0117401: Operating System
计算机原理与设计

Chapter 11: File system implementation(文件系统实现)

陈香兰
xlanchen@ustc.edu.cn
http://staff.ustc.edu.cn/~xlanchen

Computer Application Laboratory, CS, USTC @ Hefei
Embedded System Laboratory, CS, USTC @ Suzhou

May 25, 2015

温馨提示：

为了您和他人的工作学习，
请在课堂上关机或静音。

不要在课堂上接打电话。

提纲

Outline

File-System Structure

- File structure
  - Logical storage unit
  - Collection of related information
- FS resides on secondary storage (disks)
- FS organization
  - How FS should look to the user
  - How to map the logical FS onto the physical secondary-storage devices
- FS organized into layers

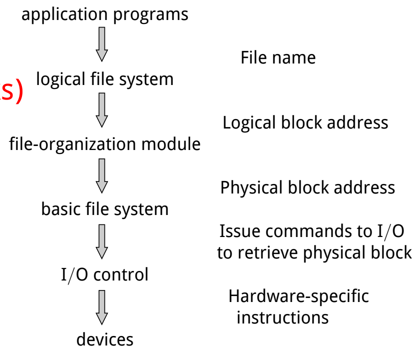


Figure: Layered File System

Outline

2 FS Implementation

FS Implementation

- Structures and operations used to implement file system operation, OS- & FS-dependment
  1. On-disk structures
  2. In-memory structures

FS Implementation

1. On-disk structures
   1. Boot control block
      - To boot an OS from the partition (volume)
      - If empty, no OS is contained on the partition
   2. Volume control block
   3. Directory structure
   4. Per-file FCB

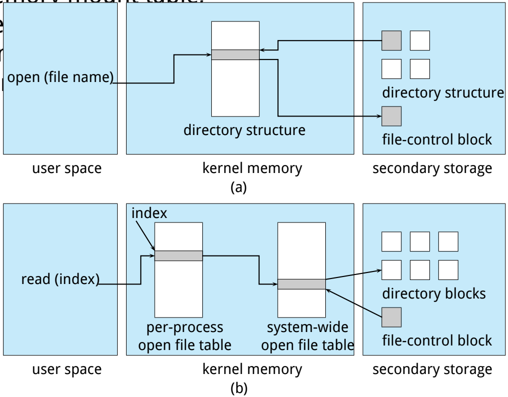
file permissions
file dates (create, access, write)
file owner, group, ACL
file size
file data blocks or pointers to file data blocks

Figure: A typical file control block

2. In-memory information: For both FS management and performence improvement via caching
   - Data are loaded at mount time and discarded at dismount
   - Structures include:
     - in-memory mount table;
     - in-memory directory-structure cache
     - system-wide open-file table;
     - per-process open-file table

FS Implementation

2. In-memory information: For both FS management and performence improvement via caching
   - Data are loaded at mount time and discarded at dismount
   - Structures include:
     - in-memory mount table:
     - in-me
     - syster
     - per-p

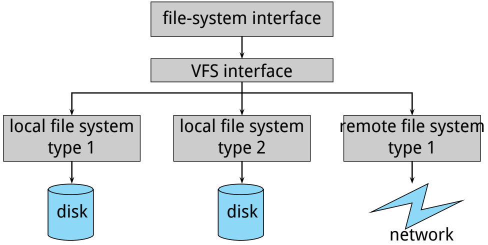


Partitions and mounting

- Partition (分区)
  - Raw (E.g. UNIX swap space & some database) VS. cooked
  - Boot information, with its own format
    - Boot image
    - Boot loader unstanding multiple FSes & OSes
      Dual-boot
- Root partition is mounted at boot time
- Others can be automatically mounted at boot or manually mounted later

Virtual File Systems (虚拟文件系统)

- Virtual File Systems (VFS, 虚拟文件系统) provide an object-oriented way of implementing file systems.
- VFS allows the same system call interface (the API) to be used for different types of file systems.
- The API is to the VFS interface, rather than any specific type of file system.



