0117401: Operating System
计算机原理与设计

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

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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

- File-System Structure
- FS Implementation
- Directory Implementation
- Allocation Methods（分配方法）
- Free-Space Management
- Efficiency（空间）and Performance（时间）
- Recovery
- Log Structured File Systems
- 小结和作业

Outline

File-System Structure

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

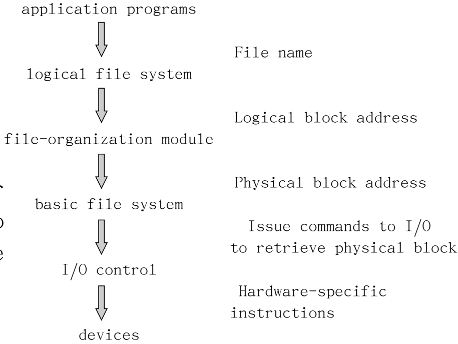


Figure: Layered File System

Outline

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
   1.1 Boot control block
      - To boot an OS from the partition (volume)
      - If empty, no OS is contained on the partition
   1.2 Volume control block
   1.3 Directory structure
   1.4 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

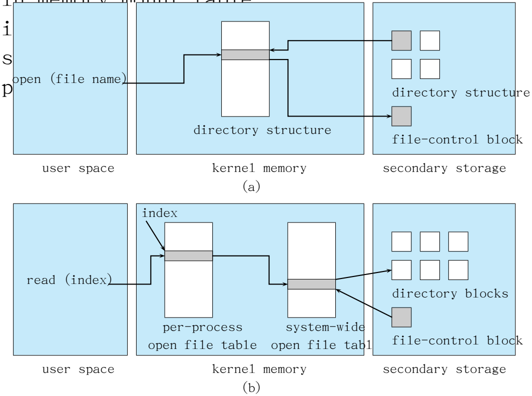
Figure: A typical file control block

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-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;
     - i
     - s
     - p

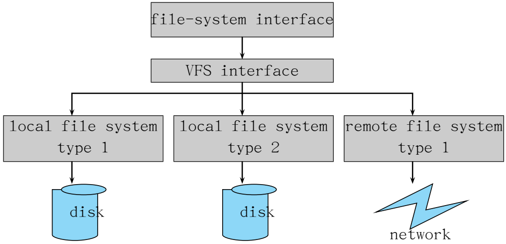


Partitions and mounting

- 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

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)

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

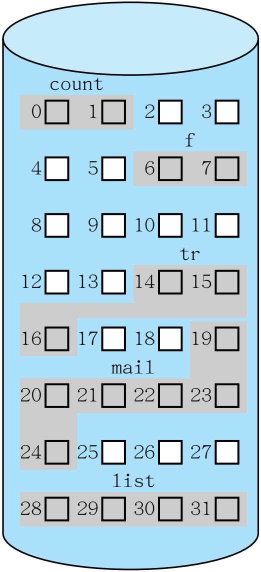
- Each file occupies a set of contiguous blocks on the disk
- Simple — directory entry only need
  - starting location (block #)
  - & length (number of blocks)
- Mapping from logical to physical

  $$\mathrm{LogicalAddress}/512 = Q \ldots \ldots R$$

  Block to be accessed = Q + starting address

  Displacement into block = R

1. Contiguous Allocation (连续分配) II



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)

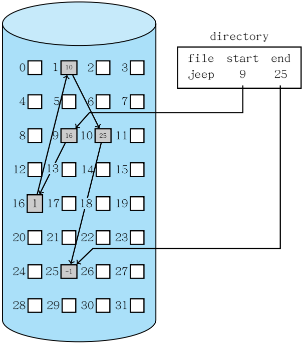
2. Linked Allocation (链接分配)

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**



2. Linked Allocation (链接分配)

1. Implicit (隐式链接)

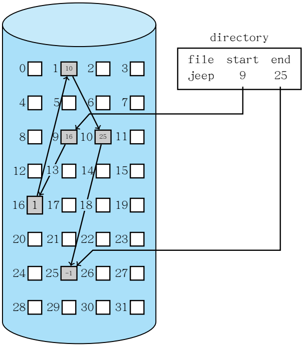
- **Disadvantage**:
  - No random access
  - Link pointers need disk sapce

