File-System Management and Optimization

Chapter 4: Section 4.4

Disk-Space Management

- Management of disk space if a major concern to file system designers
- Two general strategies for storing an n-byte file
  - n consecutive blocks of disk are allocated
  - split the file into a number of not always contiguous blocks

Block Size

- How big should the blocks be?
  - Sector, tracks and cylinders are good candidates
  - Large block size means even 1 byte files tie up a whole cylinder/sector
  - Small block size means file span multiple blocks
    - Multiple seeks and rotational delays

Block Size

- Consider a disk with 1MB per track, a rotation time of 8.33 ms and a seek time of 5 ms.
- The time in ms to read a block of k bytes is the sum of the seek, rotational delay and transfer times:

$$5 + 4.165 + (k / 1000000) * 8.33$$

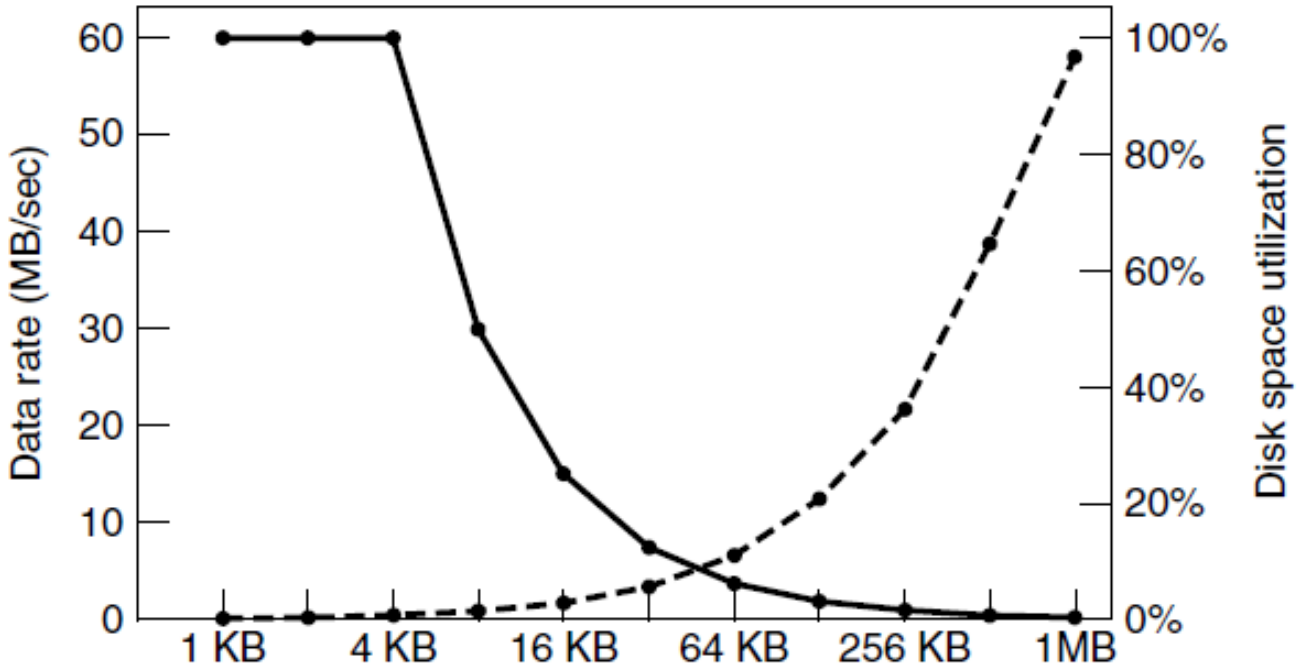
Block Size

Length	VU 1984	VU 2005	Web
1	1.79	1.38	6.67
2	1.88	1.53	7.67
4	2.01	1.65	8.33
8	2.31	1.80	11.30
16	3.32	2.15	11.46
32	5.13	3.15	12.33
64	8.71	4.98	26.10
128	14.73	8.03	28.49
256	23.09	13.29	32.10
512	34.44	20.62	39.94
1 KB	48.05	30.91	47.82
2 KB	60.87	46.09	59.44
4 KB	75.31	59.13	70.64
8 KB	84.97	69.96	79.69

Length	VU 1984	VU 2005	Web
16 KB	92.53	78.92	86.79
32 KB	97.21	85.87	91.65
64 KB	99.18	90.84	94.80
128 KB	99.84	93.73	96.93
256 KB	99.96	96.12	98.48
512 KB	100.00	97.73	98.99
1 MB	100.00	98.87	99.62
2 MB	100.00	99.44	99.80
4 MB	100.00	99.71	99.87
8 MB	100.00	99.86	99.94
16 MB	100.00	99.94	99.97
32 MB	100.00	99.97	99.99
64 MB	100.00	99.99	99.99
128 MB	100.00	99.99	100.00