Schematic View of Virtual File System

Outline

3 Directory Implementation

Directory Implementation

1. Linear list of file names with pointer to the data blocks.
   - Simple to program
   - Time-consuming to execute
2. Hash Table – linear list with hash data structure.
   - Decreases directory search time
   - Collisions – situations where two file names hash to the same location
   - Fixed & variable size or chained-overflow hash table

Outline

Allocation Methods (分配方法)

- An allocation method refers to
  how disk blocks are allocated for files
  so that disk space is utilized effectively
  & files can be accessed quickly

  1. Contiguous allocation (连续分配)
  2. Linked allocation (链接分配)
  3. Indexed allocation (索引分配)
  4. Combined (组合方式)

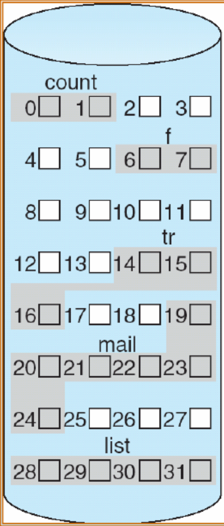
1. Contiguous Allocation (连续分配) I

- Each file occupies a set of contiguous blocks on the disk
- Simple – directory entry only need
  - starting location (block #)
  - & length (number of blocks)
- Mapping from logical to physical

  LogicalAddress$/512 =$ Q$\ldots\ldots$R

  Block to be accessed = Q + starting address

  Displacement into block = R



directory

file	start	length
count	0	2
tr	14	3
mail	19	6
list	28	4
f	6	2

1. Contiguous Allocation (连续分配) III

- Advantages:
  - Support both random & sequential access
    - Start block: b;
      Logical block number: i
      ⇒physical block number: b + i
    - Fast access speed, because of short head movement
- Disadvantages:
  - External fragmentation
    - Wasteful of space (dynamic storage-allocation problem).
  - Files cannot grow,
    or File size must be known in advance.
    ⇒Internal fragmentation

Extent-Based Systems

- Many newer file systems (I.e. Veritas File System) use a modified contiguous allocation scheme
- Extent-based file systems allocate disk blocks in extents
- An extent is a contiguous block of disks
  - Extents are allocated for file allocation
  - A file consists of one or more extents.

2. Linked Allocation (链接分配)

- Each file is a linked list of disk blocks: blocks may be scattered anywhere on the disk.
- Two types
  1. Implicit (隐式链接)
  2. Explicit (显式链接)

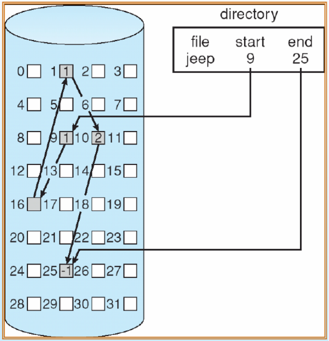
2. Linked Allocation (链接分配)

1 Implicit (隐式链接)

- Directory contains a pointer to the first block & last block of the file.
- Each block contains a pointer to to the next block.

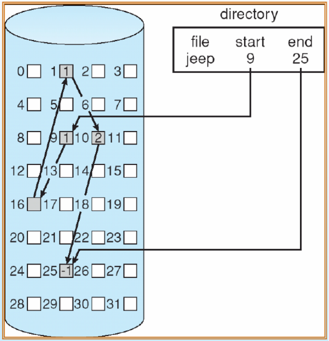
a block = pointer

- Allocate as needed, link together
  - Simple – need only starting address
  - Free-space management system – no waste of space



1 Implicit (隐式链接)

- Disadvantage:
  - No random access
  - Link pointers need disk sapce
    E.g.: 512 per block, 4 per pointer $\Rightarrow$0.78%
    Solution: clusters
    $\Rightarrow$ disk throughput $\uparrow$
    But internal fragmentation$\uparrow$



❶ Implicit (隐式链接)

- **Mapping:**

  Suppose

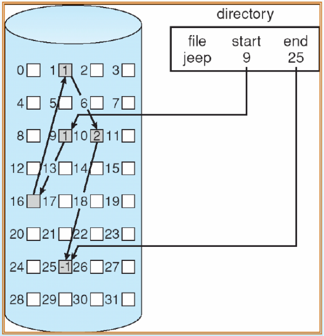
  1. block size=512bytes,
  2. block pointer size=1byte, using the first byte of a block
  3. Logical address in the file to be accessed = A

