CS 134:
Operating Systems
File System Implementation

2013-05-17

CS34

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Overview

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Implementation Issues
Caching
Failures
Disk Scheduling

API
What Goes in an API?
Two Strange APIs
Consistency
Other File Operations

Disk Caching—Class Exercise

If OS caches blocks of a file in memory,

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There's a close relationship to paging algorithms.

Disk Buffering

Allow writes to return immediately

- Copy data into a buffer
- Write out to the disk

Buffers vs. Caches

Which do we actually *need*?

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Buffers vs. Caches
Which do we actually *need*?

We *need* some kind of buffer (the write may not be the same size as the block).

We don’t need the cache; it just improves performance.

Buffer Cache

Store disk blocks waiting to write in *buffer cache*

- "Free" buffers used as cache for blocks recently read
- Dirty buffers will eventually be written to disk
- Allow buffer cache to use any free memory in the machine
- Ensure that a certain number of buffers are always available

Class Exercises & Reminders

When should we write the dirty buffers?

Per-process or system-wide?

Remind you of anything?

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Buffer Cache (cont.)

One buffer cache for all processes and all block devices

- Local disks
- Remote disks
- Tapes, CD-ROMs, etc.

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Dealing with System Failure—Class Exercise

Extending the file by one block. . .

In what order should we update the structures on disk to cause minimum damage if the system crashes?

(Assume disk will never leave a block half-written. . .)

What about

- File creation?
- File deletion?

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Recovering from System Failure

Before system failure. . .

- Backups!

After system failure. . .

- Run consistency checker—compares data in directory structure with data blocks on disk, tries to fix inconsistencies.
- Recover lost files (or disk) by restoring data from backup

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Disk Scheduling

OS needs to use all I/O devices efficiently:

- Minimize access time—composed of
  - *Seek time*
  - *Rotational latency*
- Maximize disk bandwidth
  - Bandwidth = Total Bytes Transferred / Total Time Taken
- Usually, disk requests can be re-ordered
- Several algorithms exist to schedule disk I/O requests
  - Consider, e.g., cylinders 98, 183, 37, 122, 14, 124, 65, 67 and an initial head position of 53

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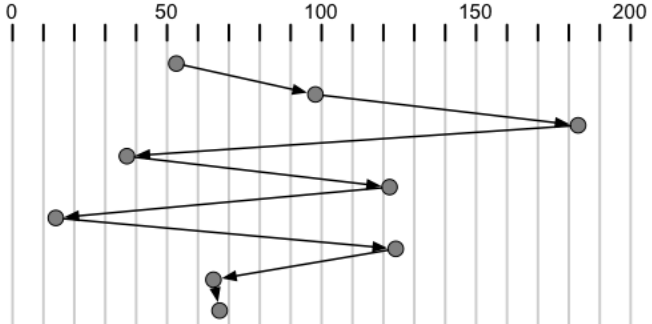
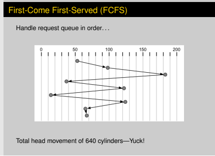
First-Come First-Served (FCFS)

Handle request queue in order. . .

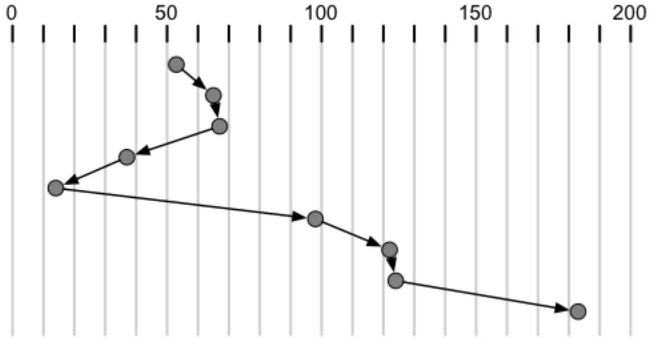


Total head movement of 640 cylinders—Yuck!

