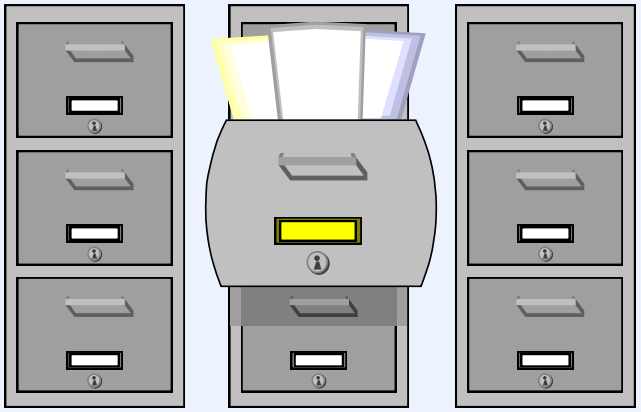
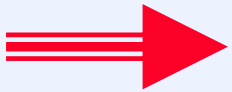
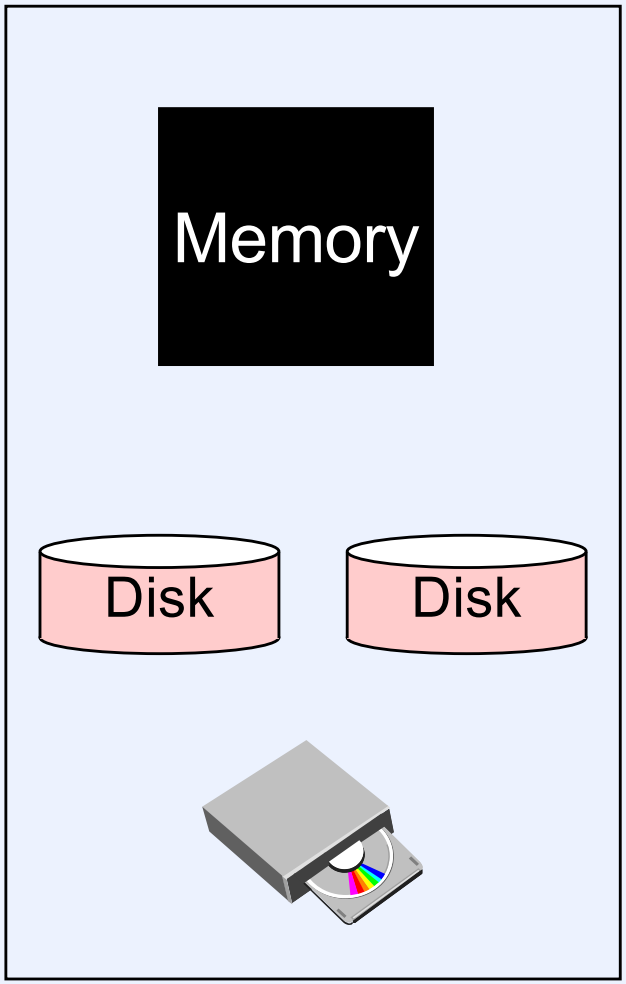
File Systems Part 1

Files







Requirements

- Permanent storage
  - resides on disk (or alternatives)
  - survives software and hardware crashes
    - (including loss of disk?)
- Quick, easy, and efficient
  - satisfies needs of most applications
    - how do applications use permanent storage?

Applications

- Software development
  - text editors
  - linkers and loaders
  - source-code control
- Document processing
  - editing
  - browsing
- Web stuff
  - serving
  - browsing
- Program execution
  - paging

