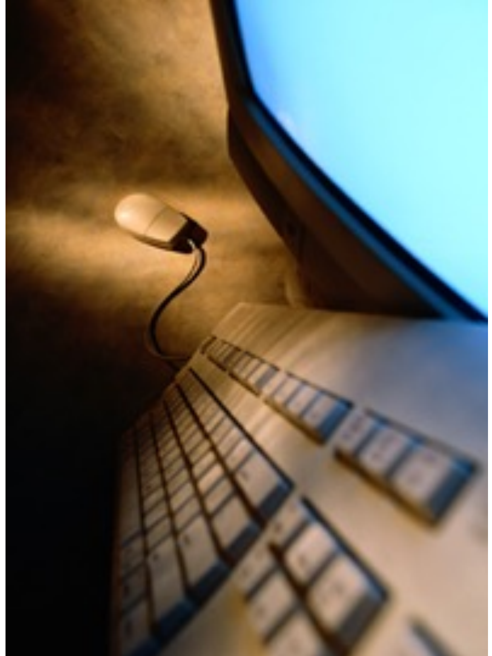

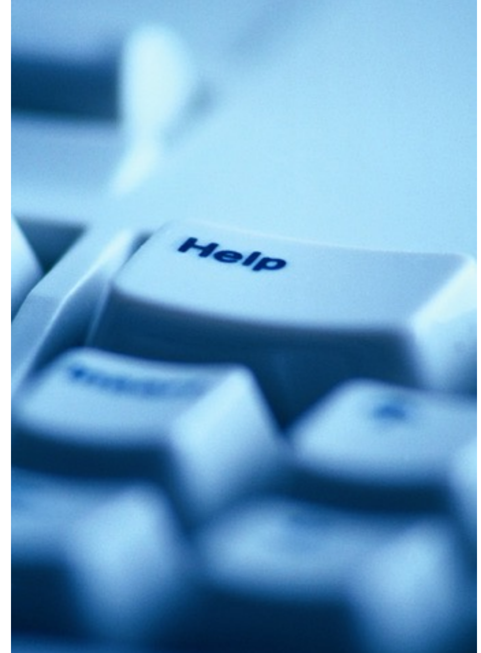

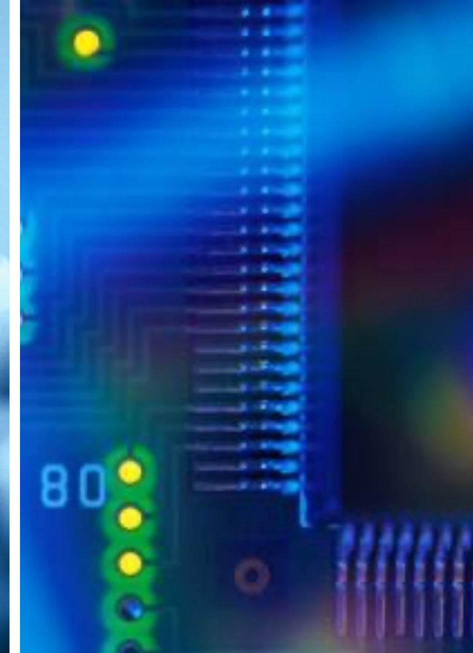

操作系统原理

Operating Systems Principles

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2024.6

AlphaDev

Article | Open Access | Published: 07 June 2023

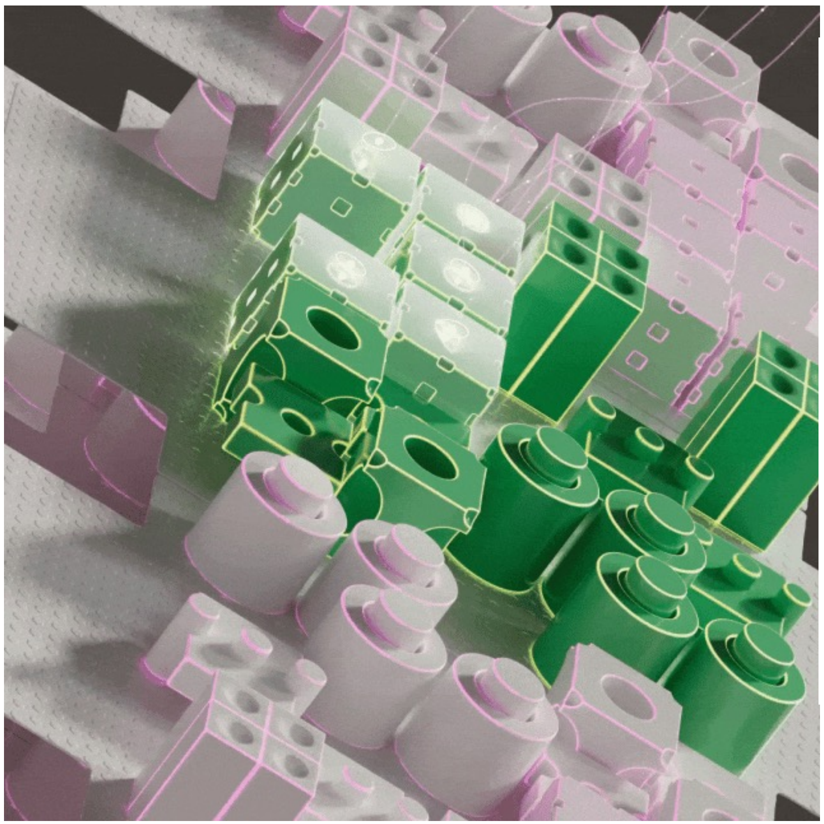
Faster sorting algorithms discovered using deep reinforcement learning

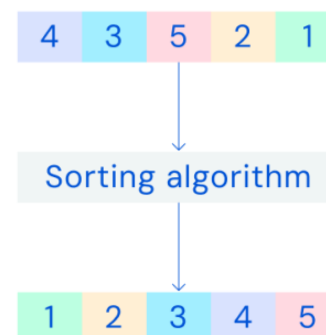
Daniel J. Mankowitz, Andrea Michi, Anton Zhernov, Marco Gelmi, Marco Selvi, Cosmin Paduraru, Edouard Leurent, Shariq Iqbal, Jean-Baptiste Lespiau, Alex Ahern, Thomas Köppe, Kevin Millikin, Stephen Gaffney, Sophie Elster, Jackson Broshear, Chris Gamble, Kieran Milan, Robert Tung, Minjae Hwang, Taylan Cemgil, Mohammadamin Barekatain, Yujia Li, Amol Mandhane, Thomas Hubert, Julian Schrittwieser, Demis Hassabis, Pushmeet Kohli, Martin Riedmiller, Oriol Vinyals & David Silver

— Show fewer authors

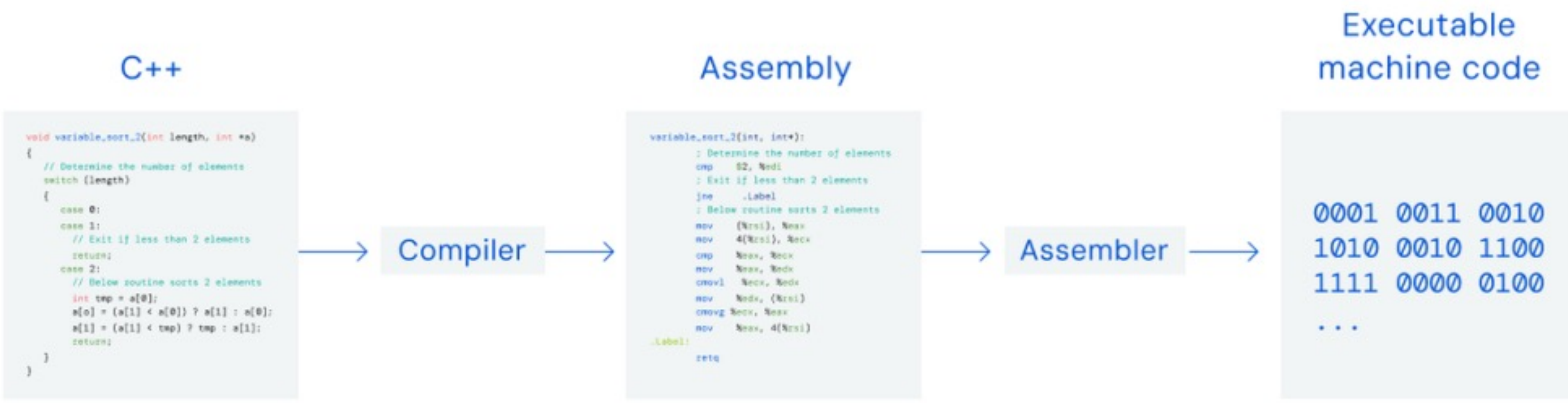
Nature **618**, 257–263 (2023) | Cite this article

❖ 排序





❖算法的执行过程


C++
Compiler
Assembly
Assembler
Executable machine code
0001 0011 0010
1010 0010 1100
1111 0000 0100
. . .