  we have

  1. Data size for each block $=512 - 1 = 511$
  2. $A/511 =$ Q . . . . . . R

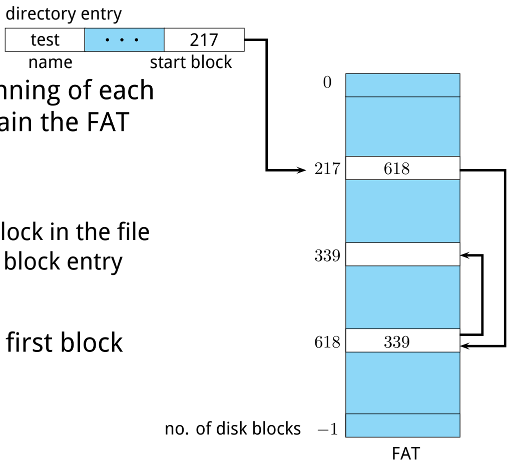
  then

  1. Block to be accessed is the Qth block in the linked chain of blocks representing the file.
  2. Displacement into block = R + 1



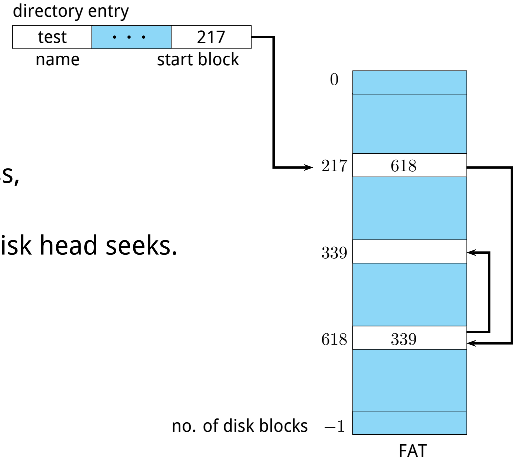
- **How to reduce searching time?**

2. **Explicit linked allocation: File Allocation table, FAT**
   Disk-space allocation used by MS-DOS and OS/2



- A section of disk at the beginning of each partition is set aside to contain the FAT
  - Each disk block one entry
  - The entry contains
    (1) the index of the next block in the file
    (2) end-of-file, for the last block entry
    (3) 0, for unused block
- Directory entry contains the first block number

2. Explicit linked allocation: File Allocation table, FAT
Disk-space allocation used by MS-DOS and OS/2



- Now support random access, but still not very efficient
- May result in a significant disk head seeks. Solution: Cached FAT

2. **Explicit linked allocation: File Allocation table, FAT**
   Disk-space allocation used by MS-DOS and OS/2

- **How to compute FAT size?**

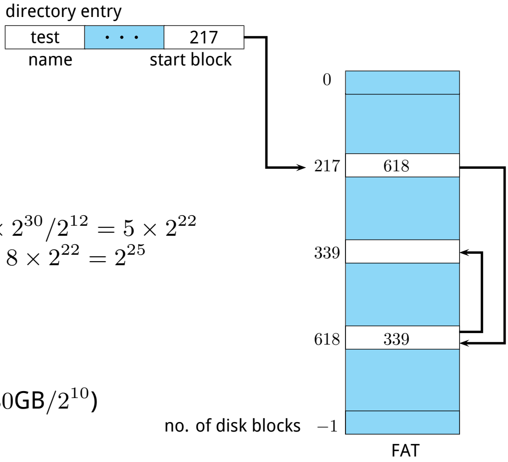
  Suppose

  1. Disk space = 80 GB
  2. Block size = 4 KB

  Then

  1. Total block number = $80 \times 2^{30}/2^{12} = 5 \times 2^{22}$
  2. $4 \times 2^{22} = 2^{24} < 5 \times 2^{22} < 8 \times 2^{22} = 2^{25}$

  - **Length of each FAT entry?**
    (25bits? 28bits? 32bits?)
  - **Length of FAT?**
    ($5 \times 2^{22} \times 4$B $= 80$MB $= 80$GB$/2^{10}$)

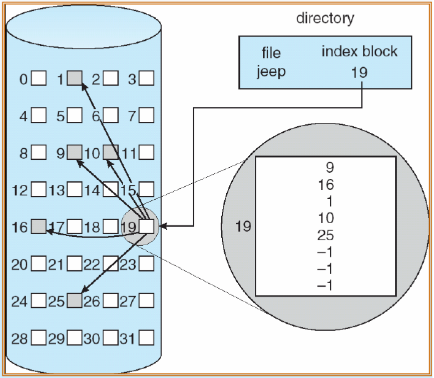


3. Indexed Allocation (索引分配)

- Indexed Allocation (索引分配):
  Brings all pointers together into one location – the index block.

