CSE 451: Operating Systems
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Module 14
From Physical to Logical: File Systems

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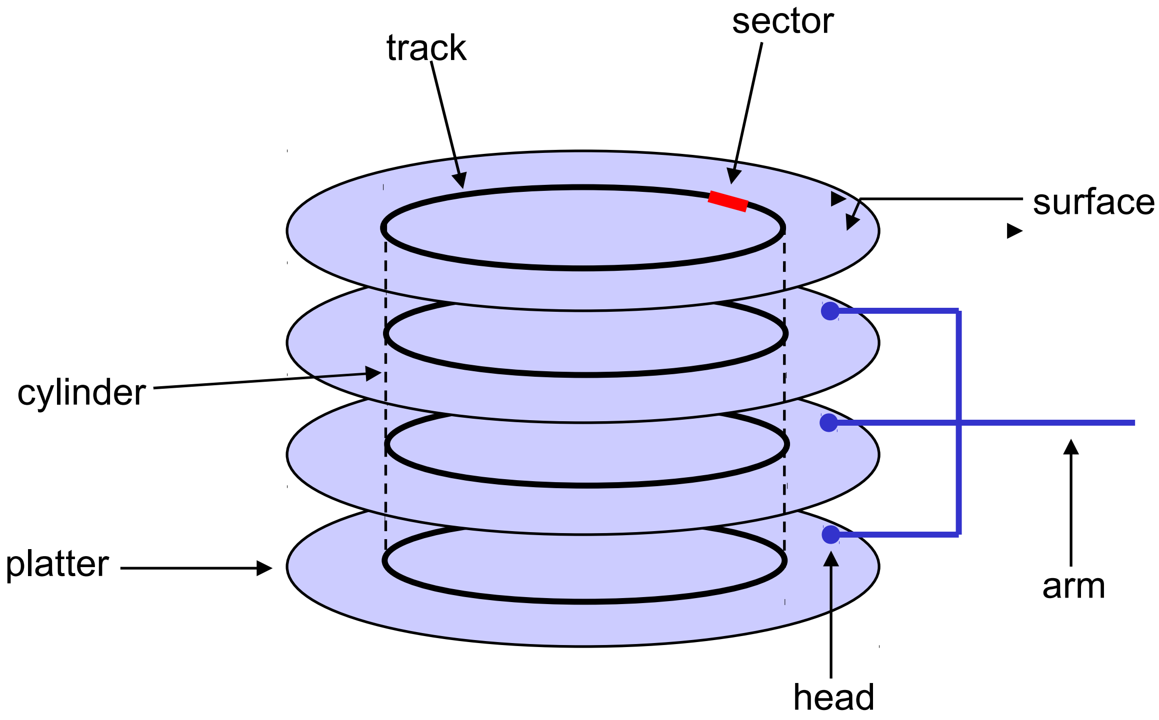
Physical disk structure

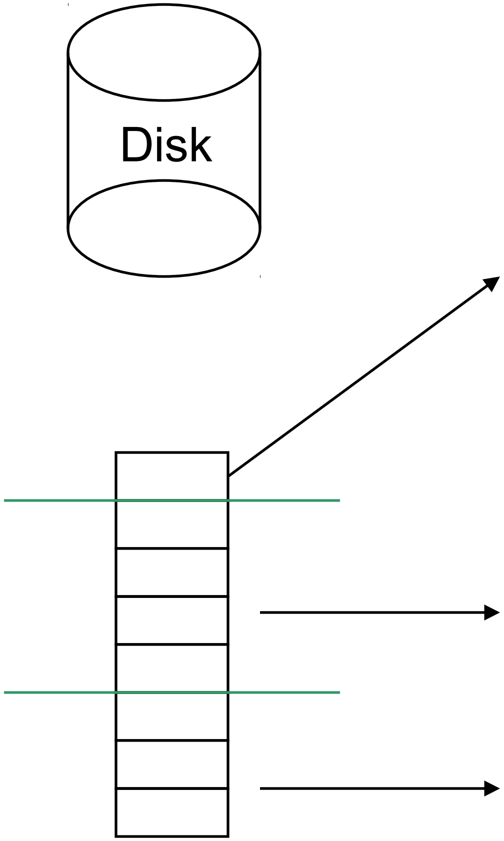
- Disk components
  - platters
  - surfaces
  - tracks
  - sectors
  - cylinders
  - arm
  - heads