    E.g.: 512 per block, 4 per pointer $\Rightarrow 0.78\%$

    Solution: clusters

    $\Rightarrow$ disk throughput $\uparrow$

    But internal fragmentation$\uparrow$



2. Linked Allocation (链接分配)

1. Implicit (隐式链接)

- **Mapping:**

  Suppose

  1.1 block size=512B,

  1.2 block pointer size=1B, using the first byte of a block

  1.3 Logical addr in the file to be accessed= A

  we have

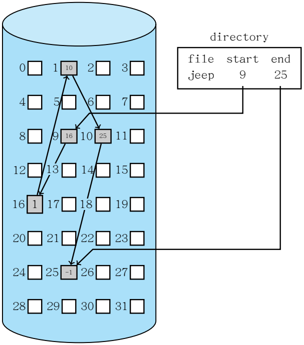
  1.1 Data size for each block $=512-1=511$

  1.2 $A/511=Q\ldots\ldots R$

  then

  1.1 Block to be accessed is the Q^{th} block in the linked chain of blocks representing the file.

  1.2 Displacement into block = R + 1

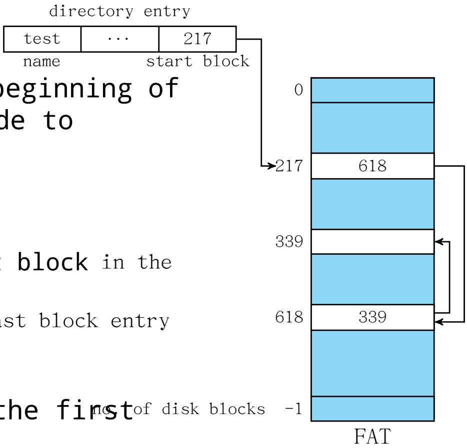


- **How to reduce searching time?**

2. Linked Allocation (链接分配)

2. Explicit linked allocation: File Allocation table, FAT

Disk-space allocation used by MS-DOS and OS/2

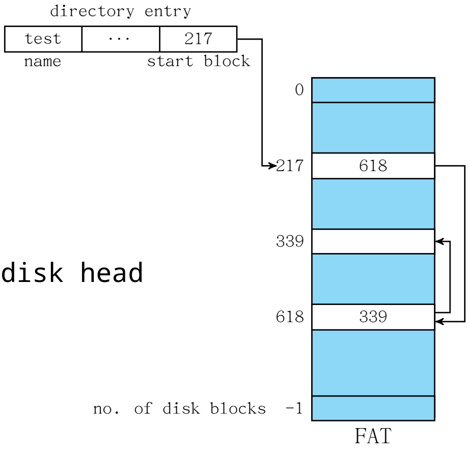


- A section of disk at the beginning of each partition is set aside to contain the FAT
  - Each disk block one entry
  - The entry contains
    (1) the index of the next block in the file
    (2) end-of-file, for the last block entry
    (3) 0, for unused block
- Directory entry contains the first block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

2. Linked Allocation (链接分配)

2. Explicit linked allocation: File Allocation table, FAT

Disk-space allocation used by MS-DOS and OS/2

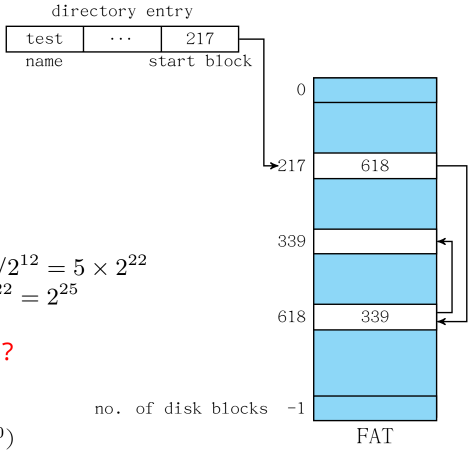


- Now support random access, but still not very efficient
- May result in a significant disk head seeks.
  Solution: Cached FAT

2. Linked Allocation (链接分配)

2. Explicit linked allocation: File Allocation table, FAT

Disk-space allocation used by MS-DOS and OS/2



- **How to compute FAT size?**

  Suppose

  2.1 Disk space = 80 GB
  2.2 Block size = 4 KB

  Then

  2.1 Total block number = $80 \times 2^{30}/2^{12} = 5 \times 2^{22}$
  2.2 $4 \times 2^{22} = 2^{24} < 5 \times 2^{22} < 8 \times 2^{22} = 2^{25}$

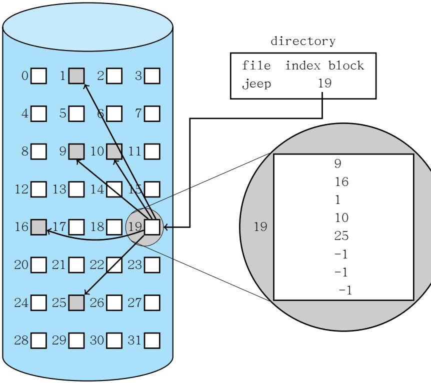
  - **Length of each FAT entry?**
    (25bits? 28bits? 32bits?)
  - **Length of FAT?**
    $(5 \times 2^{22} \times 4\text{B} = 80\text{MB} = 80\text{GB}/2^{10})$