❖算法实例

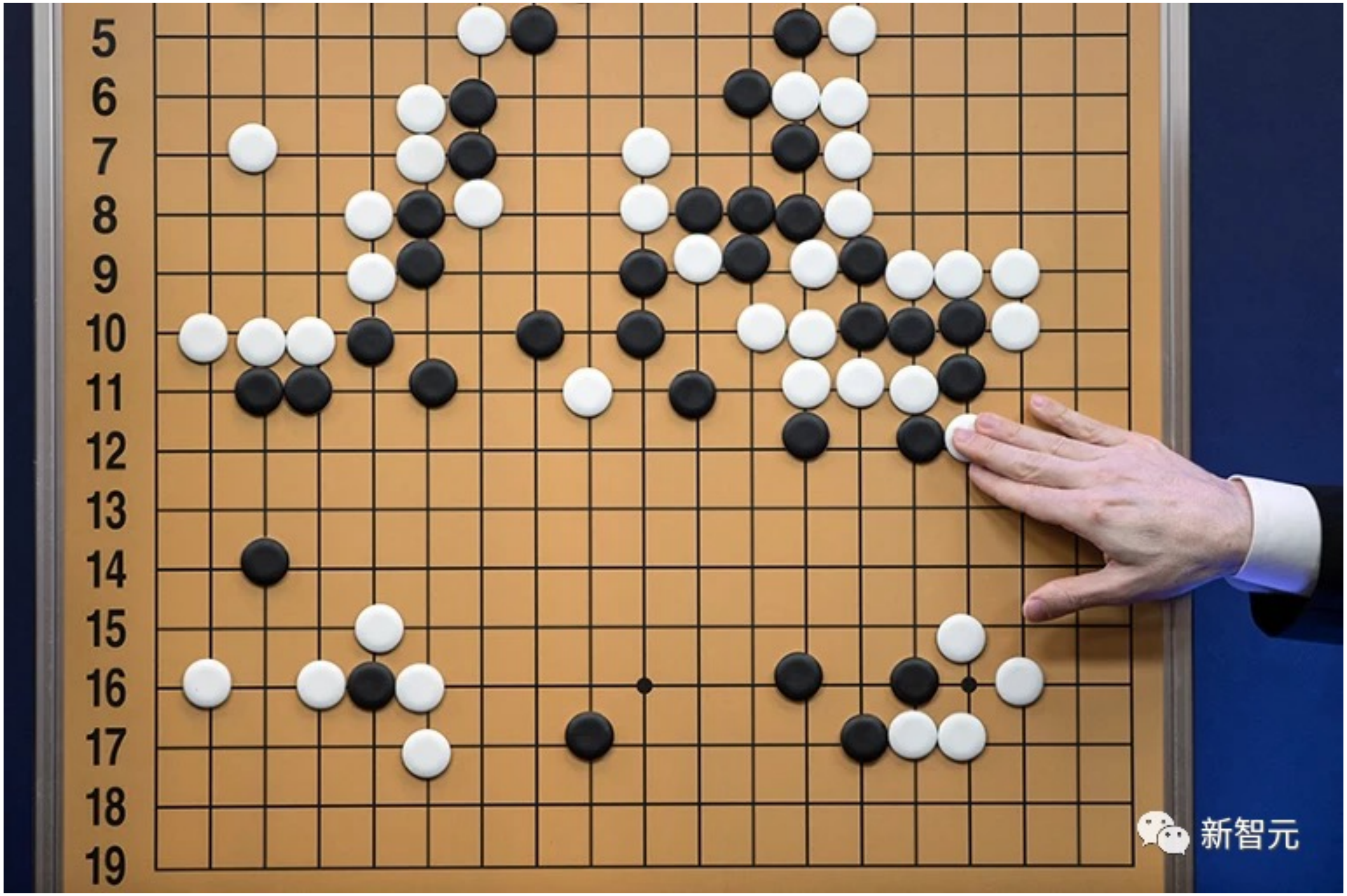
A

```
void variable_sort_2(int length, int *a)
{
   // Determine the number of elements
   switch (length)
   {
      case 0:
      case 1:
        // Exit if less than 2 elements
        return;
      case 2:
        // Below routine sorts 2 elements
        int tmp = a[0];
        a[0] = (a[1] < a[0]) ? a[1] : a[0];
        a[1] = (a[1] < tmp) ? tmp : a[1];
        return;
   }
}
```

B

```
variable_sort_2(int, int*):
        ; Determine the number of elements
        cmp     $2, %edi
        ; Exit if less than 2 elements
        jne      .Label
        ; Below routine sorts 2 elements
        mov     (%rsi), %eax
        mov     4(%rsi), %ecx
        cmp     %eax, %ecx
        mov     %eax, %edx
        cmovl    %ecx, %edx
        mov     %edx, (%rsi)
        cmovg %ecx, %eax
        mov     %eax, 4(%rsi)
.Label:
        retq
```

❖ AlpahGo



AlphaDev

Original

```
Memory[0] = A
Memory[1] = B
Memory[2] = C
Memory[3] = D

mov Memory[0] P   // P = A
mov Memory[1] Q   // Q = B
mov Memory[2] R   // R = C
mov Memory[3] S   // S = D

cmp S P
mov P T
cmovl S P   // P = min(A, D)
cmovl T S   // S = max(A, D)
cmp R P
mov P T
cmovg R P   // P = max(C, min(A, D))
cmovl R T   // T = min(A, C, D)
cmp Q T
mov T U
cmovl Q U   // U = min(A, B, C, D)
cmovl T Q   // Q = max(B, min(A, C, D))

mov U Memory[0]   // = min(A, B, C, D)
mov Q Memory[1]   // = max(B, min(A, C, D))
mov P Memory[2]   // = max(C, min(A, D))
mov S Memory[3]   // = max(A, D)
```

AlphaDev

```
Memory[0] = A
Memory[1] = B
Memory[2] = C
Memory[3] = D

mov Memory[0] P   // P = A
mov Memory[1] Q   // Q = B
mov Memory[2] R   // R = C
mov Memory[3] S   // S = D

cmp S P
mov P T
cmovl S P   // P = max(C, min(A, D))
cmovl T S   // S = max(A, D)
cmp R P

cmovg R P   // P = max(C, min(A, D))
cmovl R T   // T = min(A, C)
cmp Q T
mov T U
cmovl Q U   // U = min(A, B, C)
cmovl T Q   // Q = max(B, min(A, C))

mov U Memory[0]   // = min(A, B, C, D)
mov Q Memory[1]   // = max(B, min(A, C))
mov P Memory[2]   // = max(C, min(A, D))
mov S Memory[3]   // = max(A, D)
```