Disk performance

- Performance depends on a number of steps
  - seek: moving the disk arm to the correct cylinder
    - depends on how fast disk arm can move
      - seek times aren't diminishing very quickly (why?)
  - rotation (latency): waiting for the sector to rotate under head
    - depends on rotation rate of disk
      - rates are increasing, but slowly (why?)
  - transfer: transferring data from surface into disk controller, and from there sending it back to host
    - depends on density of bytes on disk
      - increasing, and very quickly
- When the OS uses the disk, it tries to minimize the cost of all of these steps
  - particularly seek and rotation

From Physical To Logical: Low Level



Boot block:

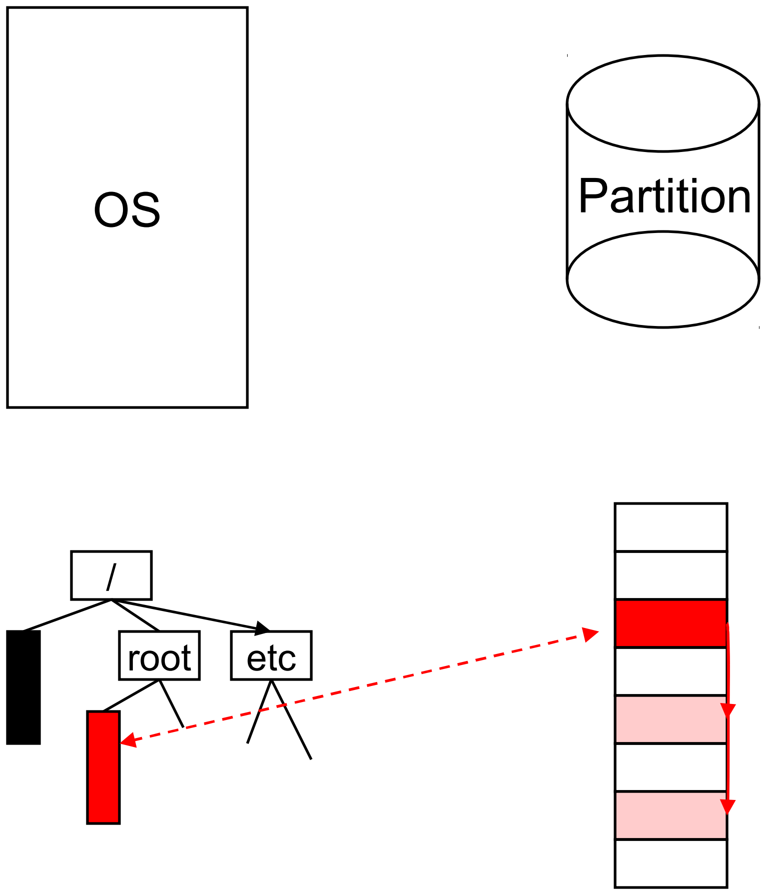
- boot loader (code)
- partition table

Partition 0:

- Independently managed group of blocks

Partition 1

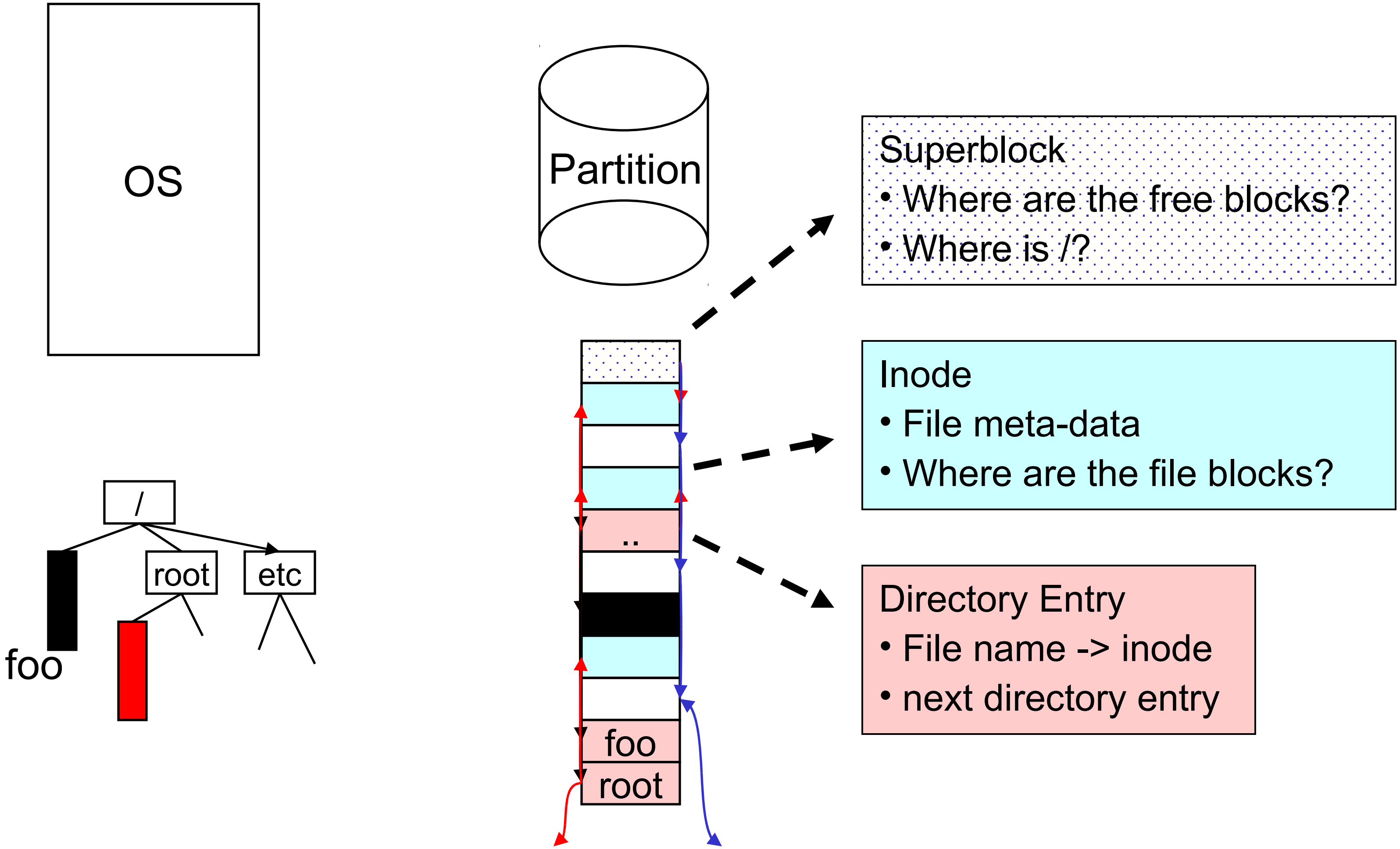
From Physical To Logical: File Systems



Need to keep track of 3 things:

