Operating system

Part VII: Deadlock [死锁]

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Outline of topics covered by this course

- **INTRODUCTION** – why should we learn OS?
- **OVERVIEW** – what problems are considered by modern OS in more details?
- **EXECUTION** – CPU management
  - Process and Thread
  - CPU scheduling
- **EXECUTION – competition (synchronization problem)**
  - Synchronization
  - Deadlock

Device management

- Deadlock
  - Definition, Model
  - Four necessary conditions
- Methods for Handling Deadlocks
  - Providing **enough resources**
  - Staying Safe
    - **Preventing** Deadlocks
    - **Avoiding** Deadlocks
  - Living Dangerously
    - Let the deadlock happen, then **detect** it and **recover** from it.
    - **Ignore** the risks

However, it also will cause some problems if ….

- If there is **no controlled access** to shared data, execution of the processes on these data can interleave🡐 **Cooperation**.
  - The results will then depend on the order in wh… modified→ **Data Inconsistency**
    - i.e. the results are non-deterministi…

We have discussed this by **synchronization**

- Concurrent processes (or threads) often need to **share data** (maintained either in shared memory or files) and **resources**
  - If there is no proper policy to assign resources among processes, it may result in that all the processes get blocked → **Deadlock** [死锁]

http://www.vijayforvictory.com/tag/pictures/

Deadlock: General

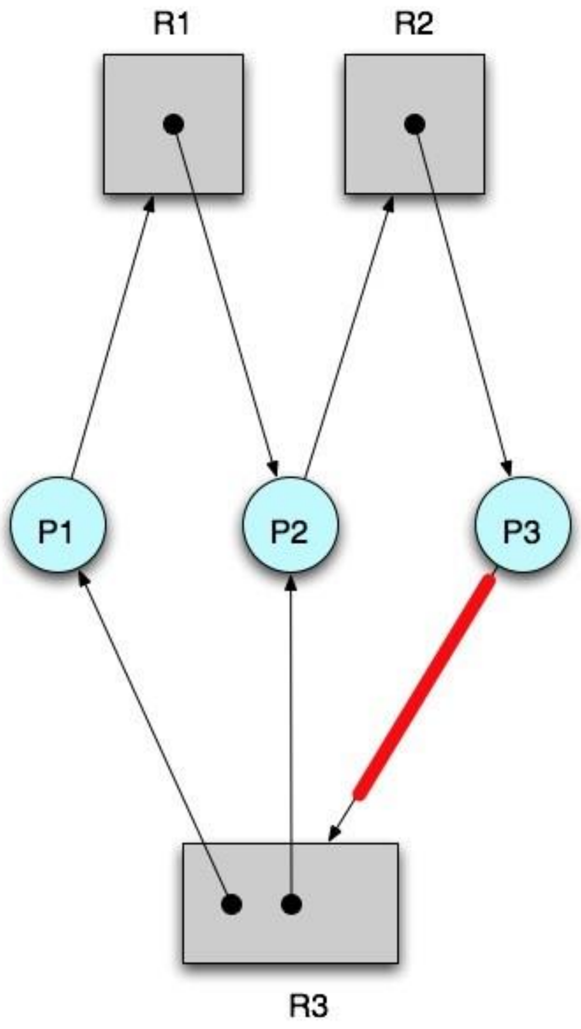
From Wikipedia, the free encyclopedia

- A deadlock is a situation wherein **two or more competing actions are waiting for the other to finish, and thus neither ever does**.
  - It is often seen in a paradox like the "chicken or the egg."

> 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.
>
> — Illogical statute passed by the Kansas Legislature

Deadlock in OS

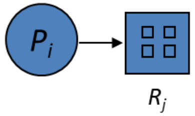
- A set of blocked processes each holding some resources and waiting to acquire a resource held by another process in the set.
- None of the processes can proceed or back-off (release resources it owns)



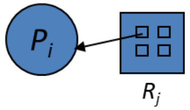
- Process

- Resource Type with 4 instanc

- P_i requests instance of R_j



- P_i is holding an instance of R_j



It seems … [Basic Facts, Theorem]

1. If there are enough materials for everyone, no deadlock at all!
2. When a deadlock occurs, four conditions must have been reached at the same time!