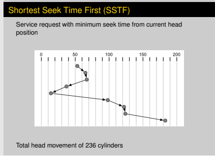


Shortest Seek Time First (SSTF)

Service request with minimum seek time from current head position



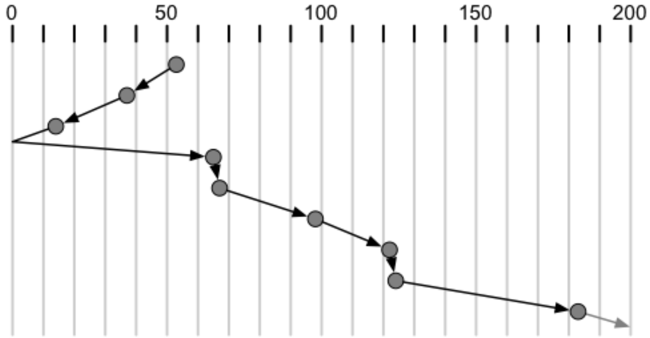
Total head movement of 236 cylinders



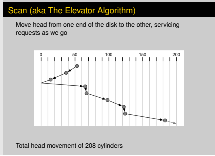
SSTF may starve requests (why?).

Scan (aka The Elevator Algorithm)

Move head from one end of the disk to the other, servicing requests as we go

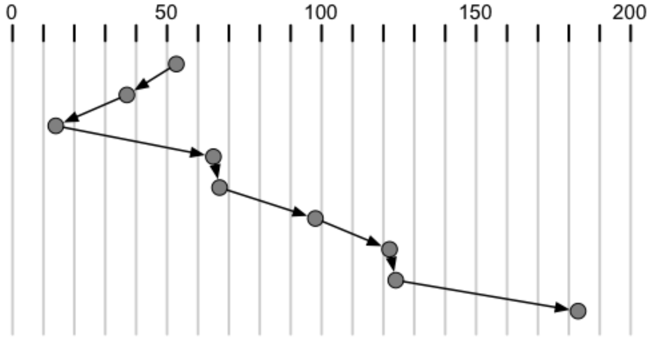


Total head movement of 208 cylinders

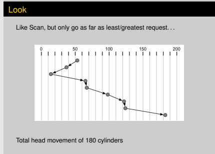


Look

Like Scan, but only go as far as least/greatest request. . .

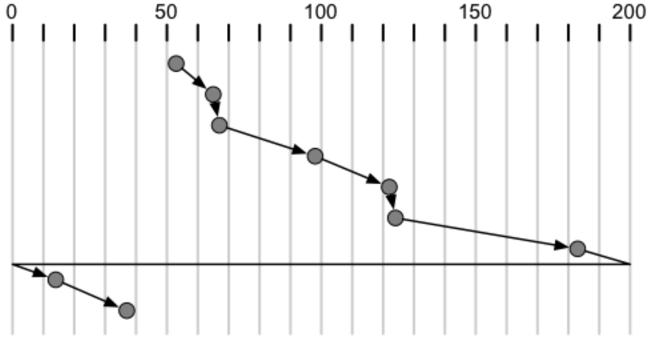


Total head movement of 180 cylinders

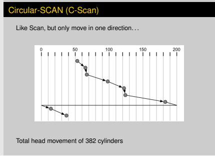


Circular-SCAN (C-Scan)

Like Scan, but only move in one direction...



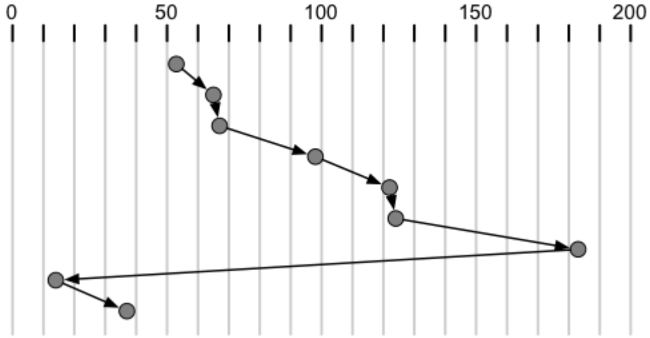
Total head movement of 382 cylinders



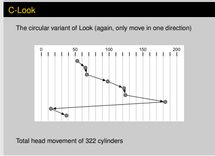
Why do this? It wastes head movement...

