPUs, there is a possibility of having deadlock
  - This approach is a bit conservative and may result in under utilization of the resources

Banker’s Algorithm

- Threads are allowed to hold locks/resources while requesting additional locks/resources
- System only grants the allocation of **additional** resources to a thread when the allocation **will not** result in an **unsafe state**
  - i.e., the system estimates that deadlock would not happen with the remaining resources
  - by means of checking whether with the remaining resources, there still exists a feasible allocation solution to satisfy all future demands from all threads that could lead to successful termination of all threads
- It has a number of weaknesses, such as
  - requiring to know ahead of time the resource needs as well as only works with a fixed number of threads and resources
    - e.g., if a device breaks and not available, the algorithm won’t work as this may cause the state to turn to unsafe

Banker's Algorithm

Declared maximum usage

Current usage

Future requests

	max()	**loan()**	**claim()**
T1	4	1	3
T2	6	4	2
T3	8	5	3
total=12		available=2	

Total unit of resources

Remain available

In this example, we only have one type of resource

If T1 asks for 1 unit, should the system grant this request?

If T2 asks for 1 unit, should the system grant this request?

Detection & Recovery

- Allow deadlocks to occasionally occur
    - "If a bad thing happens rarely, certainly one should not spend a great deal of effort to prevent it, particularly if the cost of the bad thing occurring is small"
- System takes action periodically to check whether deadlock has happened
    - Identifies processes and resources involved in the deadlock
    - Usually focus on determining if a circular wait exists
        - One technique for detecting deadlocks involves building a resource-allocation graph and looking for cycles
- Recovery
    - Solution 1: Abort all deadlocked processes
    - Solution 2: Abort one process at a time until the deadlock cycle is eliminated.
        - Successively preempt resources until deadlock no longer exists
    - No matter what, some processes become victims
        - Removal generally requires that the process be restarted from beginning or from a previous checkpoint

Summary

- Deadlock is a serious issue that commonly found in concurrent programs, such as OS, multithreaded programs, and highly parallel programs.
- When we identify a deadlock scenario, we always find the four necessary conditions appeared in that scenario
- Solutions to deadlock
  - Prevention – use restrictive rules or guidelines to deny one of the necessary conditions
    - it is the responsibility of the programmers to apply the rules / guidelines in their programs
  - Avoidance – require to have the global knowledge of locks / resources usage amongst all threads, and use these as the hint to allocate locks / resources to threads
    - Programmers are free to arrange their logic in resource acquisition; it is the responsibility of the systems to apply the strategy in avoiding deadlock
  - Detection and Recovery – a pragmatic solution with no much overhead most of the time, but need more effort in recovering from deadlock