① Mutual Exclusion [互斥]

- At least one resource is non-sharable: at most one process at a time can use it

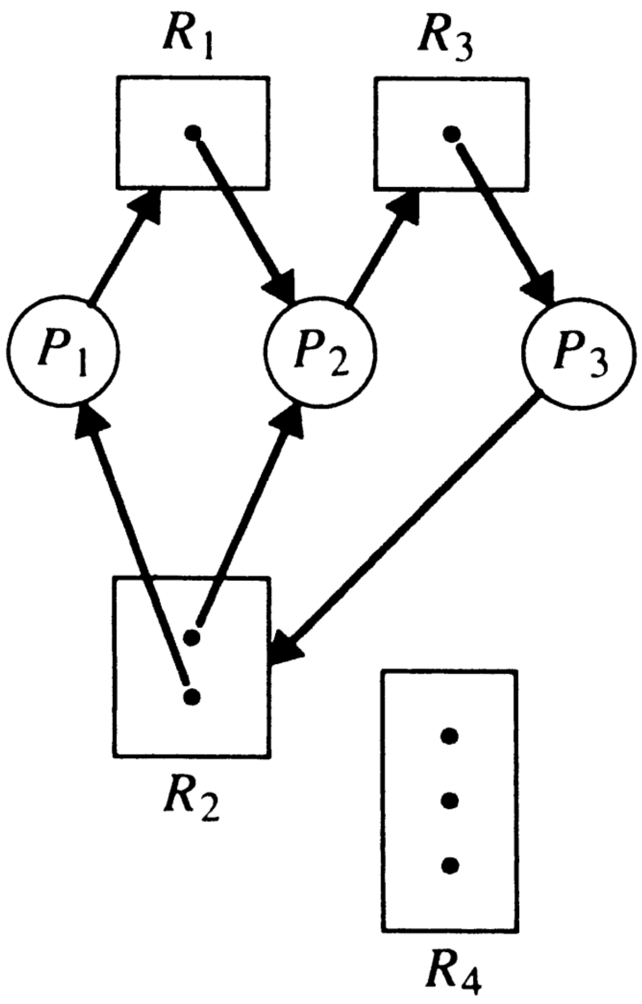
② Hold-and-Wait [占有并等待]

- At least one process is holding one resource while waiting to acquire others, that are being held by other processes

Deadlock can arise only if …

- A deadlock can arise only if all four conditions hold
  - ③ No preemption [非抢占]
    - A resource cannot be preempted (**a process needs to give it up voluntarily**)
  - ④ Circular Wait [循环等待]
    - There exists a set $\{P_0, P_1, \ldots, P_n\}$ of waiting processes such that
      - – P_i is waiting for a resource that is held by P_{i+1}, $0 \leq i < n$
      - – P_n is waiting for a resource that is held by P_0

Deadlock



Because you cannot find an execution sequence of the all three processes so that each of them can finishes its work finally.