- Each file has its own index block
- Directory entry contains the index block address
- Each index block: An array of pointers (an index table)

Logical block number i $=$ the i[th] pointer

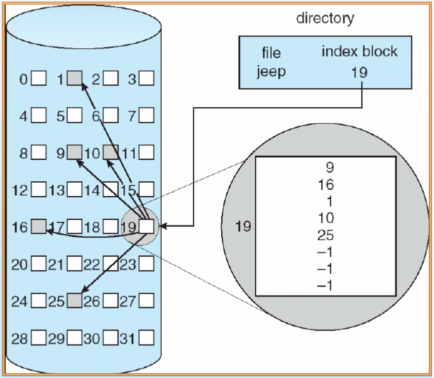


3. Indexed Allocation (索引分配)

- Indexed Allocation (索引分配):
  Brings all pointers together into one location – the index block.

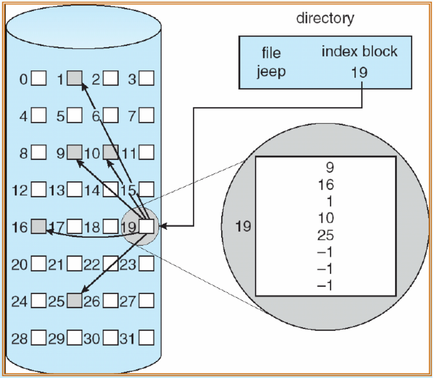
- Advantage:
  - Random access
  - Dynamic access without external fragmentation

- Disadvantage:
  - have overhead of index block.
  - File size limitation, since one index block can contains limited pointers



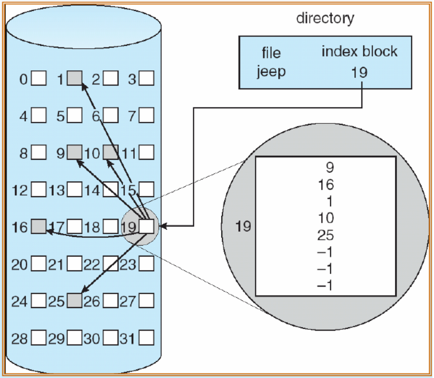
- Indexed Allocation (索引分配):
  Brings all pointers together into one location – the index block.

- Mapping from logical to physical
  Suppose
  (1) Block size = 1KB
  (2) Index size = 4B
  Then for logical address LA, we have
  $\mathrm{LA}/512 = \mathrm{Q}...\mathrm{R}$
  (3)Q = the index of the pointer
  (4)R = displacement into block
  We also have Max file size
  $= 2^{10}/4 \times 1\mathrm{KB} = 256\mathrm{KB}$



3. Indexed Allocation (索引分配)

- Indexed Allocation (索引分配):
  Brings all pointers together into one location – the index block.



- How to support a file of unbounded length?
  1. linked scheme
  2. multi-level index scheme

3. Indexed Allocation (索引分配)

1. Linked scheme
   - Link blocks of index table (no limit on size).
   - Mapping

     Suppose

     (1) Block size=1KB

     (2) Index or link pointer size = 4B

     Then

     $$\text{LA}/\left(1\text{KB}\times(1\text{K}/4-1)\right)=\text{Q}_1\ldots\text{R}_1$$

     (3) Q_1 = block of index table

     (4) R_1 is used as follows:

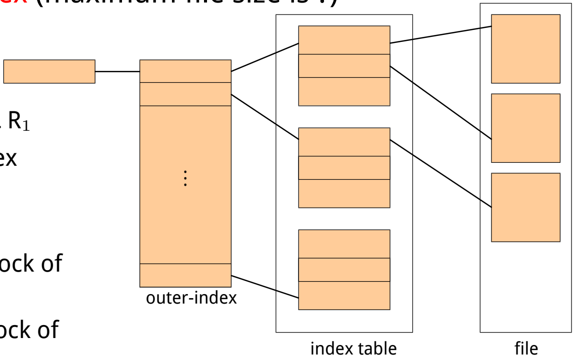
     $$\text{R}_1/1\text{K}=\text{Q}_2\ldots\ldots\text{R}_2$$

     (5) Q_2 = index into block of index table

     (6) R_2 = displacement into block of file:

multi-level index scheme

Example: Two-level index (maximum file size is ?)