性能

- 对于较短的序列，速度提高了70%，而对于超过250,000个元素的序列，速度提高了约1.7%。

(b) Algorithm	AlphaDev	Human benchmarks
	Latency ± (lower, upper)	Latency ± (lower, upper)
VarSort3	236,498 ± (235,898, 236,887)	246,040 ± (245,331, 246,470)
VarSort4	279,339 ± (278,791, 279,851)	294,963 ± (294,514, 295,618)
VarSort5	312,079 ± (311,515, 312,787)	331,198 ± (330,717, 331,850)
VarInt	97,184 ± (96,885, 97,847)	295,358 ± (293,923, 296,297)
Competitive	75,973 ± (75,420, 76,638)	86,056 ± (85,630, 86,913)

第十三讲 — 文件系统实现

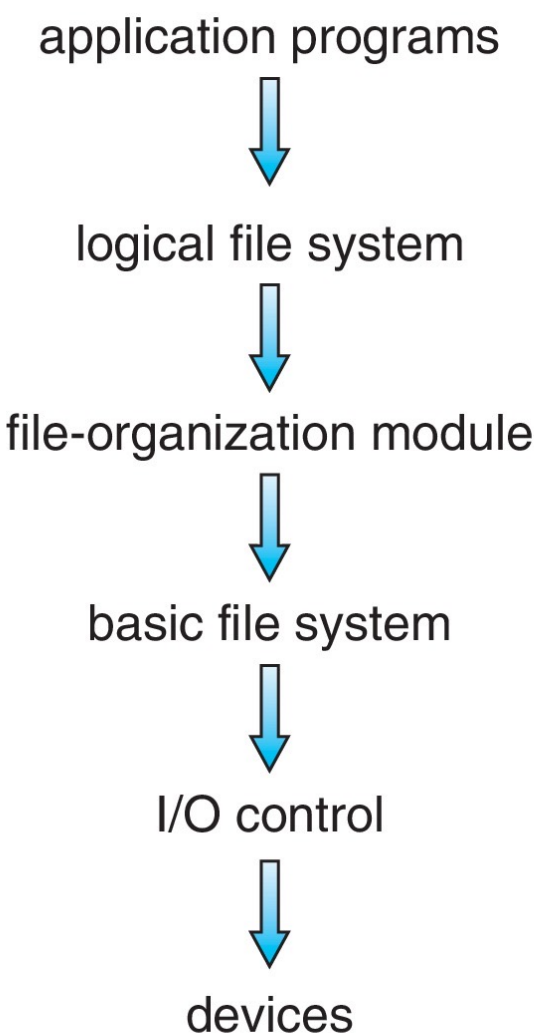
目标

- 本地文件系统和目录结构的实现细节；
- 远程文件系统；
- 块分配与空闲块的算法和权衡；

文件系统结构

- **File structure**
  - Logical storage unit
  - Collection of related information
- **File system resides on secondary storage (disks)**
  - Provided user interface to storage, mapping logical to physical
  - Provides efficient and convenient access to disk by allowing data to be stored, located retrieved easily
- **Disk provides in-place rewrite (原地重写)and random access**
  - I/O transfers performed in **blocks** of **sectors** (usually 512 bytes)
- **File control block (FCB) – storage structure consisting of information about a file**
- **Device driver controls the physical device**
- **File system organized into layers**

分层设计的文件系统


application programs
logical file system
file-organization module
basic file system
I/O control
devices

分层设计的文件系统

- **Device drivers manage I/O devices at the I/O control layer**
  - Given commands like
    - read drive1, cylinder 72, track 2, sector 10, into memory location 1060
  - Outputs low-level hardware specific commands to hardware controller
- **Basic file system given command like "retrieve block 123" translates to device driver**
- **Also manages memory buffers and caches (allocation, freeing, replacement)**
  - Buffers hold data in transit
  - Caches hold frequently used data
- **File organization module understands files, logical address, and physical blocks**
- Translates logical block # to physical block #
- Manages free space, disk allocation

分层设计的文件系统

- **Logical file system (逻辑文件系统) manages metadata information**
  - Translates file name into file number, file handle, location by maintaining file control blocks（文件控制块） (**inodes** in UNIX)
  - Directory management
  - Protection
- **Layering useful for reducing complexity and redundancy, but adds overhead and can decrease performance**
- **Logical layers can be implemented by any coding method according to OS designer**

分层设计的文件系统

- **Many file systems, sometimes many within an operating system**
  - Each with its own format:
  - CD-ROM is ISO 9660;
  - Unix has **UFS**, FFS;
  - Windows has FAT, FAT32, NTFS as well as floppy, CD, DVD Blu-ray,
  - Linux has more than 130 types, with **extended file system** ext3 and ext4 leading; plus distributed file systems, etc.)
  - New ones still arriving – ZFS, GoogleFS, Oracle ASM, **FUSE**

文件系统操作

- **We have system calls at the API level, but how do we implement their functions?**
  - On-disk and in-memory structures
- **Boot control block (引导控制块) contains info needed by system to boot OS from that volume**
  - Needed if volume contains OS, usually first block of volume
- **Volume control block （卷控制块）(superblock, master file table) contains volume details**
  - Total # of blocks, # of free blocks, block size, free block pointers or array
- **Directory structure organizes the files**
  - Names and inode numbers, master file table

文件控制块

- **OS maintains FCB per file, which contains many details about the file，包含唯一标识号**
  - Typically, inode number, permissions, size, dates
  - Example

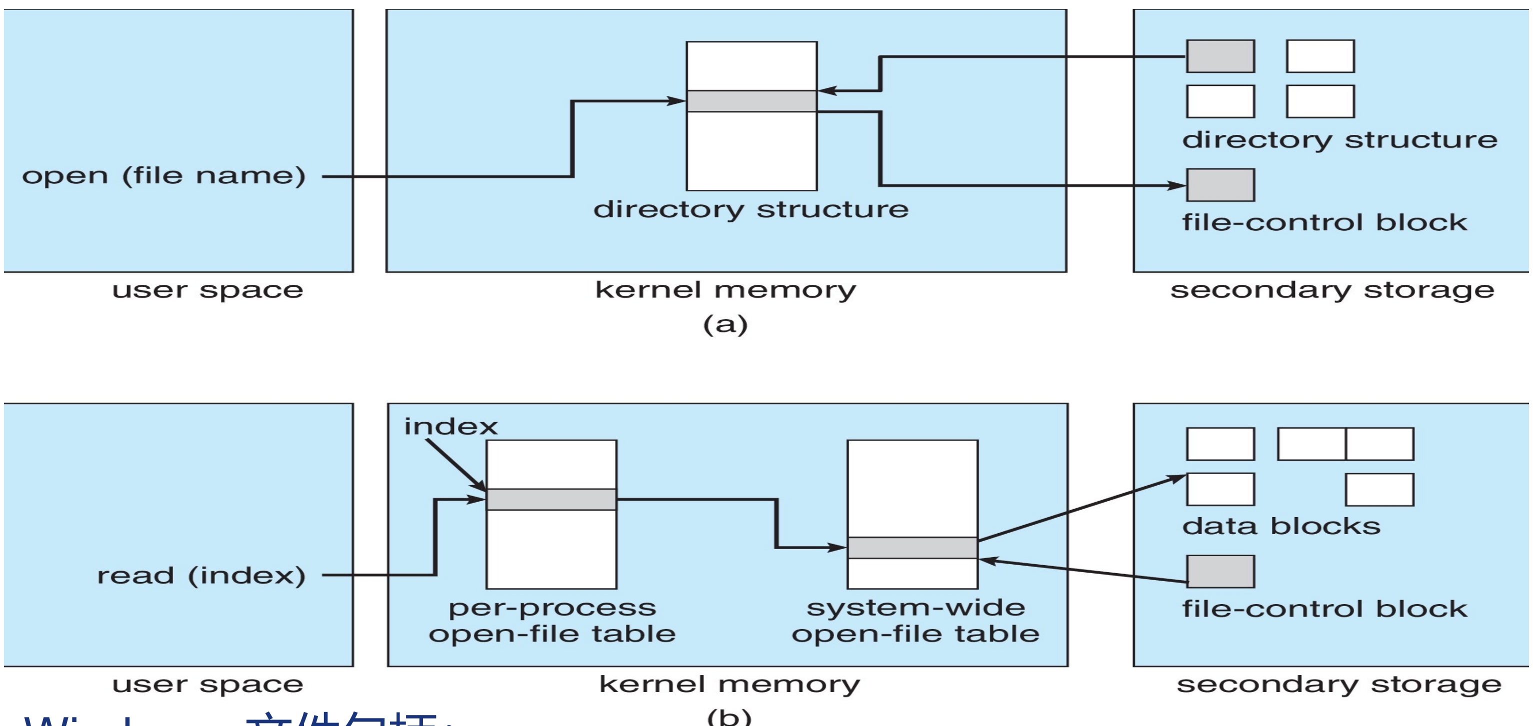
file permissions
file dates (create, access, write)
file owner, group, ACL
file size
file data blocks or pointers to file data blocks