1. Free blocks
2. Inodes
   - File blocks
1. Directory Entries

A Strawman Approach

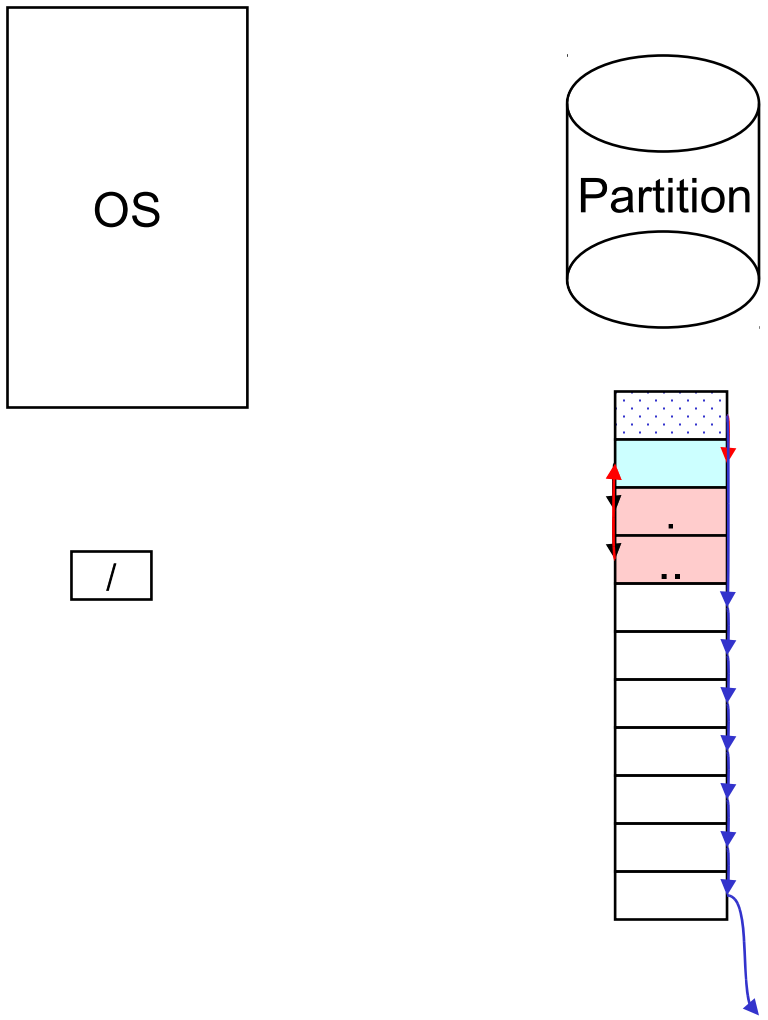


Superblock
- Where are the free blocks?
- Where is /?

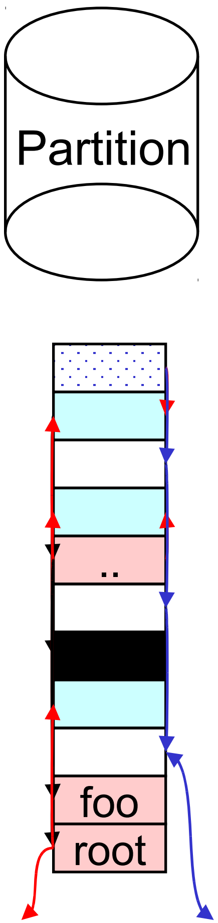
Inode
- File meta-data
- Where are the file blocks?

Directory Entry
- File name -> inode
- next directory entry

Formatting: Preparing the Empty File System



Evaluation



Positives:

- Simple
- No preset limits on:
  - File size
  - Number of files
  - Disk size

Negatives:

- Incredibly slow:
  - Many block transfers to read a directory
    - Many seek / latency delays
  - Direct access to file bytes requires walking linked list of data blocks
- Internal fragmentation
  - 1KB allocated for every inode
  - 1KB allocated for every directory entry

Solutions

- Performance
  - Pack logical items into physical blocks
    - Inodes
    - Directory entries
  - 1 seek / latency retries many items

- Keep items small
  - Fewer files than blocks ⇒ fewer bits in an inode name than a block name