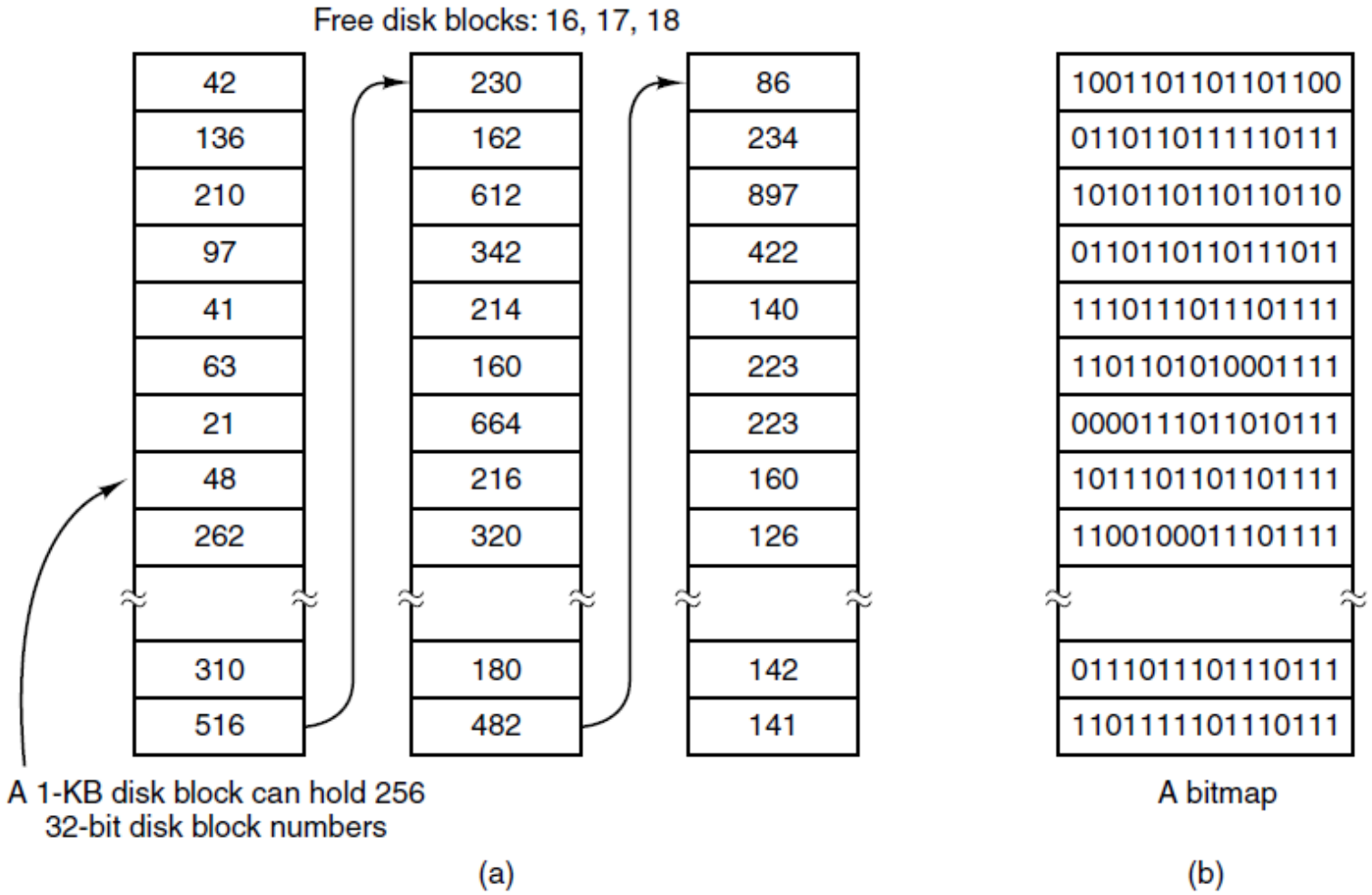
Percentage of files smaller than a given size (in bytes).

Block Size



The dashed curve (left-hand scale) gives the data rate of a disk. The solid curve (right-hand scale) gives the disk space efficiency. All files are 4 KB.

Free Blocks


Free disk blocks: 16, 17, 18
42
136
210
97
41
63
21
48
262
310
516
230
162
612
342
214
160
664
216
320
180
482
86
234
897
422
140
223
223
160
126
142
141
1001101101101100
0110110111110111
1010110110110110
0110110110111011
1110111011101111
1101101010001111
0000111011010111
1011101101101111
1100100011101111
0111011101110111
1101111101110111
A 1-KB disk block can hold 256
32-bit disk block numbers
A bitmap
(a)
(b)