内存中的文件结构

- **Mount table （安装表、挂载表）storing file system mounts, mount points, file system types**
- **System-wide open-file table contains a copy of the FCB of each file and other info**
- **Per-process open-file table contains pointers to appropriate entries in system-wide open-file table as well as other info**

内存中的文件结构

- Figure 12-3(a) refers to opening a file
- Figure 12-3(b) refers to reading a file



Windows: 文件句柄;
Unix：文件描述符

目录实现

- **Linear list of file names with pointer to the data blocks**
  - Simple to program
  - Time-consuming to execute
    - Linear search time
    - Could keep ordered alphabetically via linked list or use B+ tree
- **Hash Table – linear list with hash data structure**
  - Decreases directory search time
  - **Collisions** – situations where two file names hash to the same location
  - Only good if entries are fixed size, or use chained-overflow method

分配方法

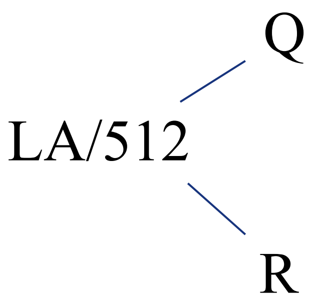
- **An allocation method refers to how disk blocks are allocated for files:**
  - Contiguous
  - Linked
  - Indexed

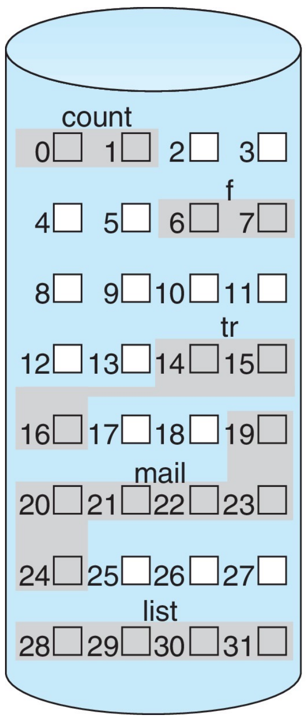
连续分配方法

- **An allocation method refers to how disk blocks are allocated for files:**
- **Each file occupies set of contiguous blocks**
  - Best performance in most cases (寻道数量最小，寻道时间最小)
  - Simple – only starting location (block #) and length (number of blocks) are required
  - 支持顺序访问和直接访问；
  - Problems include:
    - Finding space on the disk for a file,
    - Knowing file size,
    - External fragmentation, need for **compaction off-line (downtime)** or **on-line** 外部碎片

连续分配方法

- Mapping from logical to physical (block size =512 bytes)





directory

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

- Block to be accessed = starting address + Q
- Displacement into block = R

基于扩展的系统

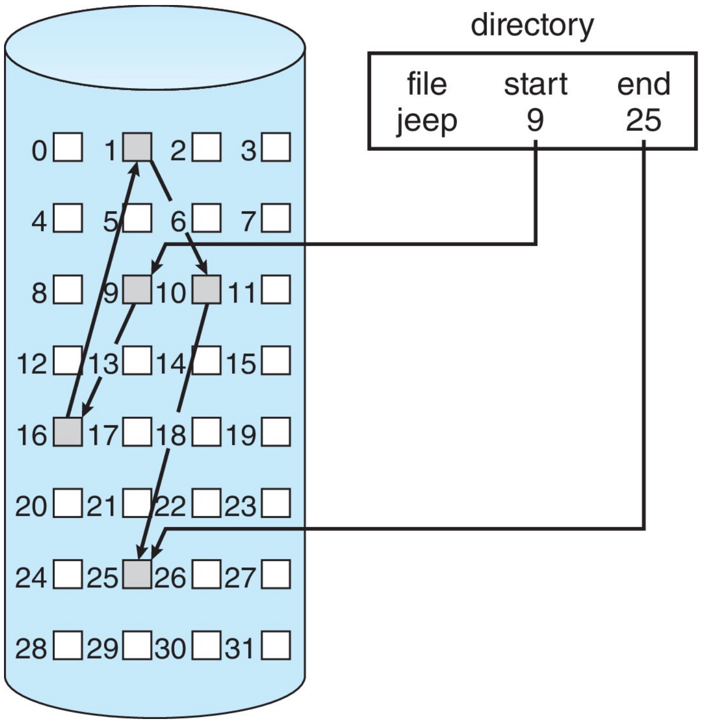
- **Many newer file systems (i.e., Veritas File System) use a modified contiguous allocation scheme**
- **Extent-based file systems allocate disk blocks in extents**
- **An extent is a contiguous block of disks**
  - Extents are allocated for file allocation
  - A file consists of one or more extents
  - 文件块的位置记录为：地址、块数、下一个扩展的首块的指针；

链接分配

- Each file is a linked list of blocks
- File ends at nil pointer
- No external fragmentation
- Each block contains pointer to next block
- No compaction, external fragmentation
- Free space management system called when new block needed
- Improve efficiency by clustering blocks into groups but increases internal fragmentation
- Reliability can be a problem
- Locating a block can take many I/Os and disk seeks