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

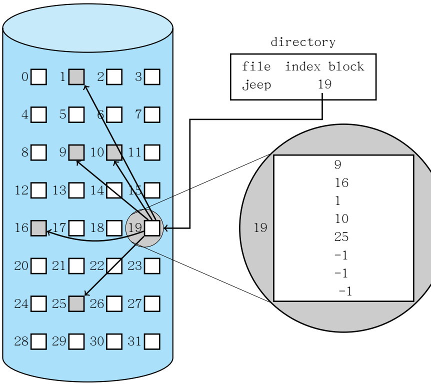


3. Indexed Allocation (索引分配)

- **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



3. Indexed Allocation (索引分配)

- **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

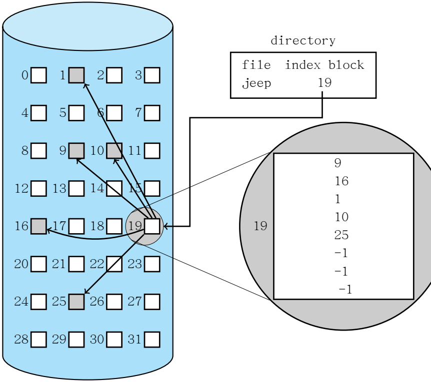
  $$LA/512 = Q...R$$

  (3)Q = the index of the pointer

  (4)R = displacement into block

  We also have Max file size

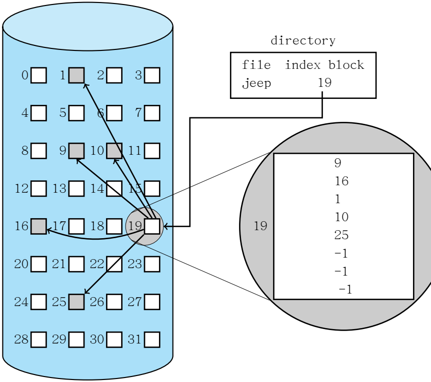
  $$= 2^{10}/4 \times 1\text{KB} = 256\text{KB}$$



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

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

(3) Q_1 = block of index table
(4) R_1 is used as follows:

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

(5) Q_2 = index into block of index table
(6) R_2 = displacement into block of file:

3. Indexed Allocation (索引分配)

2. multi-level index scheme

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

- We have

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

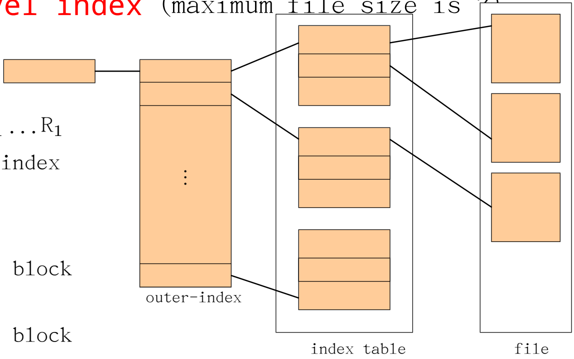
(1) Q_1 = index into outer-index

(2) R_1 is used as follows:

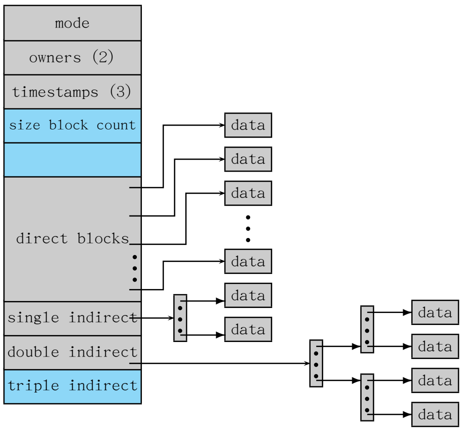
$$R_1/1KB = Q_2 \ldots R_2$$

(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

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

       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:

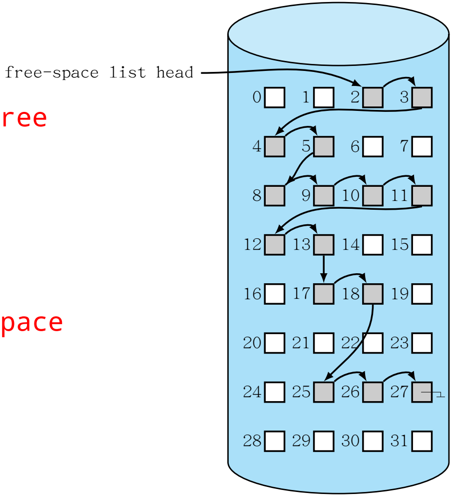
       Set bit[i] = 1 in memory.
       Allocate block[i]
       Set bit[i] = 1 in disk

