# Disk Allocation

ECE595
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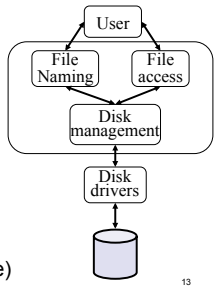
## Roadmap

- Functionality (API)
  - Basic file system
    - Data structures / disk layout
    - File operations
  - Directories
- Performance
  - → Disk allocation
  - Disk scheduling
  - Buffer cache
    - interactions with VM
  - File system interface (alternative)
  - RAID






## Disk Allocation Problem

- Definition: allocate disk blocks when a file is created or grows, and free them when a file is removed or shrinks
- Does this sound familiar?
- Shall we approach it like segmentation or paging?
- Is there locality in disk accesses?
- What kind of locality matters to allocation?
  - Temporal?
  - Spatial?

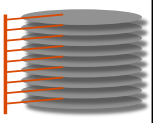


## Disk allocation problem

- Two tasks:
  - How to allocate blocks for a file?
  - How to design inode to keep track of blocks?

## Disk mechanics & performance

- Platter / Head / Tracks / Sectors / Cylinders
- Rotation 1000's of RPM (7200, 10k, 15k)
- Avg seek 5-10 ms



- Assume
  - 255 heads *38913 tracks * 63 sectors * 512 bytes = 320GB
  - Seek time =6ms, 7200 RPM ➔ rotational latency = 8ms
- Block access time = seek time + rotational latency + reading time
  - Accessing a random block: 6ms + 4 ms + 8ms/63 = 638ms/63
  - Accessing the block right after: 8ms/63
- Implications?



## Disk vs. Memory

| Memory | Disk |
|---|---|
| • Latency in 100's of processor cycles | • Latency in milliseconds<br>  ◦ 1ms = 10^6 cycles on 1Ghz machine |
| • Transfer rate ~ 1000 MB/s (DDR SDRAM) | • Transfer rate in 30KB/s -- 30MB/s |
| • Contiguous allocation gains ~10x<br>  ◦ Cache hits<br>  ◦ RAS/CAS (DRAM) | • Contiguous allocation gains ~100x |

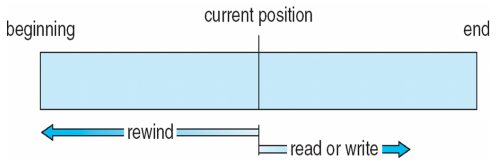


## Challenge to disk allocation problem: File Usage Patterns

- How do users access files?
  - Sequential: bytes read in order
  - Random: read/write element out of middle of arrays
  - Whole file or partial file
- How are files used (determines metadata design)?
  - Most files are small
  - Large files use up most of the disk space
  - Large files account for most of the bytes transferred
- Bad news
  - Want everything to be efficient

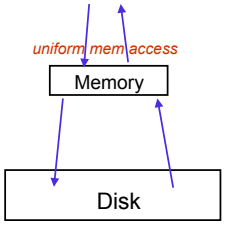


## Sequential File Access



## [lec15] Demand Paging algorithms

- Optimal
- FIFO
- FIFO with 2nd chance
- Clock: a simple FIFO with 2nd chance
- Enhanced FIFO with 2nd chance NFU
- Approximate LRU

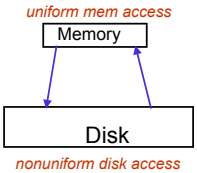



- Definition: pick victim page to swap to disk upon page fault
- Focus on reducing number of page faults (going to disk)
  - Don't care which page fault, don't care where on disk
- What kind of *locality* matters?



## Disk Allocation Problem

- Definition: allocate disk blocks when a file is created or grows, and free them when a file is removed or shrinks
- Cannot do anything about number of I/O -- Focus on performance of I/Os (that go to disk), i.e. which block
  - What kind of locality matters?




read(fd, buf, size)



## Design goals and expectation

- Optimize I/O performance
  - What can we do for random access patterns?
  - What can we do for sequential access patterns?
- Also want to minimize file header size
  - File header: for keeping track of blocks
  - Ideally fit in inode



## Disk Allocation Methods

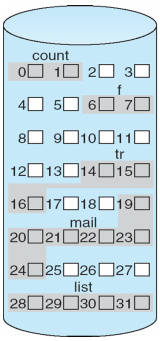
- Contiguous
- Single-level indexed
- Linked
- FAT (MS-DOS, OS/2)
- Multi-level indexed (UNIX)

## Contiguous Allocation

- Request in advance for the size of the file
- Search bit map or linked list to locate a space
- File header contains
  - first sector number
  - number of sectors



## Contiguous Allocation of Disk Space




directory

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

Analogy in memory management?

## Contiguous Allocation

- Request in advance for the size of the file
- Search bit map or linked list to locate a space
- File header contains
  - first sector number
  - number of sectors
- Pros
  - Fast sequential access
  - Easy random access
- Cons
  - External fragmentation
  - Hard to grow files

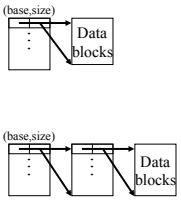


## Extent-Based Systems

- Many newer file systems (i.e. Veritas File System – 1st commercial journal FS) 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

# Example: DEMOS (OS for Cray-1, 1977)

- Idea
  - Using contiguous allocation
  - Allow non-contiguous
- Approach
  - 10 (base,size) pointers
  - Indirect for big files
- Pros & cons
  - Can grow (max 10GB)
  - fragmentation
  - Difficult to grow each segment

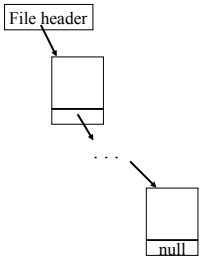





Analogy in memory management?