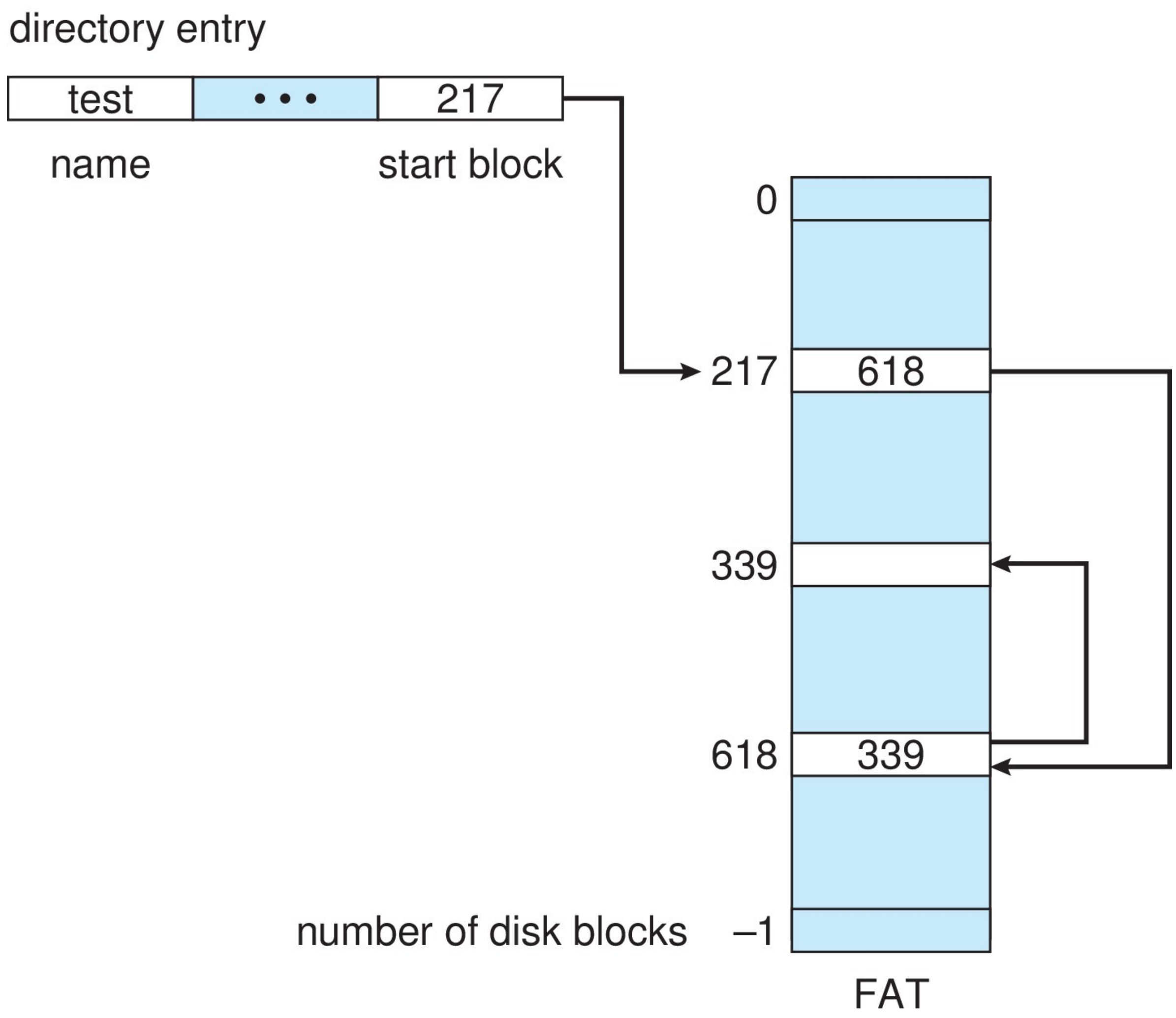
链接分配

- Each file is a linked list of disk blocks: blocks may be scattered anywhere on the disk
- Scheme



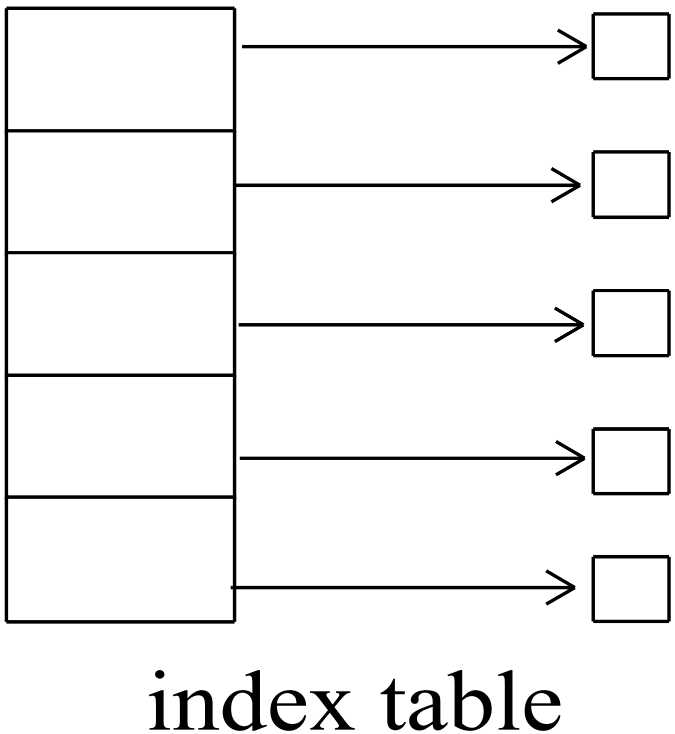
无外部碎片；但是只有效用于顺序访问，指针占空间，可靠性也是一个问题

文件分配表

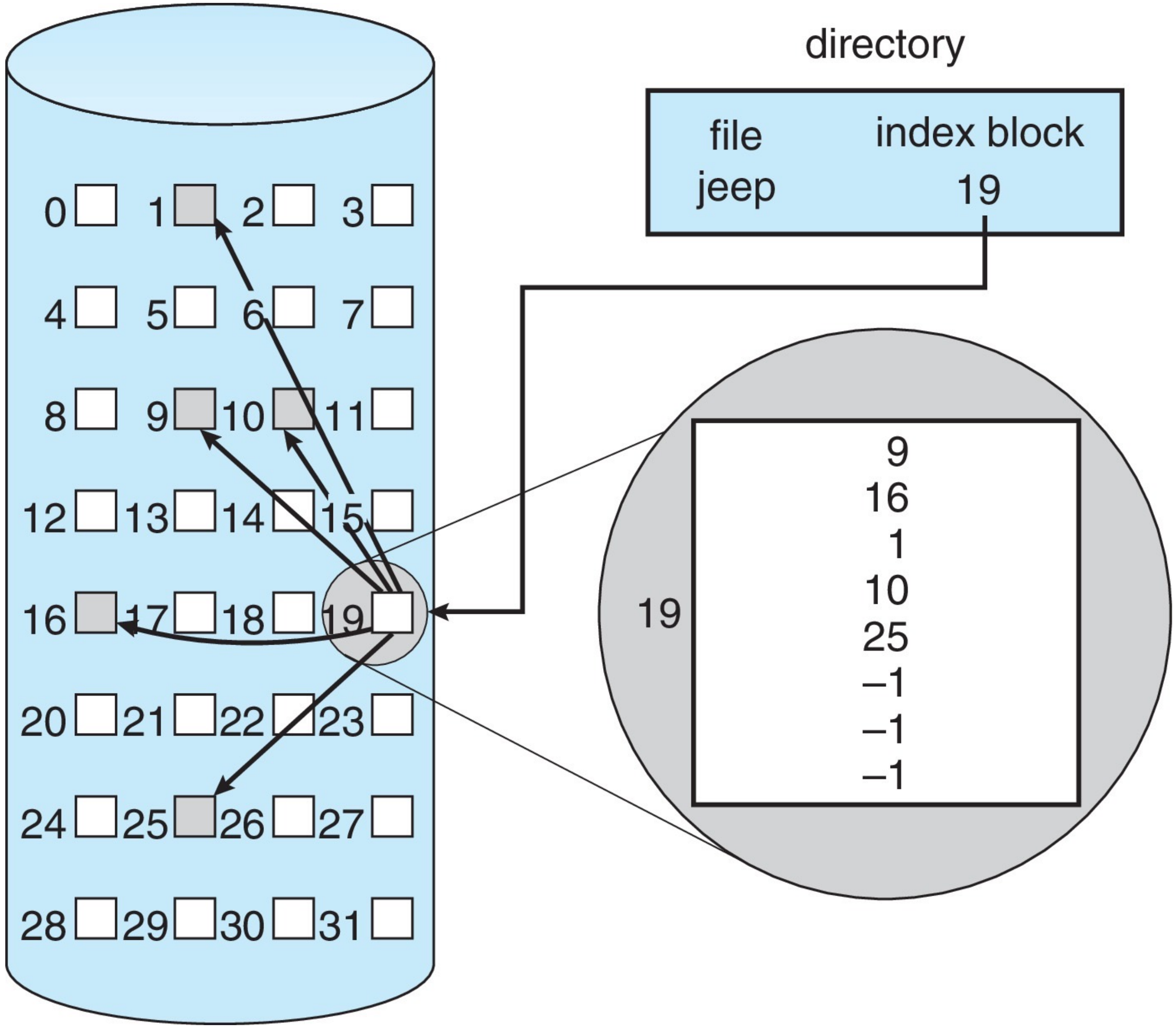

directory entry
test
• • •
217
name
start block
0
217
618
339
339
618
339
number of disk blocks
–1
FAT