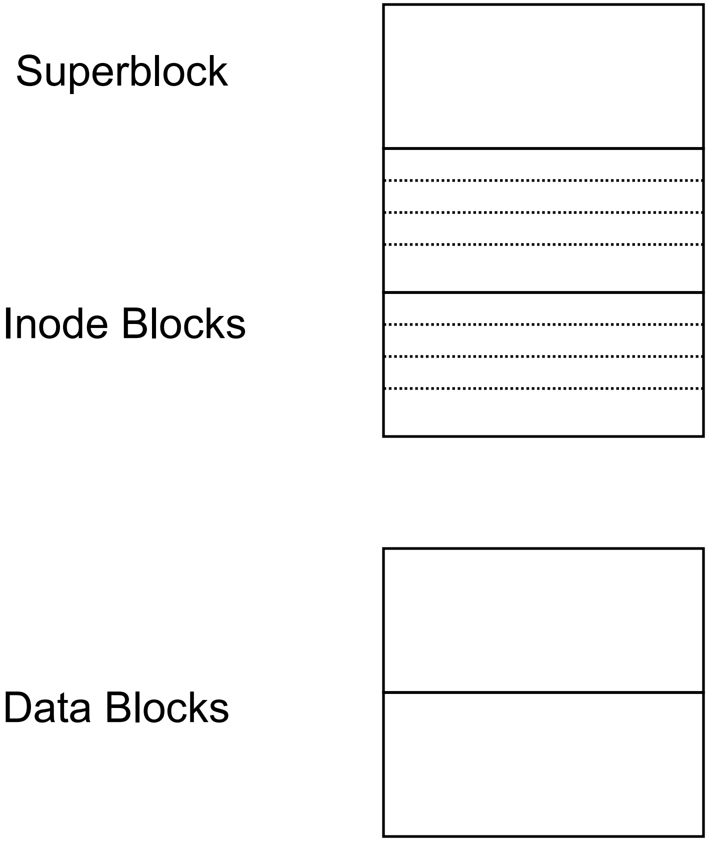
The original Unix file system

- Dennis Ritchie and Ken Thompson, Bell Labs, 1969
- "UNIX rose from the ashes of a multi-organizational effort in the early 1960s to develop a dependable timesharing operating system" – Multics
- Designed for a "workgroup" sharing a single system
- Did its job exceedingly well
  - Although it has been stretched in many directions and made ugly in the process
- A wonderful study in engineering tradeoffs

Disks are divided into many parts

- Boot block
  - can boot the system by loading from this block
  - Partition map
- Partition(s)
  - 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

Disk Partition Layout



Superblock

Inode Blocks

Data Blocks

Direct Access to inodes:

Inode K is in block
K / (BLOCK_SIZE / sizeof(inode))
At offset
K % (BLOCK_SIZE/sizeof(inode))

Directory entries are packed into blocks in a manner similar to inodes

The tree (directory, hierarchical) file system

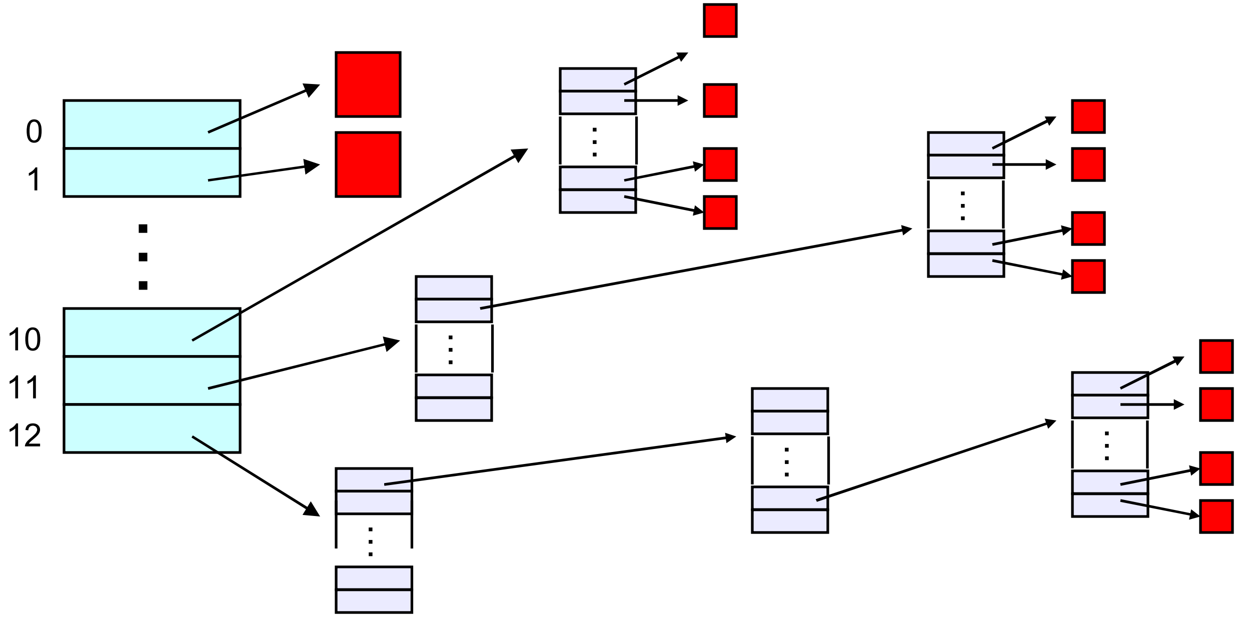
- A directory is a flat file of fixed-size entries
- Each entry consists of an i-node number and a file name