   - Need to protect:
     - Pointer to free list
     - Bit map

Free-Space Management

2. Linked Free Space List on Disk

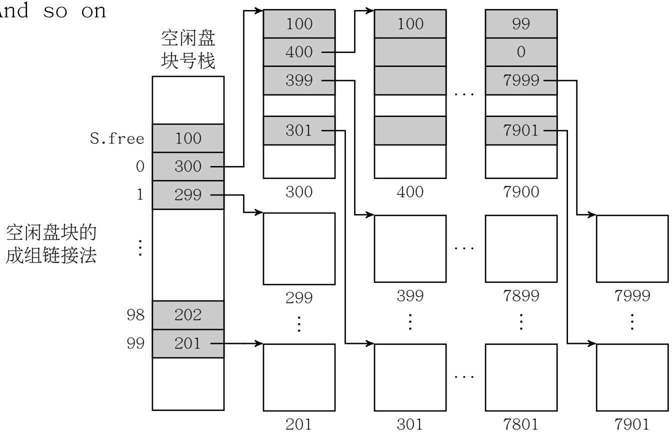
- Link together all the free disk blocks
  - First free block
  - Next pointer
- Not efficient
- Cannot get contiguous space easily
- No waste of space



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. E.g.: UNIX

- First n-1 group members are actually free
- Last one contain the next group
- And so on



Free-Space Management

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, generally counter > 1

Outline

Efficiency (空间) and Performance (时间)

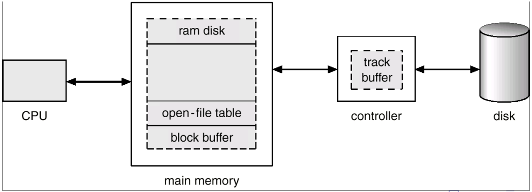
1 Efficiency (空间)

Efficiency in usage of disk space dependent on:

1. Disk allocation and directory algorithms
2. 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

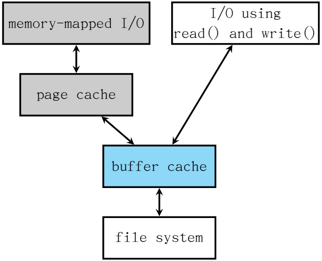
2 Performance (时间)

- Performance: other ways
  - disk cache - on disk controllers, large enough to store entire tracks at a time.
  - buffer cache — separate section of main memory for frequently used blocks
  - page cache - uses virtual memory techniques to cache file data as pages rather than as file-system-oriented blocks
  - Synchronous writes VS. Asynchronous writes
  - free-behind and read-ahead — techniques to optimize sequential access
  - improve PC performance by dedicating section of memory as virtual disk, or RAM disk

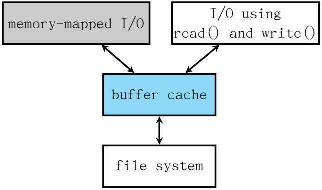


Unified Buffer Cache

- **I/O Without a Unified Buffer Cache**
  - Memory-mapped I/O uses a page cache
  - Routine I/O through the file system uses the buffer (disk) cache
  - **Problem:** double caching



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



Outline

Recovery

Recovery

- Consistency checking (一致性检查)
  - compares data in directory structure with data blocks on disk, and tries to fix inconsistencies
  - UNIX: fsck
  - MS-DOS: chkdsk
- 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
  - A typical backup schedule may be:
    Day1: full backup;
    Day2: incremental backup;
    ...
    DayN: incremental backup. Then go back to Day1.

Outline

Log Structured File Systems

Log Structured File Systems

- Log-based transaction-oriented (or journaling, 日志) 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

小结和作业

小结

- File-System Structure
- FS Implementation
- Directory Implementation
- Allocation Methods (分配方法)
- Free-Space Management
- Efficiency (空间) and Performance (时间)
- Recovery
- Log Structured File Systems
- 小结和作业

作业

12.6 设想一个在磁盘上的文件系统的逻辑块和物理块的大小都是512字节。假设每个文件的信息已经在内存中。对三种分配方法（连续分配、链接分配和索引分配），分别回答下列问题:
（1）逻辑地址到物理地址的映射在系统中是怎样进行的？（对于索引分配，假设文件总是小于512块长）；
（2）假设现在处在逻辑块10（最后访问的块是10），现在想访问逻辑块4,那么必须从磁盘上读多少个物理块?

谢谢！