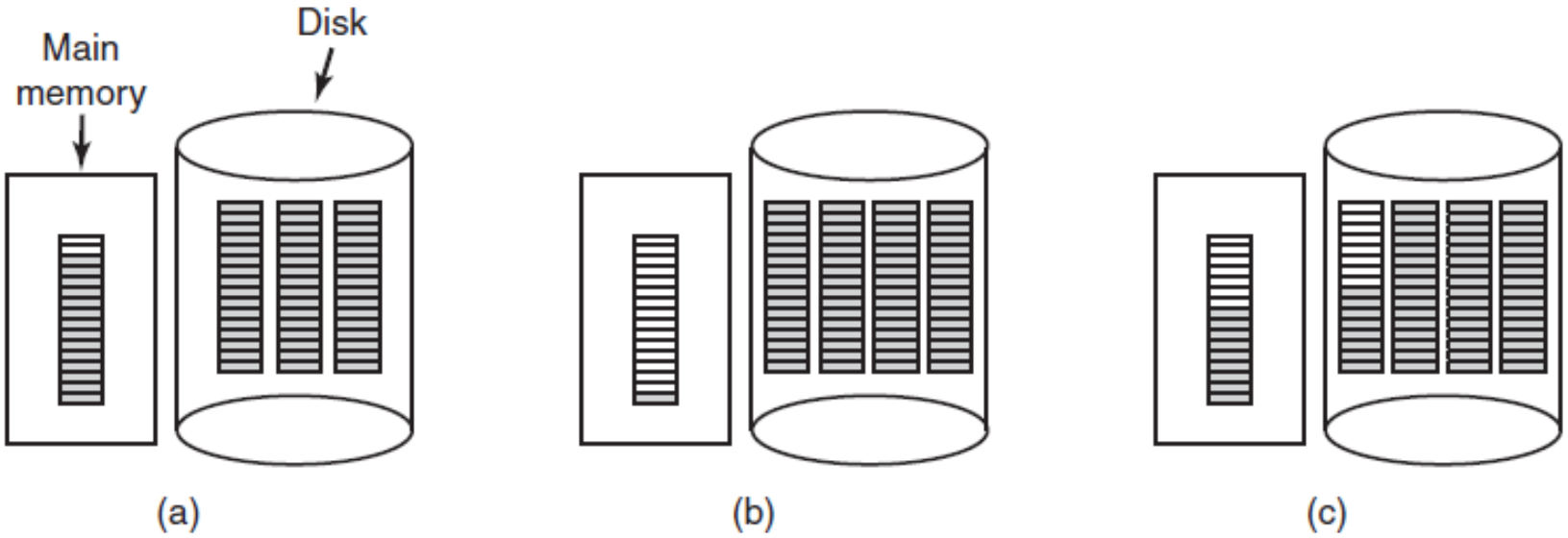
Free Blocks

- Two methods used
  - Linked list of disk blocks
  - Like inode, use a disk block to store it
    - 1-KB block, 32 bit block numbers means 255 blocks per list
    - 1 TB (1 billion disks blocks) needs 4 million blocks to track
    - Since free blocks used to store free block list: essentially free storage.

Free Blocks

- Only a single block of pointers needs to be kept in main memory.
- When a file is created the needed blocks are taken from a block of pointers.
  - Read a new block when the in memory pointers run low
- File deleted? Return pointers to memory.
- When the block of pointers is full, write it to disk

Free Blocks



(a) An almost-full block of pointers to free disk blocks in memory and three blocks of pointers on disk.

(b) Result of freeing a three-block file.

(c) An alternative strategy for handling the three free blocks. The shaded entries represent pointers to free disk blocks.

Free Blocks

- Other method is a bitmap
  - Disk with n block represented by a bitmap with n bits
  - 1-TB disk needs 1 billions bits, around 130,000 1-KB blocks
- Less space than linked list until disk nearly full.

Free Blocks

- Linked list optimization
  - Track runs of blocks rather than individual blocks
    - Best case an empty disk represented by two numbers: first free block and size.

Disk Size / Free Blocks

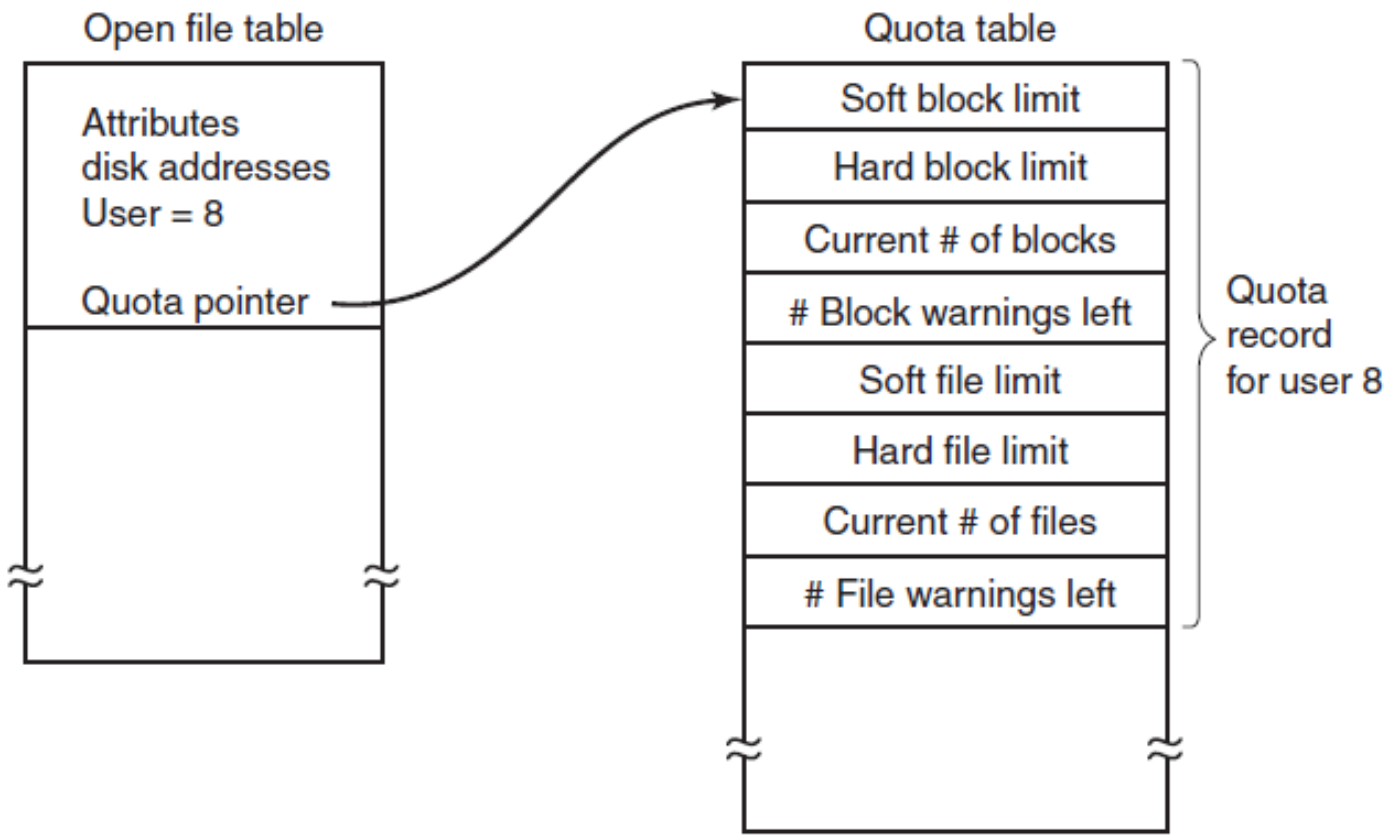
- Deciding optimal solution requires data the OS designers won't have until the system is deployed and heavily used.
- Extrapolating form even a large set of computers would not give a reasonable answer.