i-node number	File name
152	.
18	..
216	my_file
4	another_file
93	oh_my_god
144	a_directory

The “block list” portion of the i-node (Unix Version 7)

- Must be able to represent very small and very large files…
- with minimal chaining…
- and leaving inodes small

- Each inode contains 13 block pointers
  - first 10 are “direct pointers” (pointers to blocks of file data)
  - then, single, double, and triple indirect pointers



So …

- Data pointers occupy only 13 x 4B in the inode
- Can get to 10 x 512B = a 5120B file directly
  - (10 direct pointers, blocks in the file contents area are 512B)
- Can get to 128 x 512B = an additional 65KB with a single indirect reference
  - (the 11th pointer in the i-node gets you to a 512B block in the file contents area that contains 128 4B pointers to blocks holding file data)
- Can get to 128 x 128 x 512B = an additional 8MB with a double indirect reference
- Can get to 128 x 128 x 128 x 512B = an additional 1GB with a triple indirect reference
- Maximum file size is 1GB + a smidge

- A later version of Bell Labs Unix utilized 12 direct pointers rather than 10
  - Why?
- Berkeley Unix went to 1KB block sizes
  - What’s the effect on the maximum file size?
    - 256x256x256x1K = 17 GB + a smidge
  - What’s the price?
- Suppose you went to 4KB blocks?
  - 1Kx1Kx1Kx4K = 4TB + a smidge

File system consistency

- Both i-nodes and file blocks are cached in memory
- The “sync” command forces memory-resident disk information to be written to disk
  - system does a sync every few seconds
- A crash or power failure between sync’s can leave an inconsistent disk
- You could reduce the frequency of problems by reducing caching, but performance would suffer big-time

i-check: consistency of the flat file system

- Is each block on exactly one list?
  - create a bit vector with as many entries as there are blocks
  - follow the free list and each i-node block list
  - when a block is encountered, examine its bit
    - If the bit was 0, set it to 1
    - if the bit was already 1
      - if the block is both in a file and on the free list, remove it from the free list and cross your fingers
      - if the block is in two files, call support!
  - if there are any 0's left at the end, put those blocks on the free list

d-check: consistency of the directory file system

- Do the directories form a tree?
- Does the link count of each file equal the number of directories links to it?
  - I will spare you the details
    - uses a zero-initialized vector of counters, one per i-node
    - walk the tree, then visit every i-node

File System Performance 1: Disk scheduling

- Seeks are very expensive, so the OS attempts to schedule disk requests that are queued waiting for the disk
  - FCFS (do nothing)
    - reasonable when load is low
    - long waiting time for long request queues
  - SSTF (shortest seek time first)
    - minimize arm movement (seek time), maximize request rate
    - unfairly favors middle blocks
  - SCAN (elevator algorithm)
    - service requests in one direction until done, then reverse
    - skews wait times non-uniformly (why?)
  - C-SCAN
    - like scan, but only go in one direction (typewriter)
    - uniform wait times

File System Performance 2: Layout

- Disk scheduling attempts to minimize the impact of blocks needed at the moment located widely over the disk
  - How effective do you imagine it is / can be?

- An alternative (complementary) approach is to allocate blocks likely to be needed together near each other?
  - Which blocks might be needed together?

- A related approach is to observe block usage patterns and move them near each other
  - The “pipe organ” layout is the simplest example