索引分配

- Each file has its own index block(s) of pointers to its data blocks
- Logical view



索引分配


directory
file
index block
jeep
19
0
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
25
26
27
28
29
30
31
19
9
16
1
10
25
–1
–1
–1

索引分配——小文件

- 需要索引表
- 随机存取
- 无外部碎片的动态访问，但有索引块的开销；
- 在最大大小为256K字节、块大小为512字节的文件中从逻辑映射到物理。索引表只需要1个块

Q

LA/512

R

- 计算：
  - Q=进入索引表的位移
  - R=块体中的位移

索引分配——大文件

- 在长度无限的文件中从逻辑到物理地址的映射（块大小为512个字）
  - 链接方案 – 索引表的链接块（大小不限）
  - 多级索引

索引分配——大文件

- 两级索引（4K块可以在外部索引->1048567数据块中存储1024个四字节指针，文件大小高达4GB）

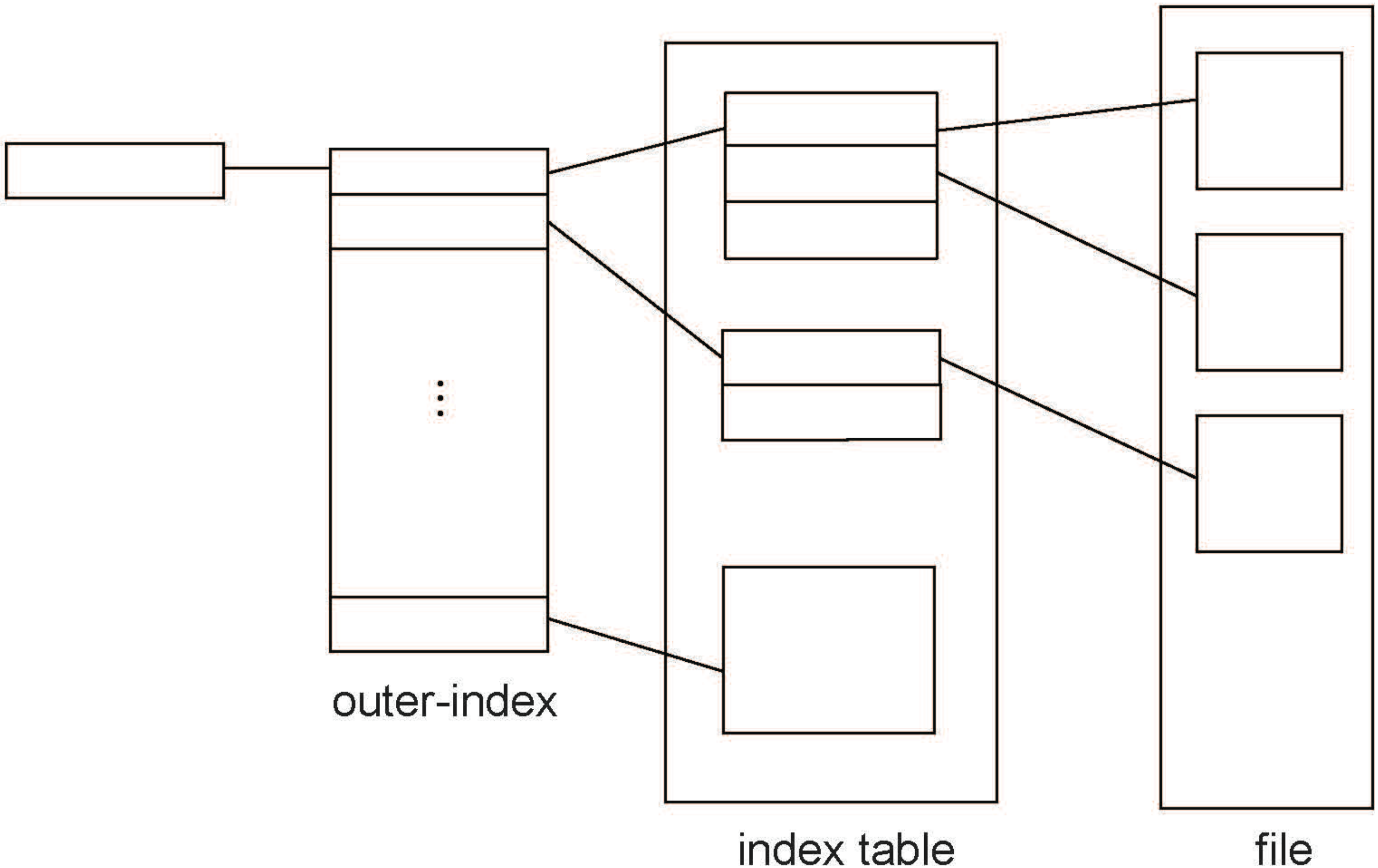
$$LA\ /\ (512 \times 512)\ \begin{cases} Q_1 \\ R_1 \end{cases}$$

- 外部索引的映射方案：
  - Q1=进入外部索引的位移
  - R1的使用方式如下：

$$R_1\ /\ 512\ \begin{cases} Q_2 \\ R_2 \end{cases}$$

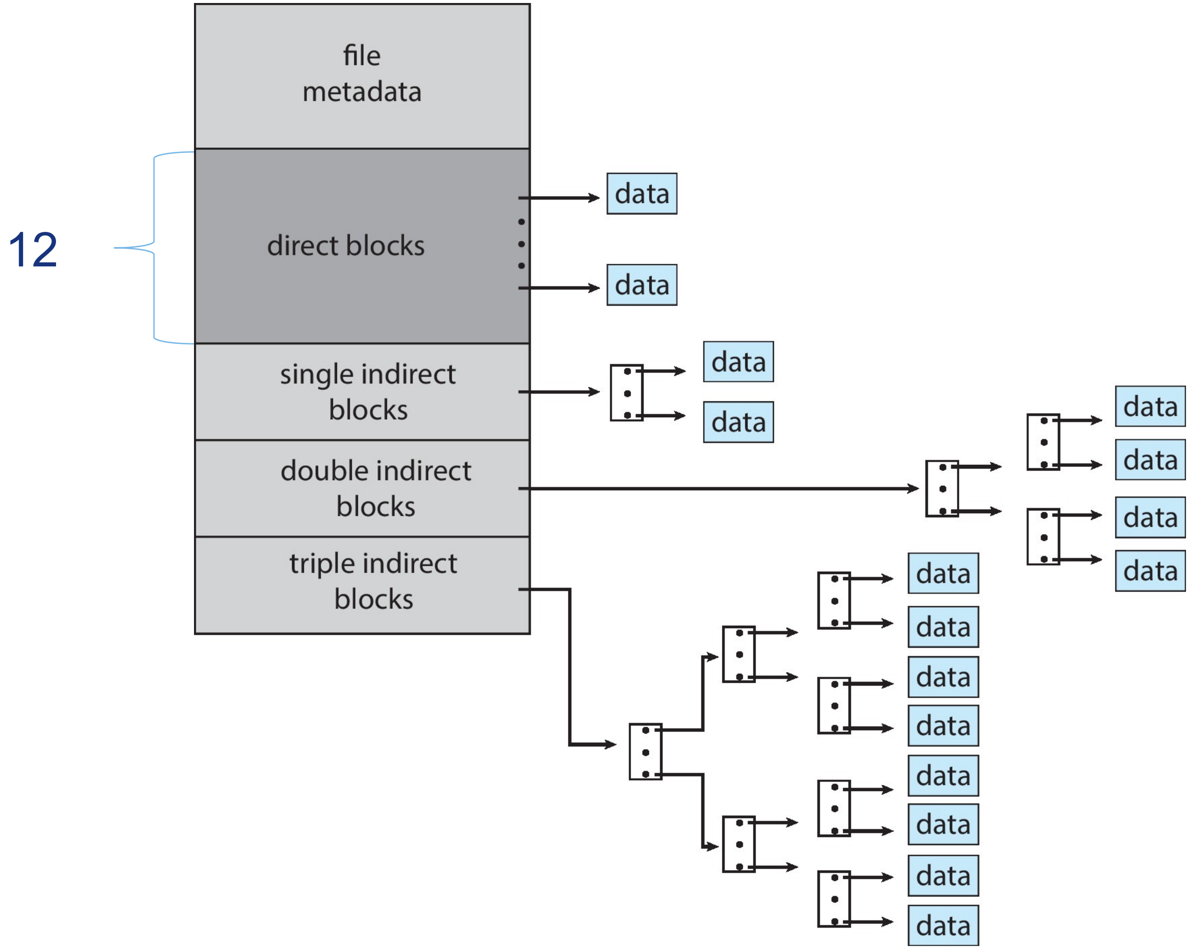
  - 索引级别的映射方案：
    - Q2=进入索引表块的位移
    - R2置换到文件块中