Disk Quotas

» Each user gets a maximum allotment of files and blocks.

```
[tbakker@omega ~]$ quota
Disk quotas for user tbakker (uid 419371): none
```

Disk Quotas



» Quota record table for every user.

File System Backups

- File system destruction is far greater disaster than computer destruction.
  - PCs can be replaced within the hour*
- If the file system is lost restoring the missing information may be time consuming or impossible
- Backups not viewed as important until it's too late

File System Backups

- Backups are generally made to handle one of two potential problems:
  - Recover from disaster
    - Fire, Flood, Disk crash
      - Rare, so people don't backup
  - Recover from stupidity.
    - Accidental file deletion

File System Backups

- Backups take time and occupy a lot of space
- Do you backup the entire file system or part?
  - Applications can be reinstalled from media
  - Unix system /dev backup would be bad
  - Wasteful to backup files that haven't changed since last backup

File System Backups

- Incremental dump
  - Complete backup weekly or monthly
  - Daily backup of modified files daily.
  - Recovery is more complicated.
- Do you encrypt your backup?
  - Corrupted byte may make entire backup unreadable.

File System Backups

- Backing up a live filesystem is difficult.
  - Snapshotting a moving target
  - Algorithms devised to snapshot critical state by copying critical data structures
    - Frozen at moment of capture

File System Backups

- Security
  - Can't leave the tapes lying around.
  - Backups must be kept off site.
    - Daily backups do no good if a fire destroys them all.
    - Now two sites must be secured.

File System Backups

- Two strategies for dumping a disk to backup:
  - Physical and Logical
- Physical Dump
  - Starts at block 0 and writes all disk blocks in order until ti reaches the end of the disk.
  - Very simple to write. Very fast
  - Wasteful. Backing up unused blocks.
    - Skip but have to tap with block id.