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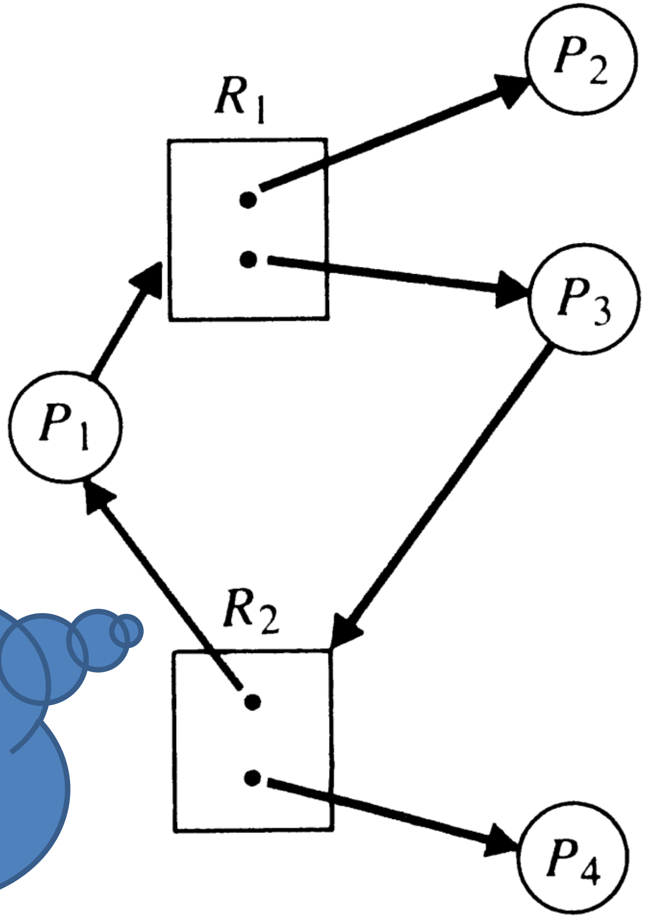
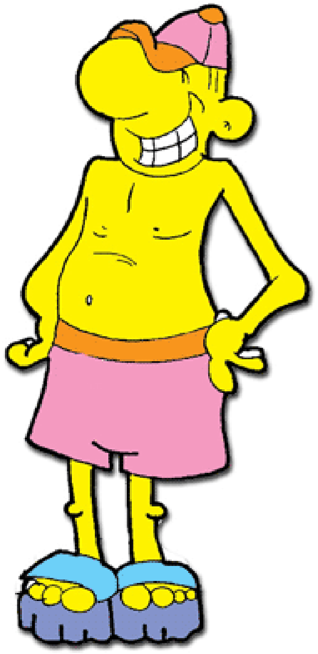
PPTs from others\www.dcs.ed.ac.uk_teaching_cs3_osslidesdeadlock.ppt

A cycle not sufficient to imply a deadlock:



Because there is a path of resource allocation to satisfy all the requirements



It seems …

1. If the graph contains no cycles, then no process is deadlocked.
2. If there is a cycle, then two situations:
   - If resource types have multiple instances, then deadlock **MAY** exist.
   - If each resource type has 1 instance, then deadlock has occurred.
     - The existence of a cycle is a sufficient and necessary condition for the existence of a deadlock
       - Each process involved in the cycle is deadlocked

Device management

- Deadlock
  - Definition, Model
- Methods for Handling Deadlocks
  - Providing **enough resources**
  - Staying Safe
    - **Preventing** Deadlocks
    - **Avoiding** Deadlocks
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    - **Ignore** the risks

Providing enough resources - A useful equation!

- Given:
  - Here are **3** processes: A, B, C. Each of them requires **5** system resources.
- Question:
  - How many resources should the system at least have so that the system is safe?
- Rule:
  - If the number of system resources satisfies the following equation, then the system is safe!

$$\sum (P_{\max} - 1) + 1 \leq R_{Total}$$

A useful equation!

$$\sum (P_{\max} - 1) + 1 \leq R_{Total}$$

- P_{max}: is the **max** number of the required resources by process P
- R_{total}: is the total resources the system has

- It could be simplified as follows, where N is the number of processes

$$(P_{\max} - 1) * N + 1 \leq R_{Total}$$

- It is easy to answer the given question:

$$(P_{\max} - 1) * N + 1 \leq R_{Total}$$

- According to the above equation
  - N is 3
  - P_{max} is 5

  - So, there should be at least (5-1)*3+1 = 13 resources in the system, then the system is in safe!

Variations

- Question:
  - A system has 10 tape drivers, which are shared by m processes, and each process requires 3 tape drivers at most. So, what should “m” be then the system could be in safe?

    A.3 B.4 C.5 D.6
- By that equation, we have
  - (3-1)*m+1 <= 10
  - So, m <= 4.5
  - B is the answer

Staying Safe - Deadlock Prevention (预防)

- Do not allow one of the four conditions to occur.
  - **Mutual Exclusion** [互斥]
    - Only one process may use a resource at a time
  - **Hold and Wait** [持有和等待]
    - A process may hold allocated resources while awaiting assignment of others
  - **No Preemption** [非抢占]
    - No resource can be forcibly removed form a process holding it
  - **Circular Wait** [循环等待]
    - A closed chain of processes exists, such that each process holds at least one resource needed by the next process in the chain

Deadlock Prevention - **negating Hold and Wait**

- Two strategies
  1. When the process begins, all the resources required by it should be assigned to it
     - inefficient - not all resources needed all the time
     - processes probably will not know in advance what resources they will need
     - may have to wait excessive time to get all resources at once - starvation
       - high priority processes may cause starvation of low priority processes