- We have

$$LA/(1K \times 1K/4) = Q_1 \ldots R_1$$

(1) Q_1 = index into outer-index

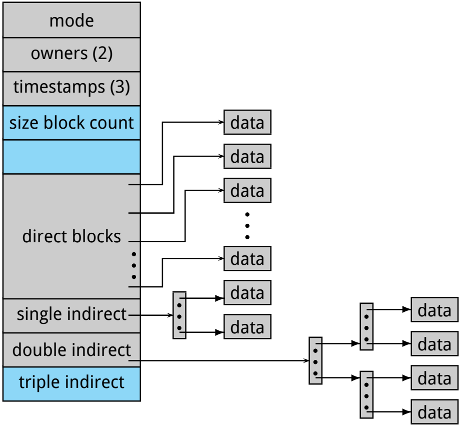
(2) R_1 is used as follows:

$$R_1/1KB = Q_2 \ldots R_2$$

(3) Q_2 = displacement into block of index table

(4) R_2 = displacement into block of file

4. Combined Scheme (组合方式): UNIX (4K bytes per block) I



4. Combined Scheme (组合方式): UNIX (4K bytes per block) II

- if 4KB per block, and 4B per entry

$$
\begin{aligned}
\text{Direct blocks} &= 10 \times 4\text{KB} = 40\text{KB} \\
\text{Number of entries per block} &= 4\text{KB}/4\text{B} = 1\text{K} \\
\text{Single indirect} &= 1\text{K} \times 4\text{KB} = 4\text{MB} \\
\text{Double indirect} &= 1\text{K} \times 4\text{MB} = 4\text{GB} \\
\text{Triple indirect} &= 1\text{K} \times 4\text{GB} = 4\text{TB}
\end{aligned}
$$

Maximnm file size = ?

Outline

Free-Space Management

- Disk Space: limited
  - Free space management: To keep track of free disk space
  - How? Free-space list?
  - Algorithms
    1. Bit vector
    2. Linked list
    3. Grouping (成组链接法)
    4. Counting

Free-Space Management

1. Bit vector
   - Free-space list is implemented as a bit map or bit vector
     - 1 bit for each block
       1=free;
       0=allocated
     - Example:
       a disk where blocks 2,3,4,5,8,9,10,11,12,13,17,18,25,26,27 are free and the rest blocks are allocated. The bitmap would be

$$0011\ 1100\ 1111\ 1100\ 0110\ 0000\ 0111\ 0000\ 0\ldots$$

     - Bit map length.
       For n blocks, if the base unit is word, and the size of word is 16 bits, then

$$\text{bit map length} = (n + 15)/16$$

       U16 bitMap[bitMaptLength];

Free-Space Management

1. Bit vector
   - How to find the first free block or n consecutive free blocks on the disk?
     - Many computers supply bit-manipulation instructions
     - To find the first free block:
       Suppose: base unit = word (16 bits) or other
       (1) find the first non-0 word
       (2) find the first 1 bit in the first non-0 word
     - If first K words is 0, & $(K+1)^{th}$ word > 0,
       the first $(K+1)^{th}$ word's first 1 bit has offset L,
       then

$$\text{first free block number } N = K \times 16 + L$$

Free-Space Management

1. Bit vector
   - Simple
   - Must be kept on disk
     Bit map requires extra space,
     Example:
       block size = 2^{12} bytes
       disk size = 2^{30} bytes (1 gigabyte)
       n = $2^{30}/2^{12} = 2^{18}$ bits (or 32K bytes)
       - Solution: Clustering

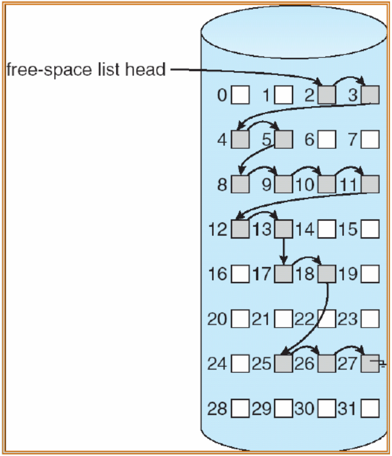
Free-Space Management

1. Bit vector
   - Efficient to get the first free block or n consecutive free blocks, if we can always store the vector in memory.
     - But copy in memory and disk may differ.
       E.g.   bit[i] = 1 in memory & bit[i] = 0 on disk
     - Solution:
       Set bit[i] = 1 in memory.
       Allocate block[i]
       Set bit[i] = 1 in disk
   - Need to protect:
     - Pointer to free list
     - Bit map