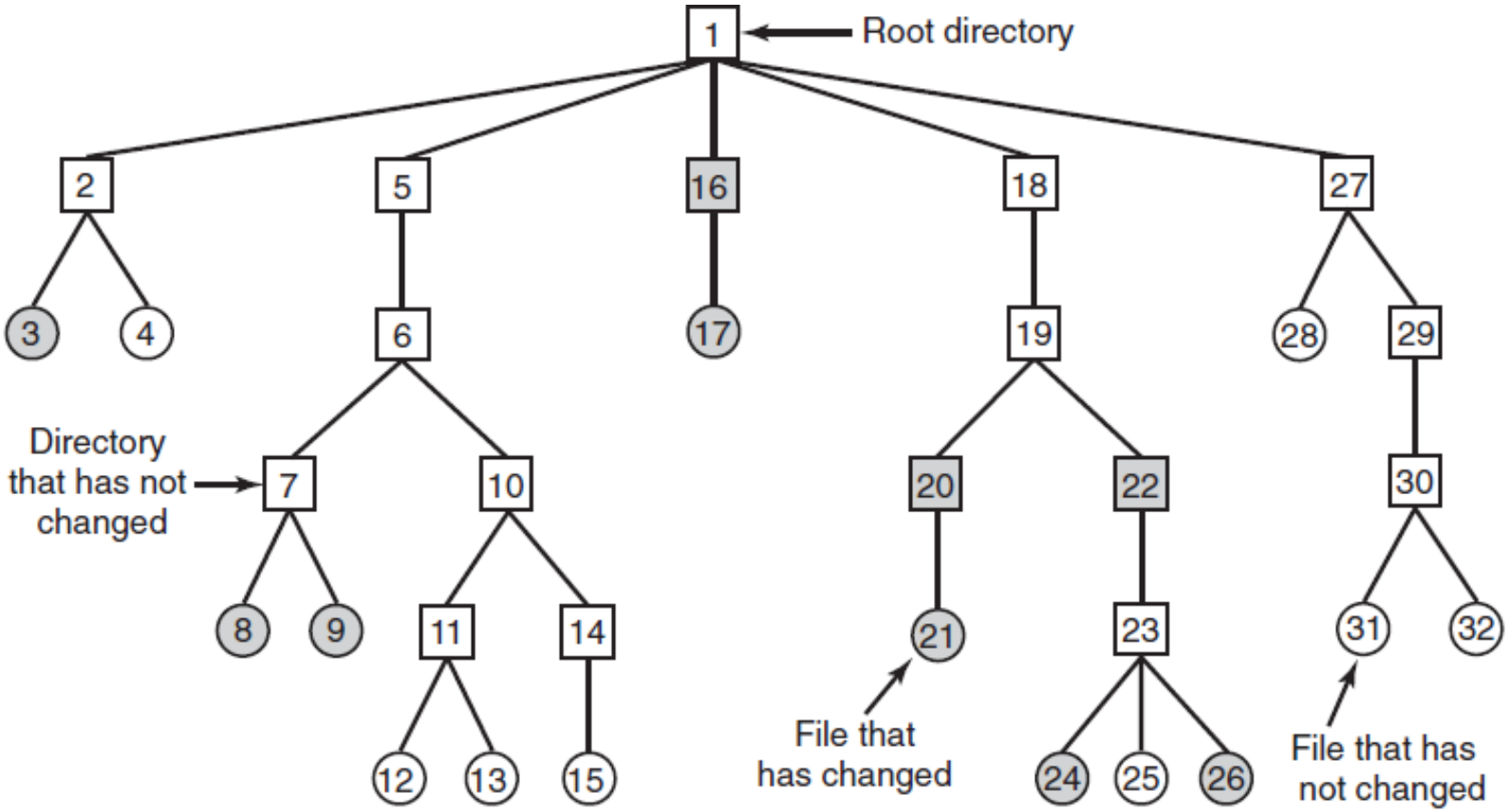
File System Backups

- Physical Dump cont.
  - Bad blocks
    - Always present.
    - Low level format occasionally detects, mark them and replace with spare blocks at the end of tracks. OS has no idea.
    - OS detects others after format and stores in unreadable file.
      - Backup program must have access to this so they don't corrupt when read back.

File System Backups

- Logical Dump
  - Starts at a directory and recursively dumps all the files that have changed since the last dump.