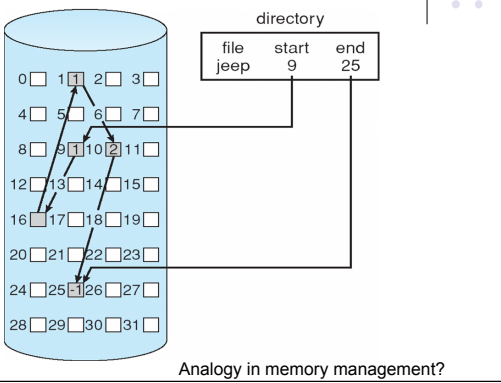
# Linked Files

- File header points to 1st block on disk
- Each block points to next
- Pros
  - Can grow files dynamically
  - No external fragmentation
  - Sequential access easy
- Cons
  - random access: horrible
  - unreliable: losing a block means losing the rest





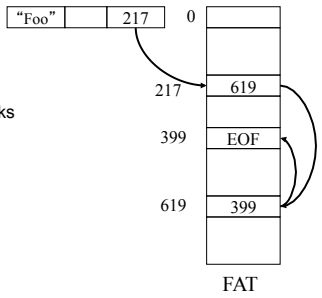

# Linked Allocation




Analogy in memory management?

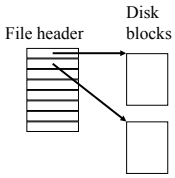
# A variation of linked files: File Allocation Table (FAT) (MS-DOS, OS2)

- Approach
  - A section of disk for each partition is reserved
  - One entry for each block
  - A file is a linked list of blocks
  - A directory entry points to the 1st block of the file
- Pros
  - Simpler than linked alloc.
- Cons
  - Always go to FAT
  - Random access slow for large files



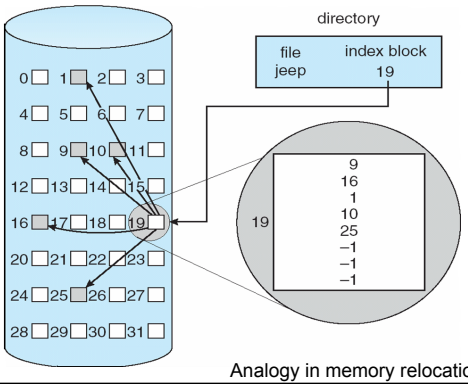
# Single-Level Indexed Files

- A user declares max size
- A file header holds an array of pointers to point to disk blocks
- Pros
  - Can grow up to a limit
  - Random access is fast
  - No external fragmentation
- Cons
  - Clumsy to grow beyond limit
  - Up-front declaration a real pain
  - file header cannot fit in inode
    - large inodes would be wasteful





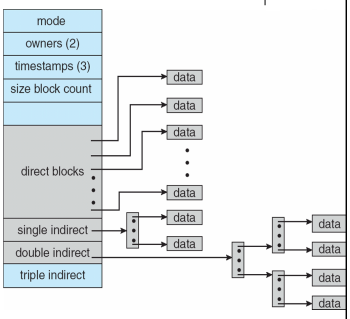

# Example of Indexed Allocation




Analogy in memory relocation?

# Multi-Level Indexed Files (UNIX)

- 13 Pointers in a header
  - 10 direct pointers
  - 11: 1-level indirect
  - 12: 2-level indirect
  - 13: 3-level indirect
- Pros & Cons
  - In favor of small files
  - Can grow
  - Limit is 16G (w/ 1K block)
  - Random access has up to 4 seeks
- How many disk accesses to load block 23, 5, 340?




Analogy in memory management?

# Linux ext2

- From Linux kernel documentation for ext2:

  "*There are pointers to the first 12 blocks which contain the file's data in the inode. There is a pointer to an indirect block (which contains pointers to the next set of blocks), a pointer to a doubly indirect block and a pointer to a trebly indirect block.*"

- ext2 has 15 pointers.
  - Pointers 1 to 12 point to direct blocks
  - pointer 13 points to an indirect block
  - pointer 14 points to a doubly indirect block
  - pointer 15 points to a trebly indirect block

## Theoretical ext2 limits under Linux

| Block size: | 1 KB | 2 KB | 4 KB | 8 KB |
|---|---|---|---|---|
| max. file size: | 16 GB | 128 GB | 1 TB | 8 TB |
| max. filesystem size: | 4 TB | 8 TB | 16 TB | 32 TB |



## Deep thinking

- What about sequential access in multi-level indexed scheme?
- Can we try multi-level indexing in page table design?



## Summary

- Seeks kill performance → exploit spatial locality
- Extent-based allocation optimizes sequential access
- Single-level indexed allocation has speed
- Unix file system has great flexibility
- Bitmaps show contiguous free space
- Linked lists easy to search for free blocks



## Reading

- Chapters 10-11