索引分配——两级方案



索引分配——组合方案

- 每个块4K字节，32位地址



- 超过32位文件指针可寻址的索引块

性能

- **最佳方法取决于文件访问类型**
  - 连续序列和随机序列
- **链接适用于顺序，而不是随机**
- **在创建时声明访问类型**
  - 选择连续分配或链接分配；
- **索引分配更复杂**
  - 单块访问可能需要读取2个索引块（二级索引），然后读取数据块；
  - 性能取决于：索引的结构、文件的大小以及所需块的位置；
- **对于NVM，没有磁盘头，因此需要不同的算法和优化**
  - 使用旧算法会占用大量CPU周期，试图避免不存在的头部移动；
  - 目标是减少CPU周期和I/O所需的总体路径；

空闲空间管理

- **File system maintains free-space list to track available blocks/clusters**
  - (Using term “block” for simplicity)
- **Bit vector or bit map (*n* blocks)**

0	1	2					n-1
						…	

$$\text{bit}[i] = \begin{cases} 1 \Rightarrow \text{block}[i] \text{ free} \\ 0 \Rightarrow \text{block}[i] \text{ occupied} \end{cases}$$

Block number calculation

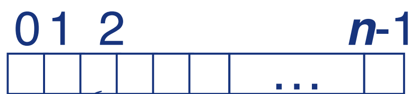
(number of bits per word) *
(number of 0-value words) +
offset of first 1 bit

查找第一个空闲块

CPUs have instructions to return offset within word of first “1” bit

空闲空间管理

- **File system maintains free-space list to track available blocks**
- **Bit vector or bit map (*n* blocks)**



$$\text{bit}[i] = \begin{cases} 1 \Rightarrow \text{block}[i] \text{ free} \\ 0 \Rightarrow \text{block}[i] \text{ occupied} \end{cases}$$

- **Bit map requires extra space**
  - Example:

    block size = 4KB = 2^{12} bytes

    disk size = 2^{40} bytes (1 terabyte)

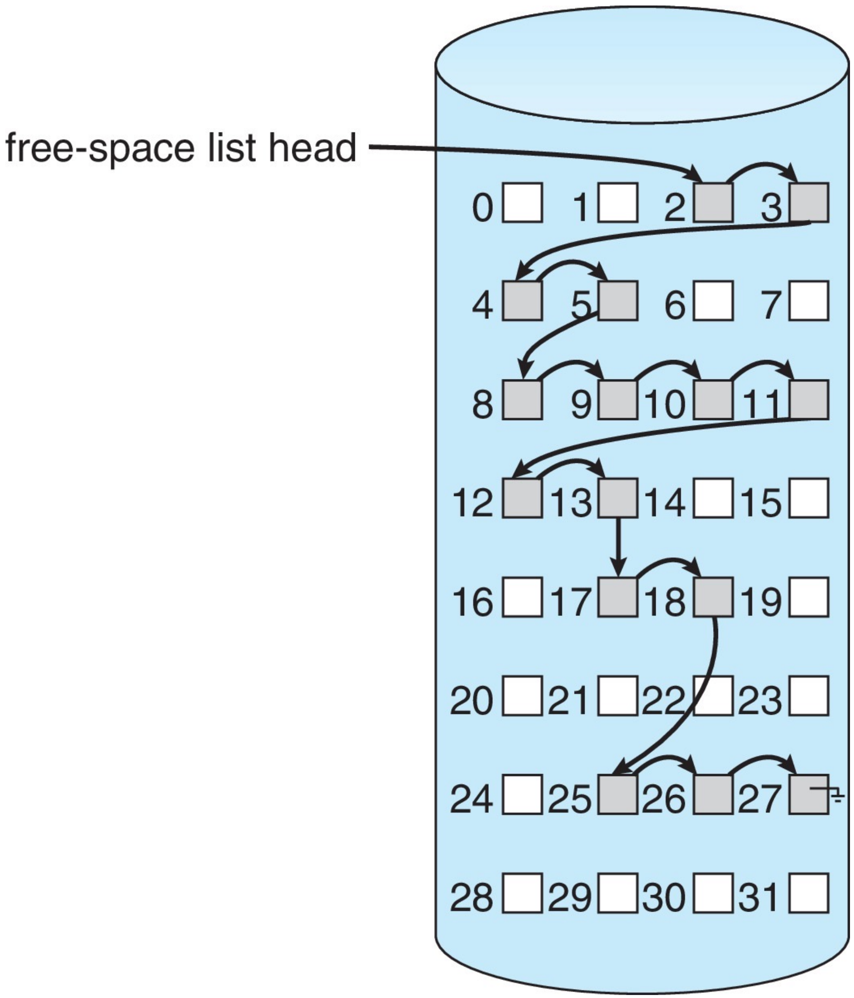
    $n = 2^{40}/2^{12} = 2^{28}$ bits (or 32MB)

    if clusters of 4 blocks -> 8MB of memory

- **Easy to get contiguous files**

空闲空间管理——链表

- Linked list (free list)
  - Cannot get contiguous space easily
  - No waste. Linked Free Space List on Disk of space
  - No need to traverse the entire list (if # free blocks recorded)



空闲空间管理

- **Grouping**
  - Modify linked list to store address of next *n-1* free blocks in first free block, plus a pointer to next block that contains free-block-pointers (like this one)

- **Counting**
  - Because space is frequently contiguously used and freed, with contiguous-allocation allocation, extents, or clustering
    - Keep address of first free block and count of following free blocks
    - Free space list then has entries containing addresses and counts

空闲空间管理

- **Space Maps**
  - Used in **ZFS**
  - Consider meta-data I/O on very large file systems
    - Full data structures like bit maps cannot fit in memory → thousands of I/Os
  - Divides device space into **metaslab** units and manages metaslabs
    - Given volume can contain hundreds of metaslabs
  - Each metaslab has associated space map
    - Uses counting algorithm
  - But records to log file rather than file system
    - Log of all block activity, in time order, in counting format
  - Metaslab activity → load space map into memory in balanced-tree structure, indexed by offset
    - Replay log into that structure
    - Combine contiguous free blocks into single entry

效率和性能

- **Efficiency （效率） dependent on:**
  - Disk allocation and directory algorithms
  - Types of data kept in file’s directory entry
  - Pre-allocation or as-needed allocation of metadata structures
  - Fixed-size or varying-size data structures