File-System Backups

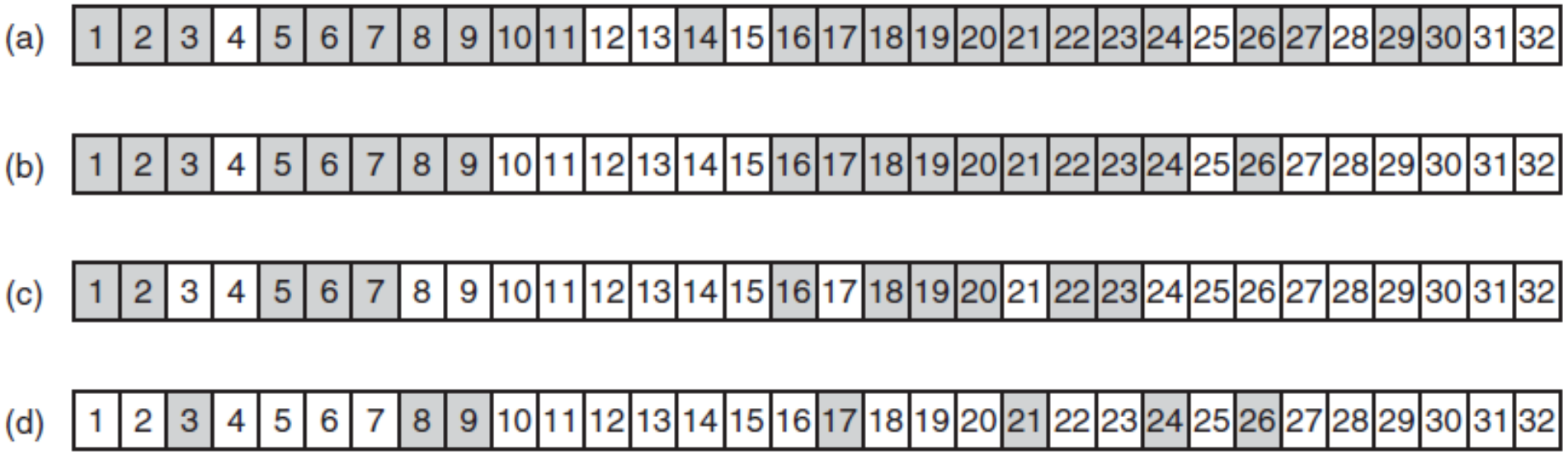


A file system to be dumped. The squares are directories and the circles are files. The shaded items have been modified since the last dump. Each directory and file is labeled by its i-node number.

File-System Backups

» Dump algo maintains a bitmap indexed by i-node number with several bits per inode.

  » bits are set and cleared as also works in 4 phases

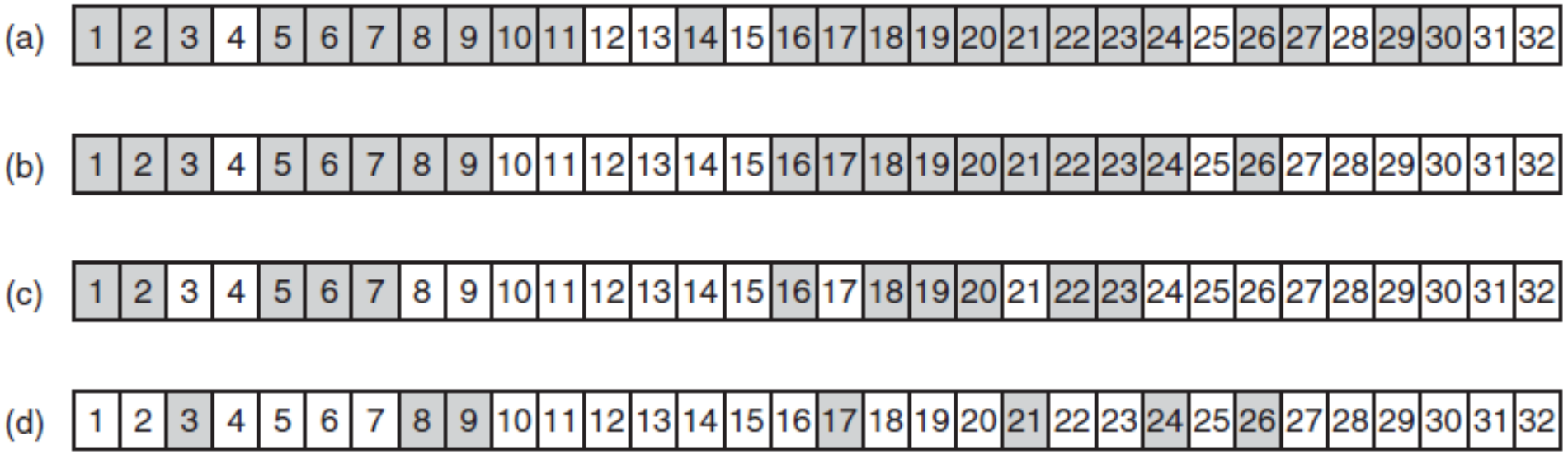


File-System Backups

» Phase 1: At the starting directory, examine all entries.

