CSE 451: Operating Systems
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Module 16
BSD UNIX Fast File System

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File system implementations

- We've looked at disks
- We've looked at file systems generically
- We've looked in detail at the implementation of the original Bell Labs UNIX file system
  - a great *simple yet practical* design
  - exemplifies engineering tradeoffs that are pervasive in system design
- Now we'll look at some more advanced file systems
  - First, the Berkeley Software Distribution (BSD) UNIX Fast File System (FFS)
    - enhanced performance for the UNIX file system
    - at the heart of most UNIX file systems today

BSD UNIX FFS

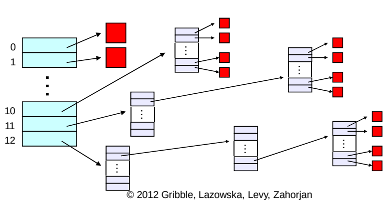
- Original (1970) UNIX file system was elegant but slow
  - poor disk throughput
    - far too many seeks, on average
- Berkeley UNIX project did a redesign in the mid '80's
  - McKusick, Joy, Fabry, and Leffler
  - improved disk throughput, decreased average request response time
  - principal idea is that FFS is aware of disk structure
    - it places related things on nearby cylinders to reduce seeks

Recall the UNIX disk layout

- Boot block
  - can boot the system by loading from this block
- Superblock
  - specifies boundaries of next 3 areas, and contains head of freelists of inodes and file blocks
- i-node area
  - contains descriptors (i-nodes) for each file on the disk; all i-nodes are the same size; head of freelist is in the superblock
- File contents area
  - fixed-size blocks; head of freelist is in the superblock
- Swap area
  - holds processes that have been swapped out of memory

Recall the UNIX block list / file content structure

- directory entries point to i-nodes – file headers
- each i-node contains a bunch of stuff including 13 block pointers
  - first 10 point to file blocks (i.e., 512B blocks of file data)
  - then single, double, and triple indirect indexes



UNIX FS data and i-node placement

- Original UNIX FS had three major performance problems:
  - data blocks are allocated randomly in aging file systems
    - blocks for the same file allocated sequentially when FS is new
    - as FS "ages" and fills, it needs to allocate blocks freed up when other files are deleted
      - deleted files are essentially randomly placed
      - so, blocks for new files become scattered across the disk!
  - data blocks are relatively small
    - reduces fragmentation, but exacerbates the problem above
  - i-nodes are allocated far from blocks
    - all i-nodes at beginning of disk, far from data
    - traversing file name paths, manipulating files, directories requires going back and forth from i-nodes to data blocks
- All three of these generate many long seeks!

FFS: Cylinder groups

- FFS addressed the first and third problems using the notion of a cylinder group
  - disk is partitioned into groups of cylinders
  - data blocks from a file are all placed in the same cylinder group
  - files in same directory are placed in the same cylinder group
  - i-node for file placed in same cylinder group as file's data
- Introduces a free space requirement
  - to be able to allocate according to cylinder group, the disk must have free space scattered across all cylinders
  - in FFS, 10% of the disk is reserved just for this purpose!
    - good insight: keep disk partially free at all times!
    - this is why it may be possible for df to report >100% full!

FFS: Increased block size, fragments

- The original UNIX FS had 512B blocks
  - even more seeking
  - small maximum file size (~1GB maximum file size)
- Then a version had 1KB blocks
  - still pretty puny
- FFS uses a 4KB blocksize
  - allows for very large files (4TB)
  - but, introduces internal fragmentation
    - on average, each file wastes 2K!
      - why?
    - worse, the average Unix file size is only about 1K!
      - why?
  - fix: introduce "fragments"
    - 1KB pieces of a block

FFS: Aggressive File Buffer Cache

- Exploit locality by caching file blocks in memory
  - the cache is system wide, shared by all processes
  - even a small (4MB) cache can be very effective (why?)
  - many FS's "read-ahead" into buffer cache
- What about writes?
  - some apps assume data is on disk after write
    - either "write-through" the buffer cache
    - or "write-behind"
      - maintain queue of uncommitted blocks, periodically flush. Unreliable!
      - NVRAM: write into battery-backed RAM. Expensive!
      - LFS, JFS: we'll talk about this soon!
- Buffer cache issues:
  - competes with VM for physical frames
    - integrated VM/buffer cache?
  - need replacement algorithms here
    - LRU usually

FFS: Awareness of hardware characteristics

- Original UNIX FS was unaware of disk parameters
- FFS parameterizes the FS according to disk and CPU characteristics
  - e.g., account for CPU interrupt and processing time, plus disk characteristics, in deciding where to lay out sequential blocks of a file, to reduce rotational latency

FFS: Performance

- This was a long time ago – look at the relative performance, not the absolute performance!

Type of File System	Processor and Bus Measured	Read Speed	Read Bandwidth	Read % CPU
old 1024	750/UNIBUS	29 Kbytes/sec	29/983 3%	11%
new 4096/1024	750/UNIBUS	221 Kbytes/sec	221/983 22%	43%
new 8192/1024	750/UNIBUS	233 Kbytes/sec	233/983 24%	29%
new 4096/1024	750/MASSBUS	466 Kbytes/sec	466/983 47%	73%
new 8192/1024	750/MASSBUS	466 Kbytes/sec	466/983 47%	54%

(983KB/s is theoretical disk throughput)

(block size / fragment size)

Table 2a – Reading rates of the old and new UNIX file systems.

Type of File System	Processor and Bus Measured	Write Speed	Write Bandwidth	Write % CPU
old 1024	750/UNIBUS	48 Kbytes/sec	48/983 5%	29%
new 4096/1024	750/UNIBUS	142 Kbytes/sec	142/983 14%	43%
new 8192/1024	750/UNIBUS	215 Kbytes/sec	215/983 22%	46%
new 4096/1024	750/MASSBUS	323 Kbytes/sec	323/983 33%	94%
new 8192/1024	750/MASSBUS	466 Kbytes/sec	466/983 47%	95%

(CPU maxed doing block allocation!)

Table 2b – Writing rates of the old and new UNIX file systems.

FFS: Faster, but less elegant (warts make it faster but ugly)

- Multiple cylinder groups
  - effectively, treat a single big disk as multiple small disks
  - additional free space requirement (this is cheap, though)
- Bigger blocks
  - but fragments, to avoid excessive fragmentation
- Aggressive File Buffer Cache
- Aware of hardware characteristics
  - ugh!