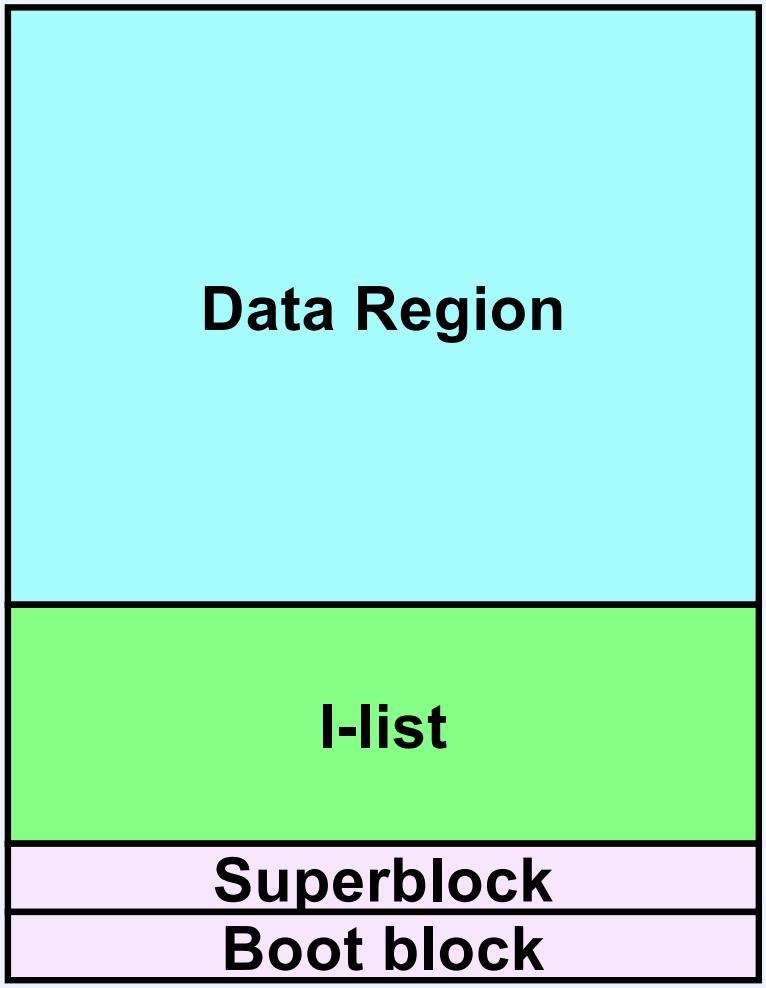
Needs

- Directories
  - convenient naming
  - fast lookup
- File access
  - sequential is very common!
  - “random access” is relatively rare

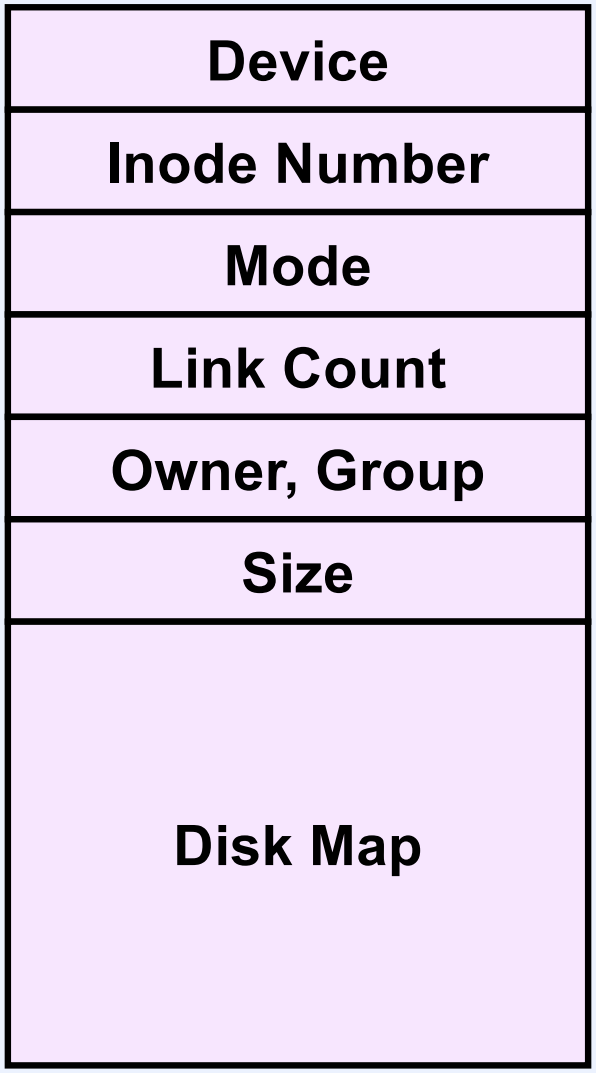
S5FS

- A simple file system
  - slow
  - not terribly tolerant to crashes
  - reasonably efficient in space
    - no compression
- Concerns
  - on-disk data structures
    - file representation
    - free space
- It's the Weenix file system!