- Two strategies
  2. When a new request is needed by a processes
     A. it could release existing resources it holds if it fails to get a new resource immediately (try again later)
     B. the process always releases its existing resources and asks for all of them at once

Deadlock Prevention - **negating Circular Wait**

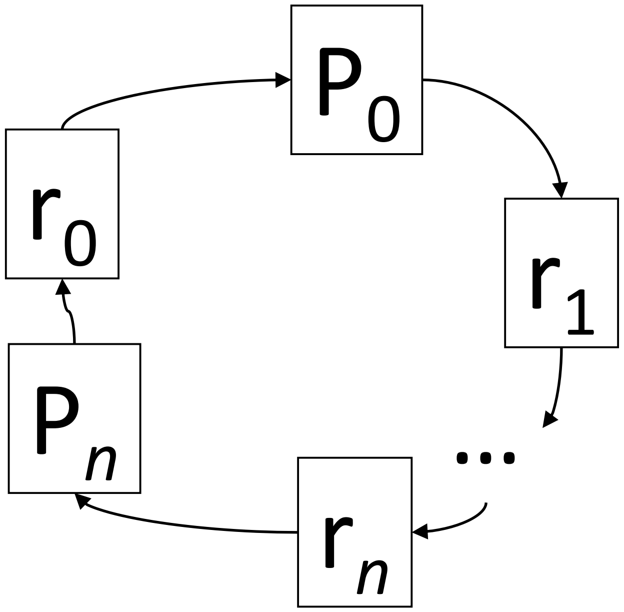
- Ordered resource allocation [资源顺序分配法]
  - Quite popular in management science (such as MBA)
  - Steps:
    - Assign each resource class with a unique number

$$
\begin{array}{cccc}
r_1, & r_2, & \ldots, & r_i \\
\downarrow & \downarrow & & \downarrow \\
1 & 2 & & i
\end{array}
\qquad F(r_i) = i
$$

    - The process should apply for all its required m-class resources following the order of resource class numbers

- Since all the resources lower m… re the process requires the resource… not be cycle!

This implies … request has been known. You’ve to propose your request at the beginning



NO WAY!

Staying Safe - Deadlock Avoidance (避免)

- Deadlock prevention → low device utilization and reduced system throughput.
- Deadlock avoidance
  - Given the complete sequence of requests and releases for each process, we can decide for each request whether or not the process should wait.
  - For every request, the system
    - considers the resources currently **available**, the resources currently **allocated**, and the **future (Needed)** requests and releases of each process, and
    - decides whether the current request can be satisfied or must wait to avoid a possible future deadlock.

Example 2:

- 5 processes P_0 through P_4;

  3 resource types:

  A (**10** instances), B (**5**instances), 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	
P_2	3 0 2	9 0 2	
P_3	2 1 1	2 2 2	
P_4	0 0 2	4 3 3	

Example 2 (cont')

- We can compute the matrix ***Need*** as ***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

Available

A	B	C
3	3	2

SAFE or not is determined by if we could find a sequence!

P3

Example 2 (cont')

	Need
	A B C
P0	7 4 3
P1	1 2 2
P2	6 0 0
P3	**0 0 0**
P4	4 3 1

Available
A B C
5 4 3

- Compare the available resources and the needed resources for each process to find if there is some process whose requirement could be satisfied.
  - P1 1 2 2
  - P3 0 1 1
- Randomly select one, here we select P3
- The available now is
  - <3, 3, 2> + <2,1,1> ➔ <5, 4, 3>

	Allocation
P3	2 1 1

Example 2 (cont')

P3 ➡ P1

	Need
	A B C
P0	7 4 3
P1	**0 0 0**
P2	6 0 0
P3	**0 0 0**
P4	4 3 1

Available
A B C
7 4 3

- Similarly, there are two processes whose requirements could be satisfied.
  - P1 1 2 2
  - P4 4 3 1
- Randomly select one, here we select P1
- The available now is
  - <5, 4, 3> + <2,0,0> ➔ <7, 4, 3>

	Allocation
P1	2 0 0

P3 ➡ P1 ➡ P0 ➡ P2 ➡ P4

Example 2 (cont’)

	Need
	A B C
P0	7 4 3
P1	**0 0 0**
P2	6 0 0
P3	**0 0 0**
P4	4 3 1

Available

A B C

7 4 3

- Similarly, there are three processes whose requirements could be satisfied.
  - P0 7 4 3
  - P2 6 0 0
  - P4 4 3 1
- We can direc
  processes co
  - P0 ➔ P2 ➔

So, system is safe at the snapshot time t0!