C-Look

The circular variant of Look (again, only move in one direction)



Total head movement of 322 cylinders



Fairness

What if we had two processes, each producing the following requests

- 0, 5, 10, . . . , 75
- 125, 130, 135, . . . , 200

How fair would these techniques be?

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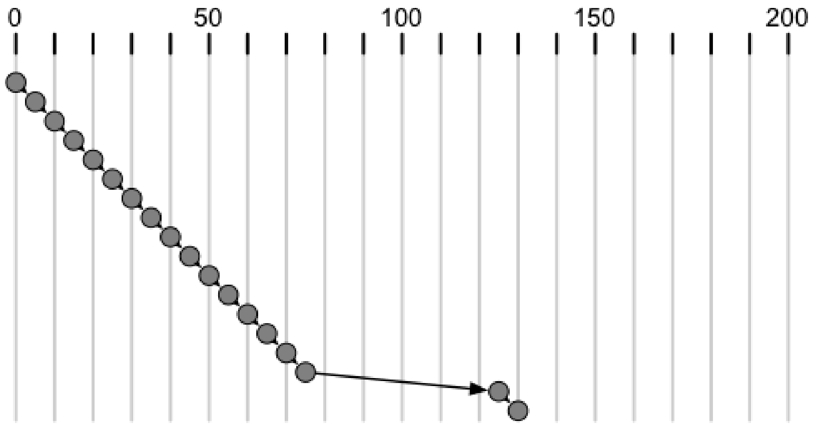
Fairness—Look



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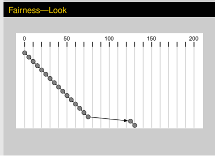
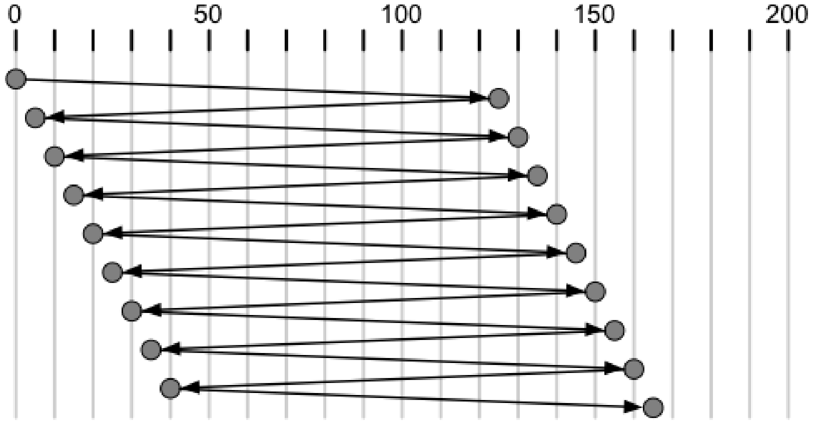
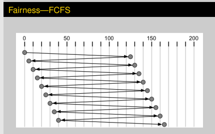
Fairness—Look

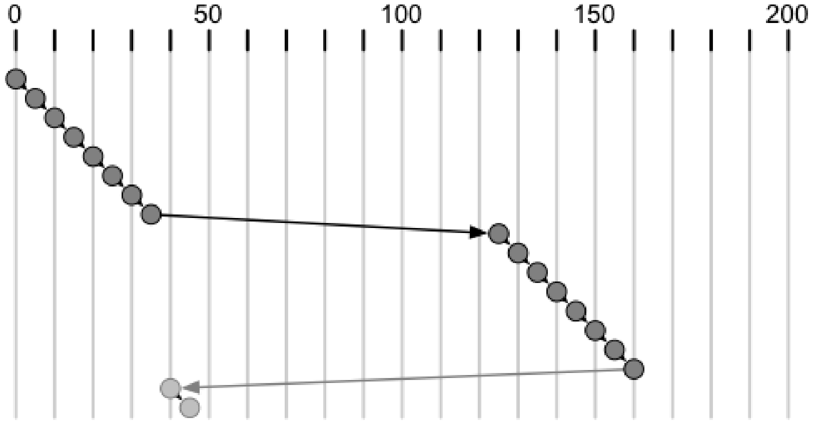


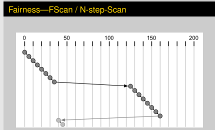
Fairness—FCFS





Fairness—FScan / N-step-Scan





Selecting a Disk-Scheduling Algorithm

Comparing algorithms, we find that:

- FCFS can be okay **if** disk controller manages the scheduling (many do these days)
- SSTF is common and has natural appeal
- LOOK works well (lowest amount of head moment in our test)
- LOOK and C-LOOK perform better for systems under heavy load

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Modern Disk Geometry

Modern disks maximize utilization by varying the number of sectors per cylinder

- Logical block→(Sector, Track/Cylinder)?
  - Complex or impossible for operating system to calculate!

Sometimes tracks are even laid out in a zig-zag pattern

Consequences?

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Consequences?

Disk scheduling becomes impossible to perform perfectly. But approximations work reasonably well. Or we can just hand it off to the disk (modern disks are *smart*).

But careful placement of vital data across platters may not work out.

File-Access API

Class Exercise

What operations should we provide for accessing files?

Describe & Develop

- Basic requirements for a file access API
- A stateful interface that satisfies those requirements
- A *stateless* interface that satisfies them

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This is a lengthy exercise; they should divide into groups and do it on paper.

Stateful File Access

OS maintains some "context" for each open file...

File access

- *handle* = `open` (*filename, mode*)
- `read` (*handle, length, buffer*)
- `write` (*handle, length, buffer*)
- `truncate` (*handle, length*)
- `seek` (*handle, position*)
- `close` (*handle*)

File management

- `info` (*name, info*)
- `delete` (*name*)
- `change_directory` (*dirname*)
- `create_dir` (*dirname*)
- `move` (*name, name*)

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Stateless File Access

No (apparent) internal state—each system call fully describes the desired operation

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Contrast these two approaches. . .

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Completeness: Each method can simulate the other
Stateless operation:

- Simple
- Works well in a multi-threaded program
- Basis for NFS

Stateful operation:

- Assumes file-locality and sequential access is common
- Provides the operating system with more information about which files are being used
- Maps well to other kinds of device besides files (e.g., read/write to a terminal)
- May add arbitrary limitations (e.g, maximum open files)

Michigan Terminal System (60's)

- Files divided into variable-length "lines"
  - Even binary files made up of lines
  - Each line numbered (fixed-point, 6 fractional decimal digits)
  - Could read by line number or by "next line"
  - Could write by line number (inserting in middle if appropriate) or (?) just append at end
- No user access to devices
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RSX-11M/VMS (70's)

- "inodes" exposed to application
- Directories identified by OS but accessed with file API
- OS responsible for allocating blocks upon request
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Consistency Model

Additional complications:

- Multiple processes can access files
  —Two (or more) processes could read and write same file
- Asynchronous writes + errors = ?
- What if file is moved/renamed/deleted while a process is using it?

What should the rules be?

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Unix Consistency Model

Unix uses the following rules:

- All file operations are globally atomic
- File is only deleted when its link (name) count is zero—an `open` counts as a link
- `write` in one process is globally visible immediately afterwards
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These rules do not map well onto a stateless I/O interface.

NFSv2 Consistency Model

Classic NFS uses the following rules:

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These rules map well onto a stateless I/O interface, but are not entirely consistent with the POSIX file model.

File Locking

What if we want to lock sections of a file?

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File Access—Leveraging the VM System

Use virtual memory system to provide file access

- “Map” file into memory
- Page faults retrieve file’s data from disk
- Provide copy-on-write or writeback semantics

Add the following system calls:

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(This mechanism doesn’t allow extending or truncating the file.)

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More File Access

Besides calls for protection, there are other system calls we might want:

- Control owner, permissions, etc.
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- Find (remaining) capacity of the disk
- Eject disk
- Discover whether any reads/writes have failed
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Generic Mechanisms

Two approaches

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Generic Mechanisms

Two approaches
- ioctl(handle, request, buffer)
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Ioctl is clumsy, hard to use, prone to inconsistency. Pseudo-files aren't good for adding one new feature (such as locking).