Free-Space Management

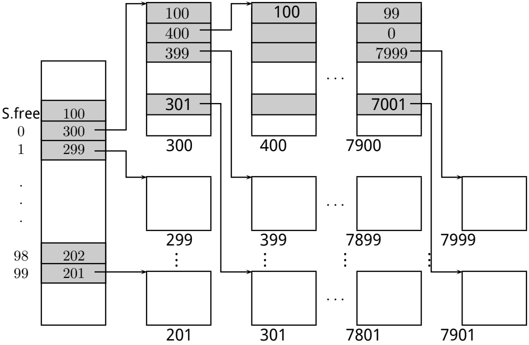
② Linked Free Space List on Disk

- Link together all the free disk blocks
  - First free block
  - Next pointer
- Not efficient
- Cannot get contiguous space easily
- No waste of space



Free-Space Management

3. Grouping(成组链接法)
   - To store the addresses of n free blocks (a group) in the first free block
     - First n-1 group members are actually free
     - Last one contain the next group
     - And so on
   - E.g.: UNIX



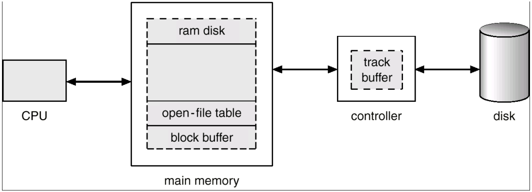
4. Counting
   - Assume:
     - Several contiguous blocks may be allocated or freed simultaneously
   - Each = first free block number & a counter (number of free blocks)
   - Shorter than linked list at most time, counter > 1

Outline

Efficiency

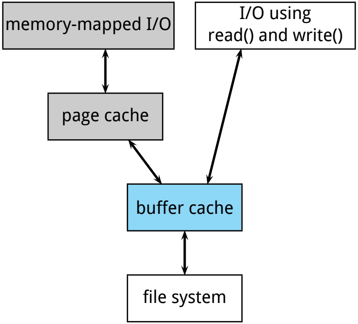
- Efficiency dependent on:
  - Disk allocation and directory algorithms
  - Various approaches
    - Inodes distribution
    - Variable cluster size
    - Types of data kept in file’ s directory entry
    - Large pointers provides larger file length, but cost more disk space

- Performance
  - disk cache – separate section of main memory for frequently used blocks
  - free-behind and read-ahead – techniques to optimize sequential access
  - improve PC performance by dedicating section of memory as virtual disk, or RAM disk



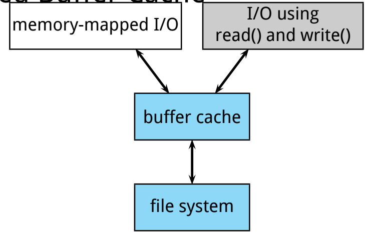
Page Cache I

- A page cache caches pages rather than disk blocks using virtual memory techniques
- Memory-mapped I/O uses a page cache
- Routine I/O through the file system uses the buffer (disk) cache
- This leads to the following figure
  - I/O Without a Unified Buffer Cache



Unified Buffer Cache

- A unified buffer cache uses the same page cache to cache both memory-mapped pages and ordinary file system I/O
- I/O Using a Unified Buffer Cache



Outline

Recovery

- Consistency checking (一致性检查)
  - compares data in directory structure with data blocks on disk, and tries to fix inconsistencies
- Backup & restore
  - Use system programs to back up data from disk to another storage device (floppy disk, magnetic tape, other magnetic disk, optical)
  - Recover lost file or disk by restoring data from backup

Outline

Log Structured File Systems

- Log structured (or journaling) file systems record each update to the file system as a transaction
- All transactions are written to a log
  - A transaction is considered committed once it is written to the log
  - However, the file system may not yet be updated
- The transactions in the log are asynchronously written to the file system
  - When the file system is modified, the transaction is removed from the log
- If the file system crashes, all remaining transactions in the log must still be performed

Outline

小结

谢谢！