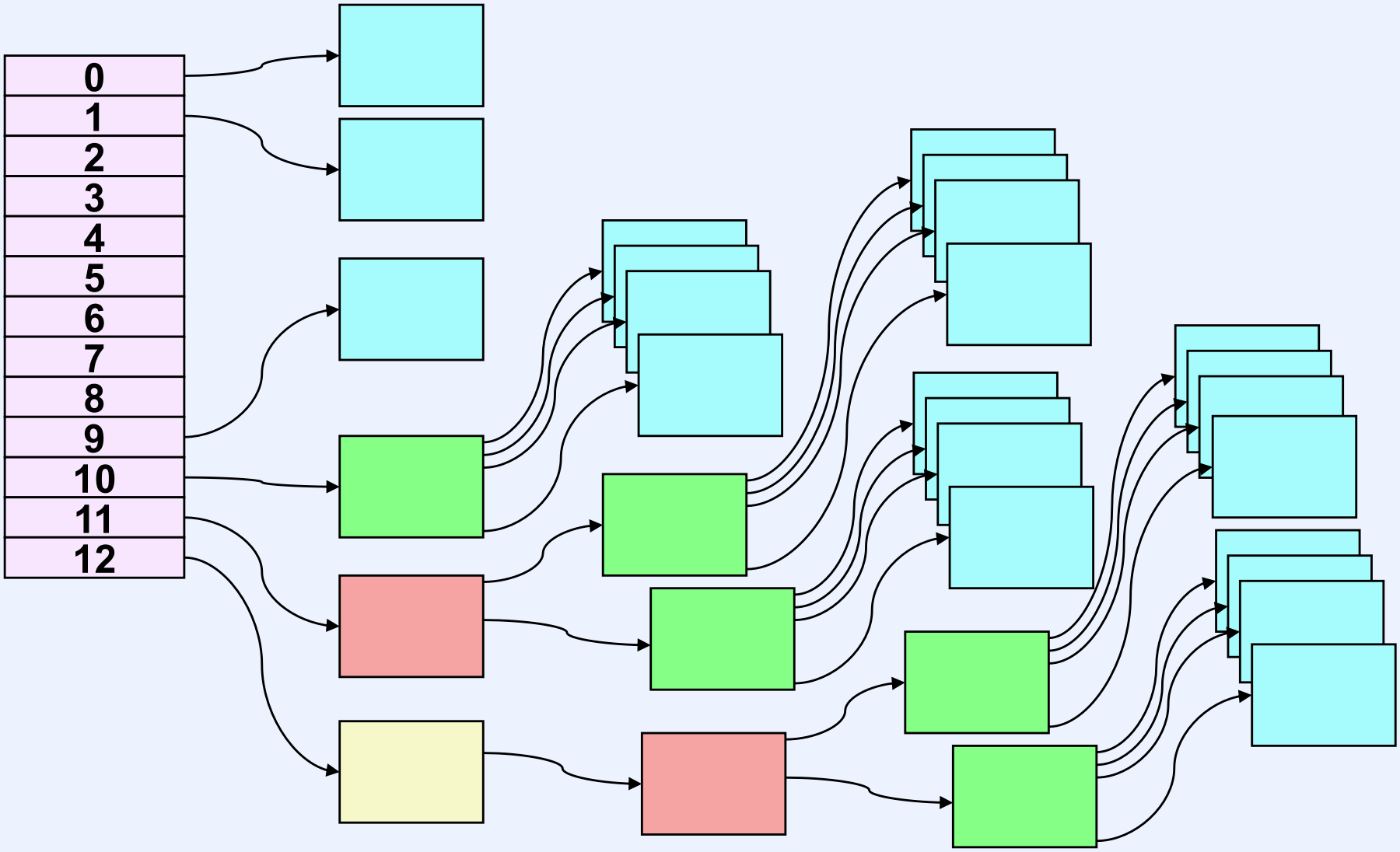
S5FS Layout



S5FS: Inode



Disk Map



Quiz 1

Suppose a new file is created. (At this point it occupies zero blocks.) Then one byte is written to it at byte offset $266 \times 2^{10} + 1$. Assume the block size is 2^{10} and block addresses occupy four bytes. How many blocks are required to represent the file, not counting its inode?

a) 1

b) 3

c) 270

d) more than 270

Quiz 2

Suppose one now writes to all locations in the file, from its beginning up to the location written to in the previous slide. How many blocks are required to represent the file, not counting its inode?