  » For each modified file, mark its inode in the bitmap.

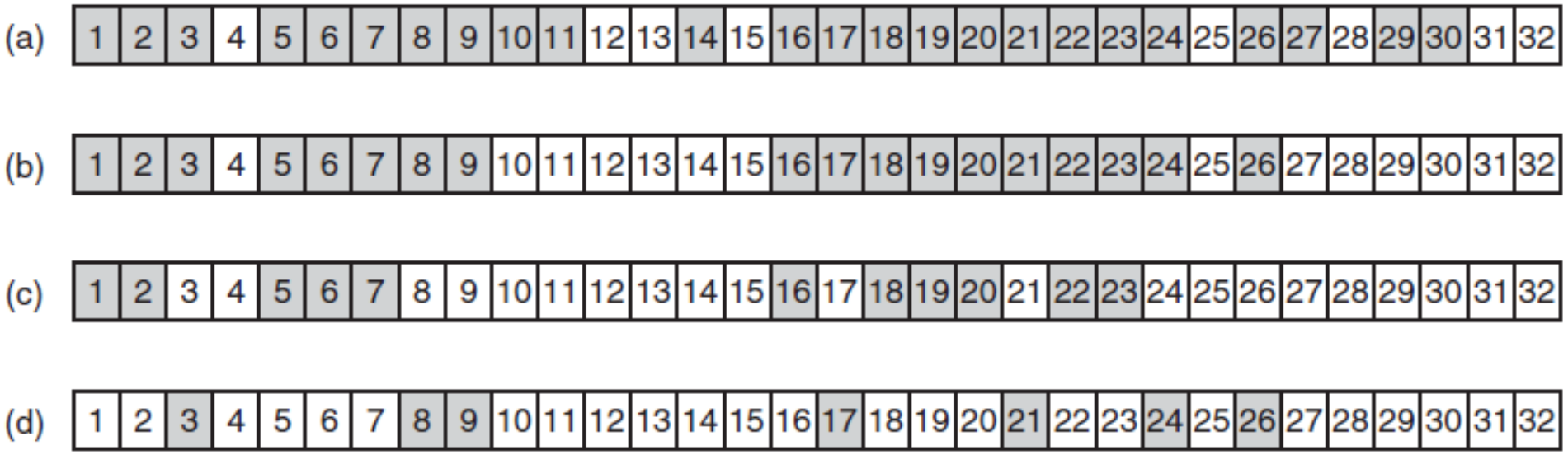
  » Mark every directory



File-System Backups

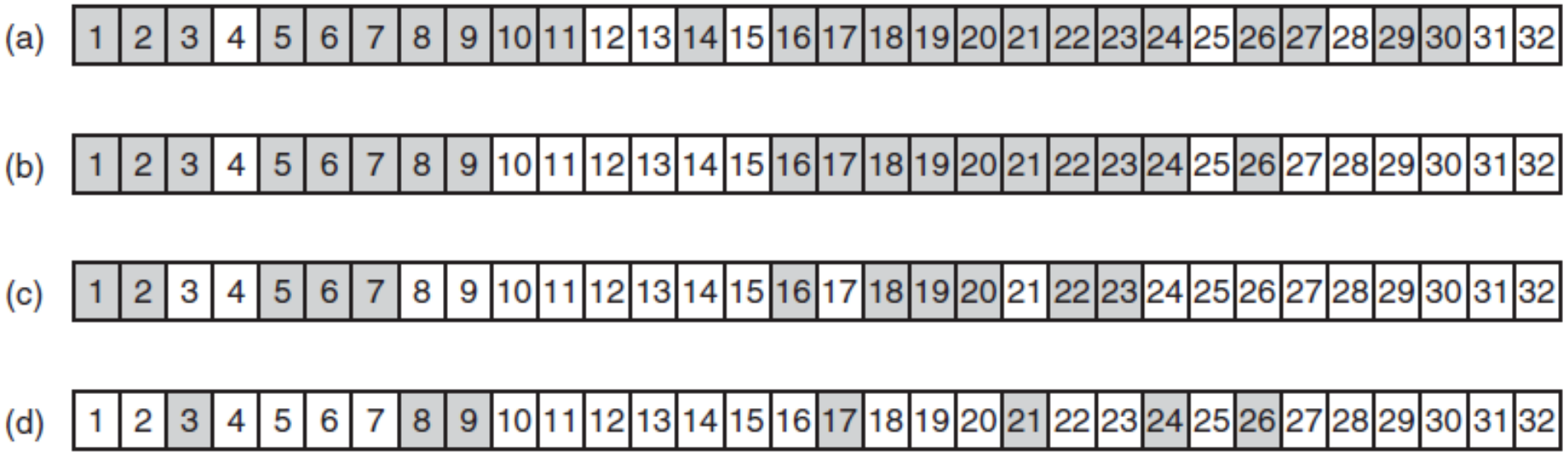
» Phase 2: Recursively walk the tree

  » Unmark directories with no unchanged files or directories



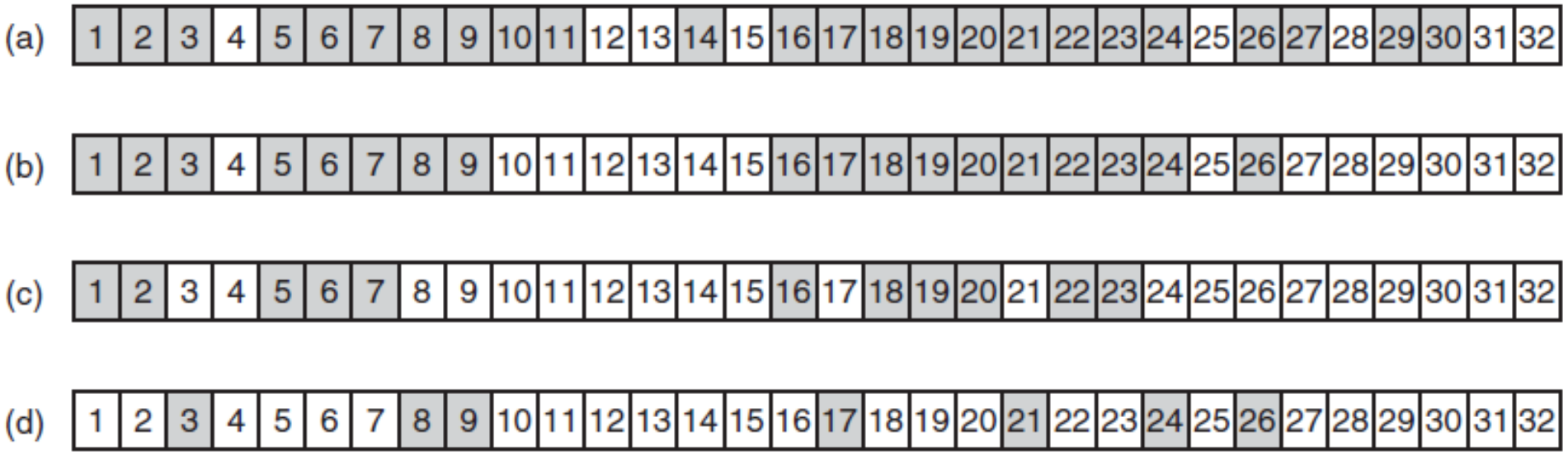
File-System Backups

» Phase 3: Scan inodes in numeric order and dump all the directories marked for dumping, preceded by their metadata



File-System Backups

» Phase 4: Dump the files, preceded by their metadata.



File-System Backups

- Restoring.
  - Create an empty file system on the disk
  - Restore the most recent full dump
    - Since directories come first they give a skeleton filesystem for the files.
    - Then restore the files
  - Restore all the subsequent incremental dumps

File-System Backups

- Logical Dumping Issues
  - Since free block list is not a file, it is not dumped and must be reconstructed form scratch after all the dumps has been restored.
  - Links: If a file is linked in two directories, only restore it once.
  - Unix files can have holes.
    - Holes are not part of the file and should not be dumped
  - Special files such as named pipes and /dev can not be stored.

File-System Consistency

- If a system crashes before all modified blocks are written the file system can be left in an inconsistent state.
  - Especially a problem if the blocks not written are the inodes, directory blocks or the free block list.

File-System Consistency

- Two consistency checks
  - Block
    - Build two tables each containing a counter for each block, initially set to zero.
    - First table tracks how many times each block is present in a file.
    - Second records how often each block is in the free list

File-System Consistency

- Read all the inodes using a raw device (ignore the file system structure)
  - Build list of all blocks in the corresponding file and increment counter in table one
- Read free block list and oil out table two.