Example 2:

- How about the snapshot as follows?

	Allocation		Need	Available
	A B C		A B C	A B C
P0	0 1 0	P0	7 4 3	1 1 1
P1	2 0 0	P1	1 2 2	
P2	3 0 2	P2	6 0 0	
P3	2 1 1	P3	0 1 1	
P4	0 0 2	P4	4 3 1	

P3

Example 2 (cont')

	Need
	A B C
P0	7 4 3
P1	1 2 2
P2	6 0 0
P3	**0 0 0**
P4	4 3 1

Available

A B C

3 2 2

- Compare the available resources and the needed resources for each process to find if there is some process whose requirement could be satisfied.
  - P3 0 1 1
- So we select P3
- The available now is
  - <1, 1, 1> + <2,1,1> ➔ <3, 2, 2>

	Allocation
P3	2 1 1

P3 ➡ P1

Example 2 (cont')

	Need
	A B C
P0	7 4 3
P1	**1 2 2**
P2	6 0 0
P3	**0 0 0**
P4	4 3 1

Available

A B C

5 2 2

- Similarly, we can see P1 could be satisfied.
  - P1 1 2 2
- So we select P1
- The available now is
  - <3, 2, 2> + <2,0,0> ➔ <5, 2, 2>

	Allocation
P1	2 0 0

P3 ➡ P1

Example 2 (cont')

	Need
	A B C
P0	7 4 3
P1	**0 0 0**
P2	6 0 0
P3	**0 0 0**
P4	4 3 1

Available

A B C

5 2 2

- After P1, available res is <5, 2, 2>
- Sadly, this time, the rest three processes could not be satisfied <5, 2, 2>.
  - P0 7 4 3
  - P2 6 0 0
  - P4 4 3 1
- This means it is not safe for the snapshot of example 2!

Example 3:

- 5 processes P_0 through P_4;
  3 resource types:
  A (**10** instances), B (**5**instances), 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	
P_2	3 0 2	9 0 2	
P_3	2 1 1	2 2 2	
P_4	0 0 2	4 3 3	

Could the request of P0=<2 1 1> be satisfied or not?

- The logic for that satisfaction is
  - Pretend to satisfy the request first, and check if the change will lead the system into unsafe state or not
    - Still safe, the request could be satisfied
- We need update the resource allocation first – the **available** and the **needed** for P0

	Allocation	***Needed***	**Available**
	A B C	*A B C*	A B C
P0	**2 2 1**	**5 3 2**	**1 2 1**
P1	2 0 0	1 2 2	
P2	3 0 2	6 0 0	
P3	2 1 1	0 1 1	
P4	0 0 2	4 3 1	

You've learned how to verify if the system is safe or not from **Example 1**

Drawbacks of Banker's Algorithm

- processes are rarely known in advance how many resources they will need
- the number of processes changes as time progresses
- resources once available can disappear
- the algorithm assumes processes will return their resources within a reasonable time
- processes may only get their resources after an arbitrarily long delay
- **practical use is therefore rare**!

Living Dangerously -

- the Ostrich[鸵鸟] or **Head-in-the-Sand** algorithm

D.J.[ˈɔstritʃ]

- **Of course**, Try to reduce chance of deadlock as far as reasonable
- **And**, accept that deadlocks will occur occasionally
  – example: kernel table sizes - max number of pages, open files etc.
- **Because**, maybe
  – MTBF versus deadlock probability ?
  – cost of any other strategy may be too high
    - overheads and efficiency

MTBF : mean-time between "failures"

Most Operating systems do this!!

Maybe it's better

– "**Don't hide** from the fact…, Be alert!"