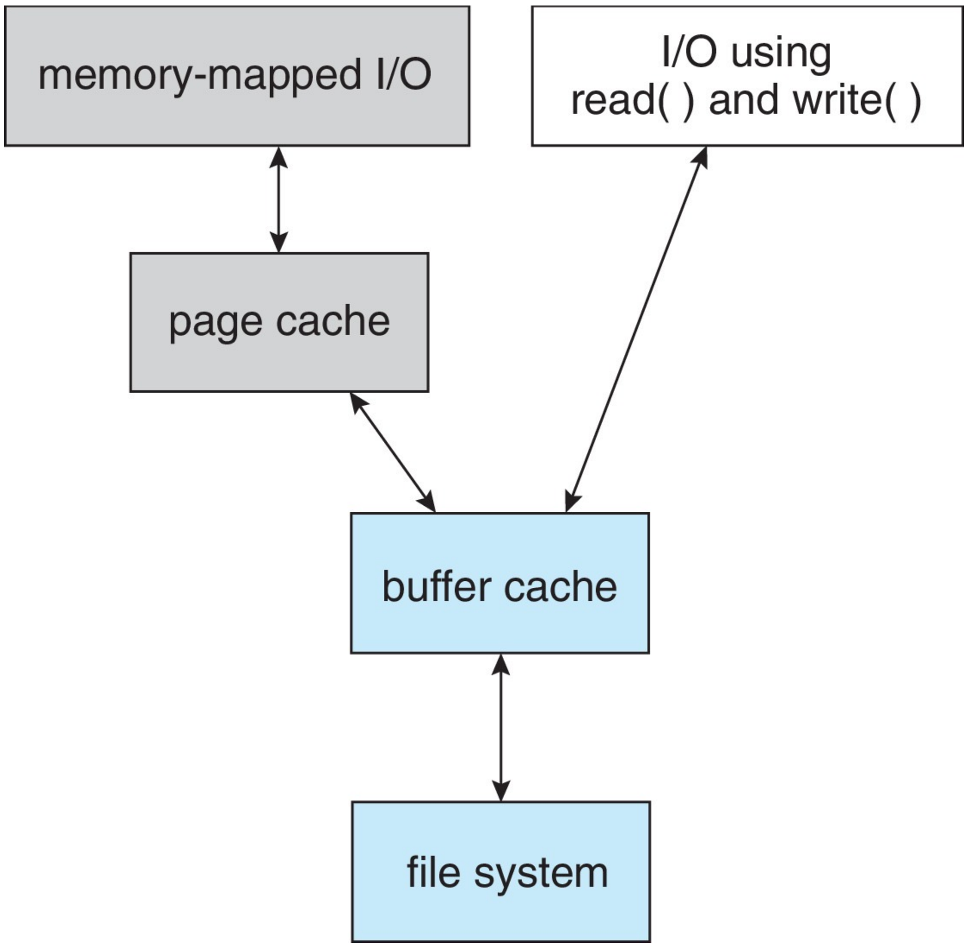
效率和性能

- **Performance**
  - Keeping data and metadata close together
  - **Buffer cache** – separate section of main memory for frequently used blocks
  - **Synchronous** writes sometimes requested by apps or needed by OS 同步写
    - No buffering / caching – writes must hit disk before acknowledgement
    - **Asynchronous** writes more common, buffer-able, faster
  - **Free-behind** and **read-ahead** – techniques to optimize sequential access
  - Reads frequently slower than writes

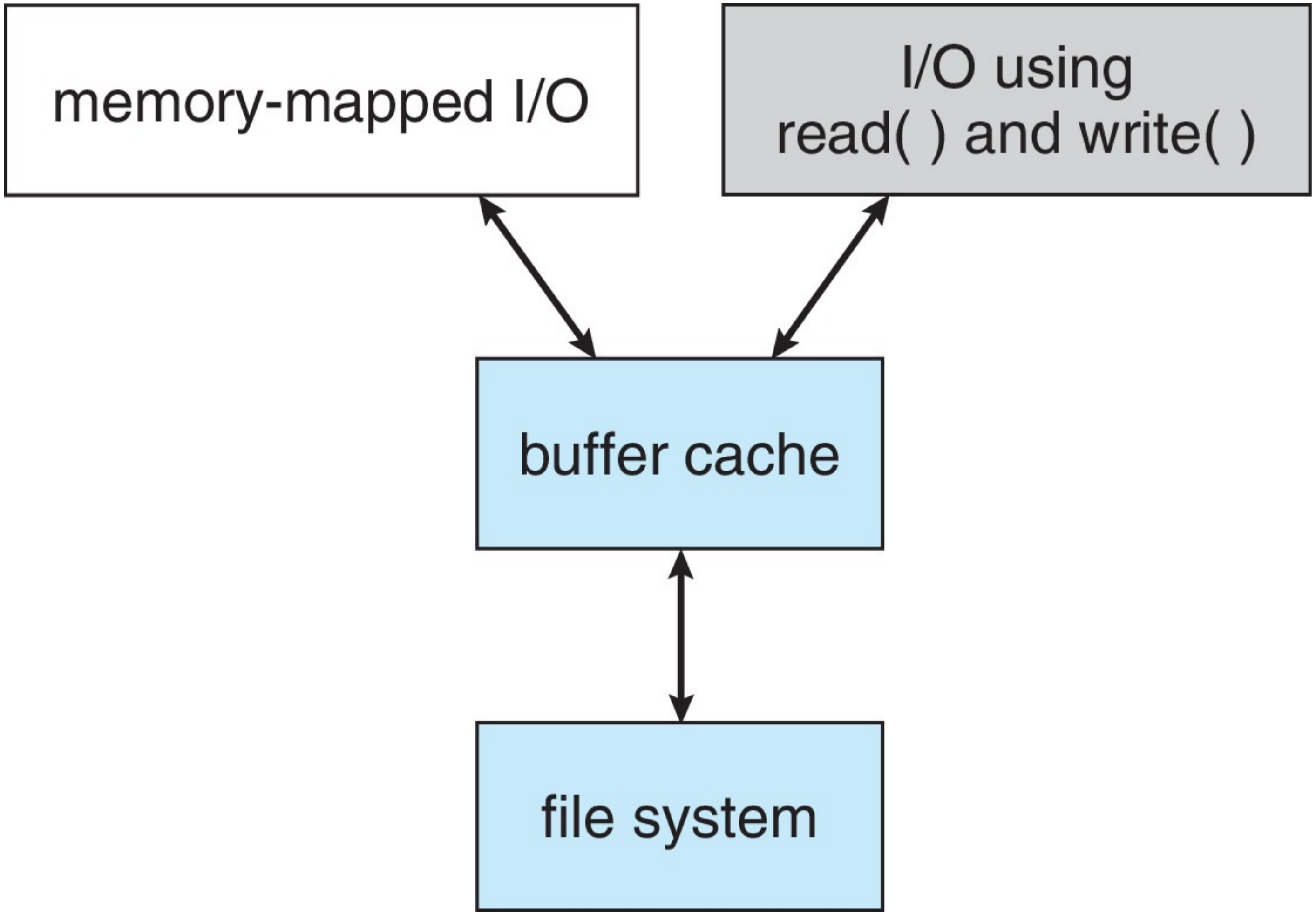
效率和性能

- A page cache caches pages rather than disk blocks using virtual memory techniques and addresses
- 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

缺少统一缓冲区缓存的I/O



统一缓冲区缓存


memory-mapped I/O
I/O using
read( ) and write( )
buffer cache
file system

恢复

- **Consistency checking – compares data in directory structure with data blocks on disk, and tries to fix inconsistencies**
  - Can be slow and sometimes fails
- **Use system programs to back up data from disk to another storage device (magnetic tape, other magnetic disk, optical)**
- **Recover lost file or disk by restoring data from backup**

基于日志的文件系统

- **Log structured (or journaling) file systems record each metadata 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 (sequentially)
  - Sometimes to a separate device or section of disk
  - However, the file system may not yet be updated
- **The transactions in the log are asynchronously written to the file system structures**
  - When the file system structures are modified, the transaction is removed from the log
- **If the file system crashes, all remaining transactions in the log must still be performed**
- **Faster recovery from crash, removes chance of inconsistency of metadata**

谢谢