File-System Consistency

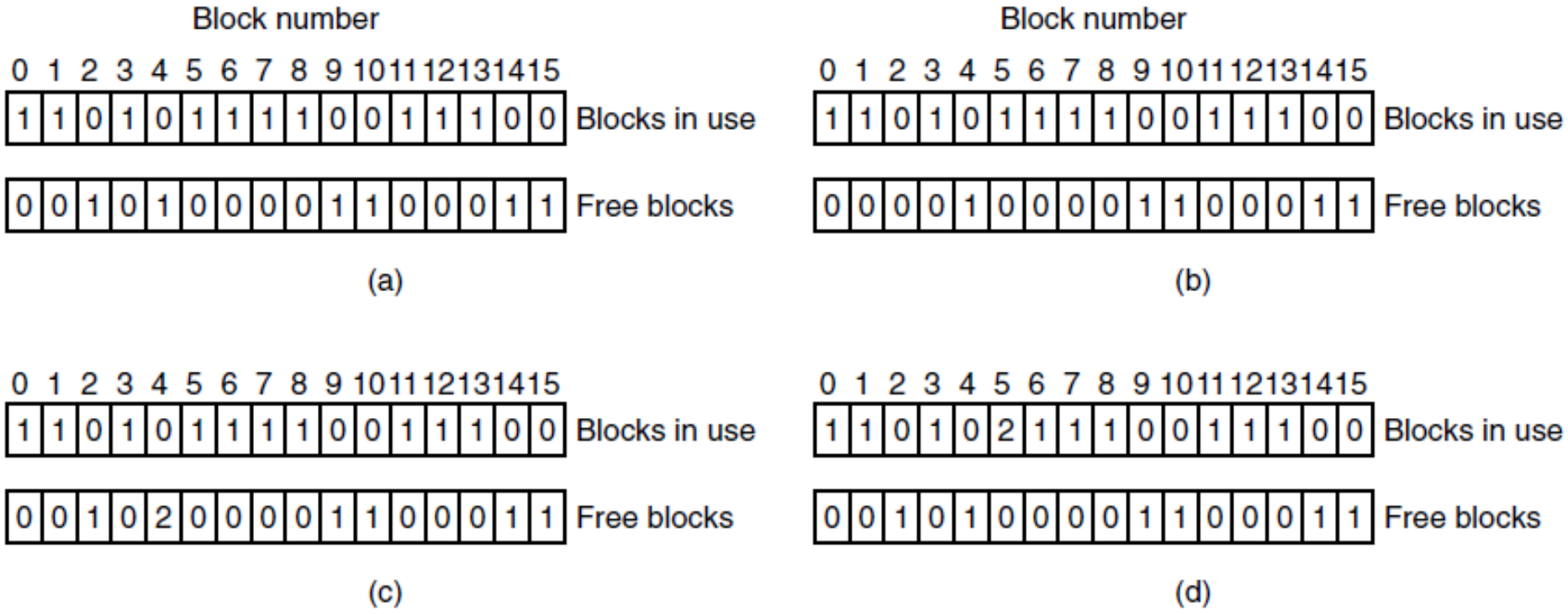


Figure 4-27. File system states. (a) Consistent. (b) Missing block. (c) Duplicate block in free list. (d) Duplicate data block.

File-System Consistency

- Missing block (b) - No real harm but wasted space.
- Twice in the free list (c) - Can only occur if the free block list is a list, not a bitmap. Solution: Rebuild the free list
- Block in two or more files (d): Bad. If either file is removed the block will be both free and used.
  - To fix: Allocate a block. Copy the data and update one of the inodes.

File-System Consistency

- Directory checks
  - Use per file table rather than per block
  - Recurse through the tree
    - For every inode in every directory increment a counter for the files usage.
      - Hard links mean multiple counts
      - Symbolic links don't count

File-System Consistency

- When done the list is a list indexed by inode telling how many directories contain the file.
- Compare against the nodes individual link count.
  - Starts at 1 at file creation. Incremented each hard link.

File-System Consistency

- Two errors can occur
  - Link count can be too high or too low
    - If count is too high even removing all the files would result in some inodes not being removed since count should still be greater than 0.
      - Wasted space but not serious

File-System Consistency

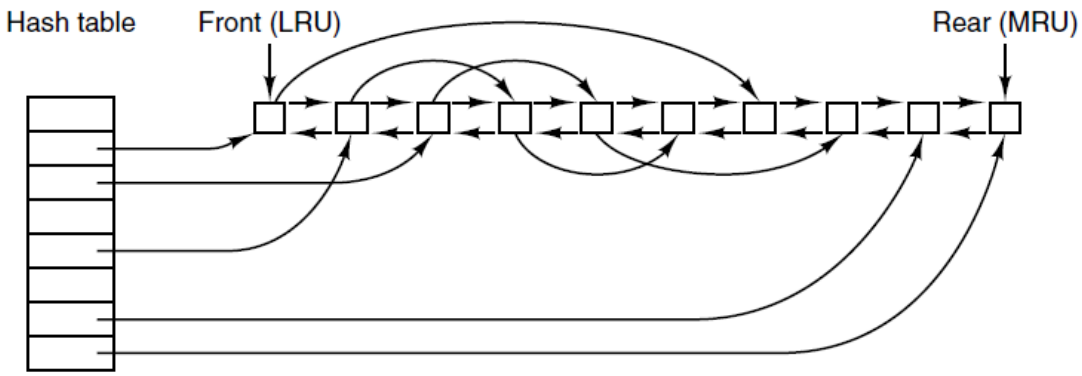
- If the link count is too low, a file may be deleted from a directory and the inode removed even though it is still referenced.
  - Force the link count in the inode to match the directory entries.

File-System Performance

- Reading a single word memory access is a million times faster than disk access.
- Three techniques we will cover to improve performance:
  - Caching
  - Block Read Ahead
  - Reducing Disk-Arm Motion

File-System Performance

- Caching
  - Block cache or Buffer cache.
  - Upon request check cache, if in cache return otherwise hit the disk.
  - Thousands of blocks in the cache.
    - Hash the device and disk address and lookup if it's in the cache.



File-System Performance

- If you read a block into cache you have to evict a block.
- Block references are relatively infrequent so an LRU implementation using a linked list is feasible.
  - Except: LRU is nor desirable

File-System Performance

- If a critical block, such as an inode block is read into cache and modified, but not rewritten to disk a crash will leave the FS in an inconsistent state.
  - Placed at the end of the LRU chain, it may be a while before it's evicted and written to disk.

File-System Performance

- Modified LRU
  - Is the block likely to be needed again soon?
    - End of list so they hang around in cache longer
  - Is the block essential to the consistency of the file system?
    - Front of list so they get removed and written to disk sooner.

File-System Performance

- Still undesirable to keep blocks in cache for too long.
  - Unix system call sync forces all modified blocks to disk.
    - *update* (pdflush on centos) runs in the background in an endless loop calling sync every 30s.
    - Windows system call FlushFileBuffers
      - Used to use a **write-through-cache**

File-System Performance

- Block Read Ahead
  - Get the blocks in cache before they are needed.
    - When request for block k is made, also check for k+1 in cache. If not there, read it in.
  - Does not work for random access and hurts performance by tying up resource

File-System Performance

- Reduce disk arm motion
- Keep disk storage in terms of groups of block rather than blocks
- File accesses, even for small files require two access: inode and data.
  - Allocate each cylinder with its own inodes.
  - Try to keep blocks in the same cylinder.

File-System Performance

» Reduce disk arm motion