When deadlock happened - Detect & Recover

- **Check** for deadlock (periodically or sporadically[偶发地,零星地]), then **recover**

- Differentiate between
  - Serially reusable resources: A unit must be allocated before being released
  - Consumable resources: Never release acquired resources; resource count is the number currently available

PPTs from others\cms.dt.uh.edu\chap10.ppt

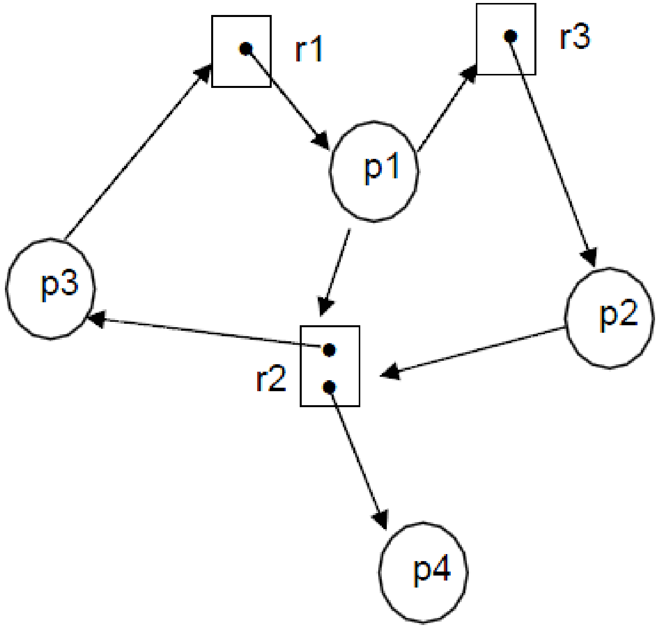
Borrow Banker's algorithm for several instances

Available = [0 0 0]

$$\text{Allocation} = \begin{bmatrix} 1 & 0 & 0 \\ 0 & 1 & 0 \\ 0 & 0 & 1 \\ 0 & 0 & 1 \end{bmatrix}$$

$$\text{Request} = \begin{bmatrix} 0 & 1 & 1 \\ 0 & 0 & 1 \\ 1 & 0 & 0 \\ 0 & 0 & 0 \end{bmatrix}$$

$$\text{Finish} = \begin{bmatrix} False \\ False \\ False \\ False \end{bmatrix}$$



- Find if there is a sequence of the involved processes to finish
  - If all the values in Finish vector are TRUE or not

Recovery

- Two strategies
  1. 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?
     - Priority of the process.
     - How long process has computed, and how much longer to completion.
     - Resources the process has used.
     - Resources process needs to complete.
     - How many processes will need to be terminated.
     - Is process interactive or batch?

Recovery

- Two strategies
  2. Resource Preemption
     - Choose a blocked process
     - Preempt it (releasing its resources)
       – Back up each deadlocked process to some previously defined checkpoint
     - Run the detection algorithm
     - Iterate it until the state is not a deadlock state

  – Selection Criteria Deadlocked Processes
     - Least amount of processor time consumed so far
     - Least number of lines of output produced so far
     - Most estimated time remaining
     - Least total resources allocated so far
     - Lowest priority

Combined Approach to Deadlock Handling

- Combine the three basic approaches (**prevention**, **avoidance**, and **detection**), allowing the use of the optimal approach for each class of resources in the system.
- Partition resources into hierarchically ordered classes； Use most appropriate technique for handling deadlocks within each class.
- An example:
  - Internal resources (Prevention through resource ordering)
  - Central memory (Prevention through preemption)
  - Job resources (Avoidance)
  - Swappable space (Pre-allocation)

In conclusion

- Deadlock is a situation wherein two or more competing actions are waiting for the other to finish, and thus neither ever does.
- Four necessary conditions
  - Mutual Exclusion [互斥]
  - Hold-and-Wait [占有并等待]
  - No preemption [非抢占]
  - Circular Wait [循环等待]
- Strategies to overcome the deadlock situation
  - Providing enough resources
  - Staying Safe
    - **Preventing** Deadlocks
    - **Avoiding** Deadlocks → **Banker's algorithm**!
  - Living Dangerously
    - Let the deadlock happen, then **detect** it and **recover** from it.

- ICQ B [10 pts]
  - Next week
  - 1 hour, close
  - Blank-filling, Multiple choice, Computation