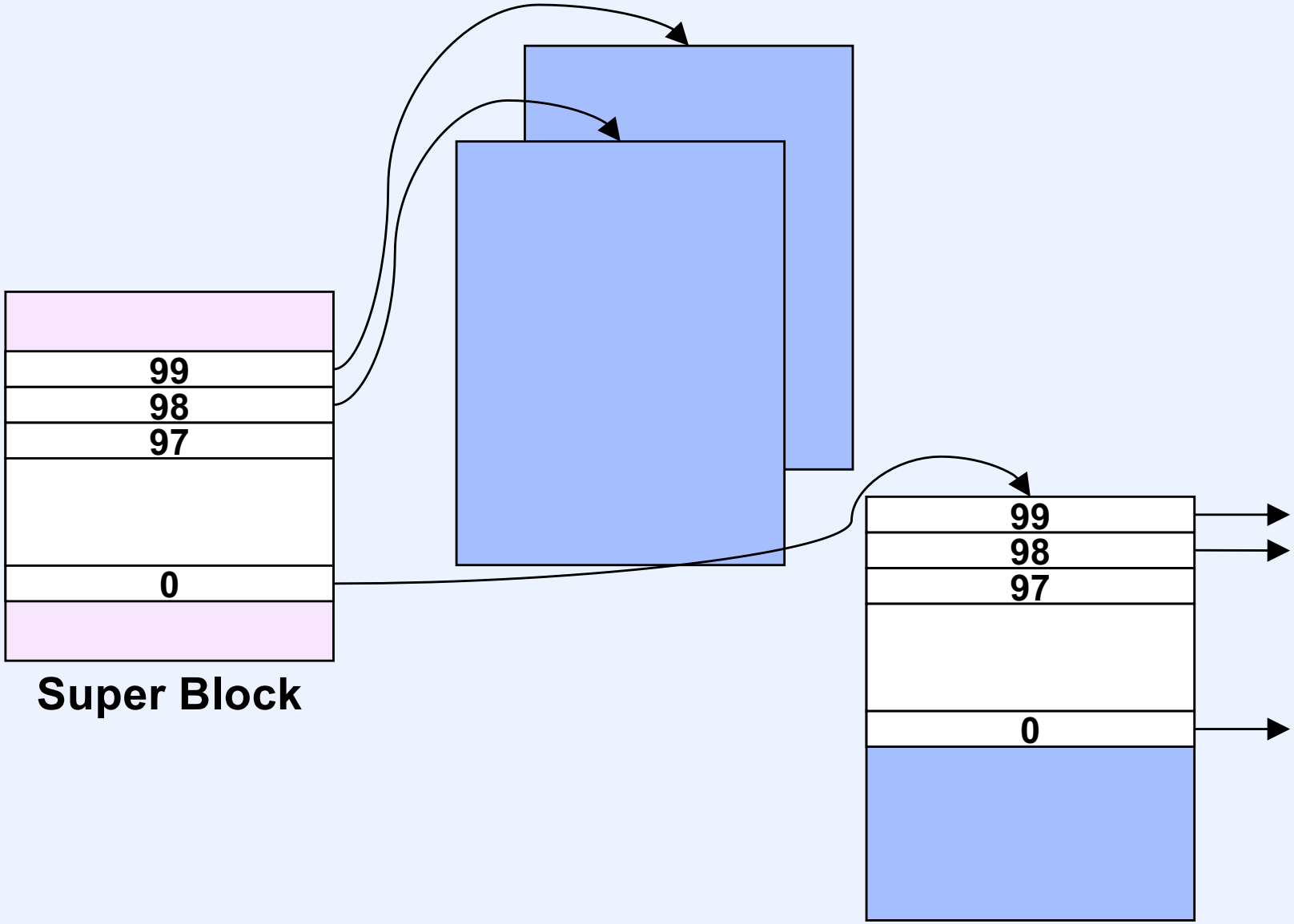
a) 1

b) 3

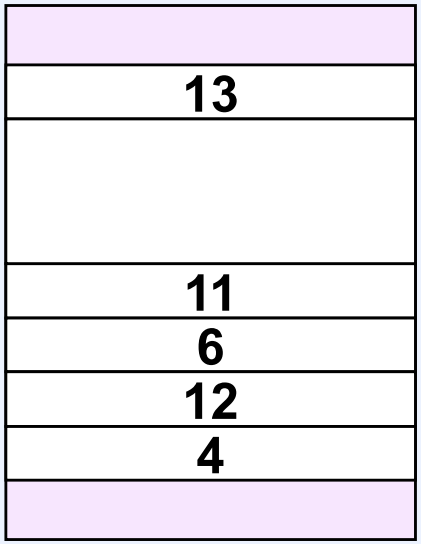
c) 270

d) more than 270

S5FS Free List



S5FS Free Inode List

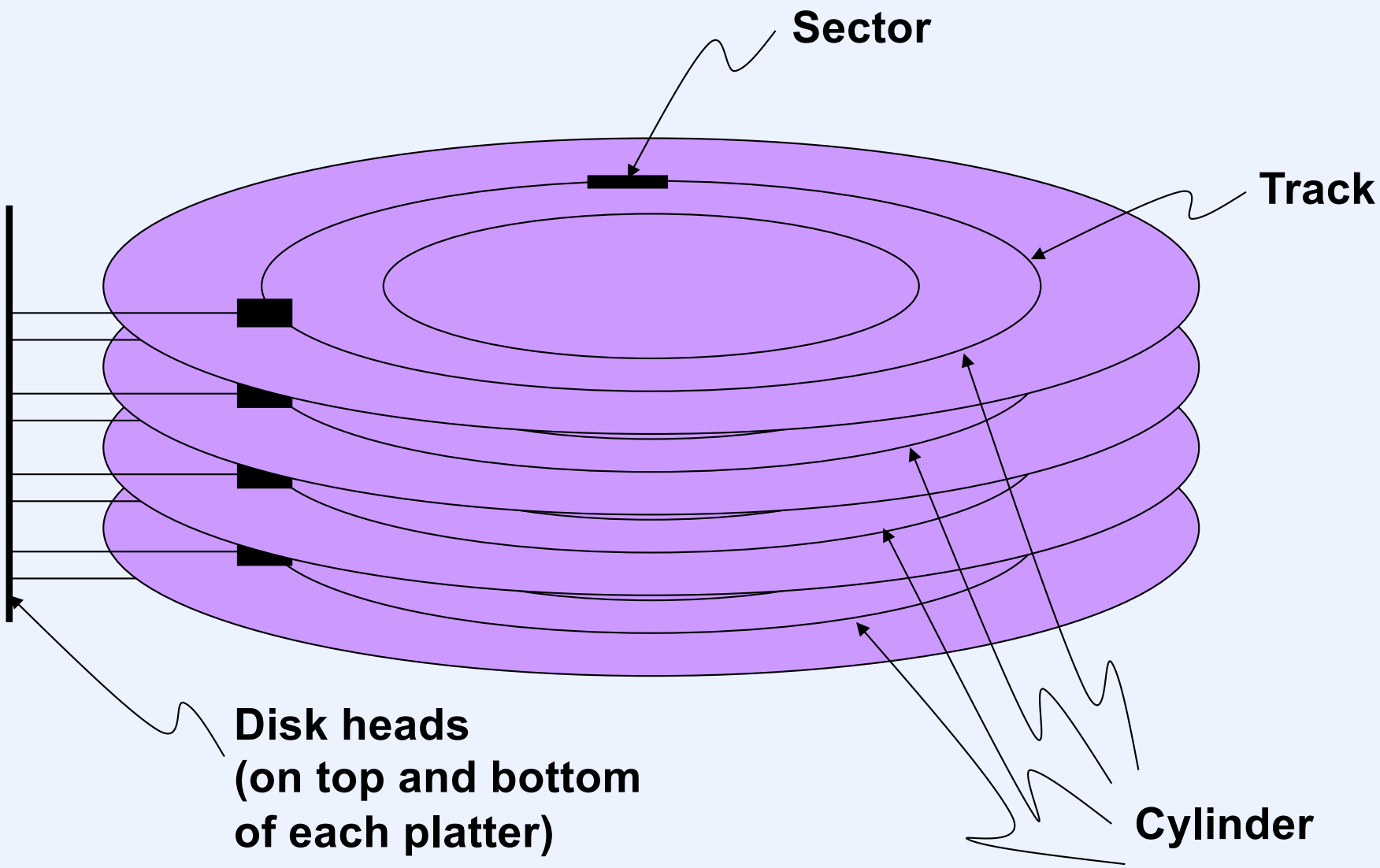


Super Block

16	0	
15		
14		
13	0	
12	0	
11	0	
10		
9	0	
8		
7		
6	0	
5		
4	0	
3		
2		
1		

I-list

Disk Architecture



Rhinopias Disk Drive

Rotation speed	10,000 RPM
Number of surfaces	8
Sector size	512 bytes
Sectors/track	500-1000; 750 average
Tracks/surface	100,000
Storage capacity	307.2 billion bytes
Average seek time	4 milliseconds
One-track seek time	.2 milliseconds
Maximum seek time	10 milliseconds

S5FS on Rhinopias
(A Marketing Disaster …)

- Rhinopias's maximum transfer speed?
  - 63.9 MB/sec
- S5FS's average transfer speed on Rhinopias?
  - average seek time:
    - < 4 milliseconds (say 2)
  - average rotational latency:
    - ~3 milliseconds
  - per-sector transfer time:
    - negligible
  - time/sector: 5 milliseconds
  - transfer time: 102.4 KB/sec (.16% of maximum)

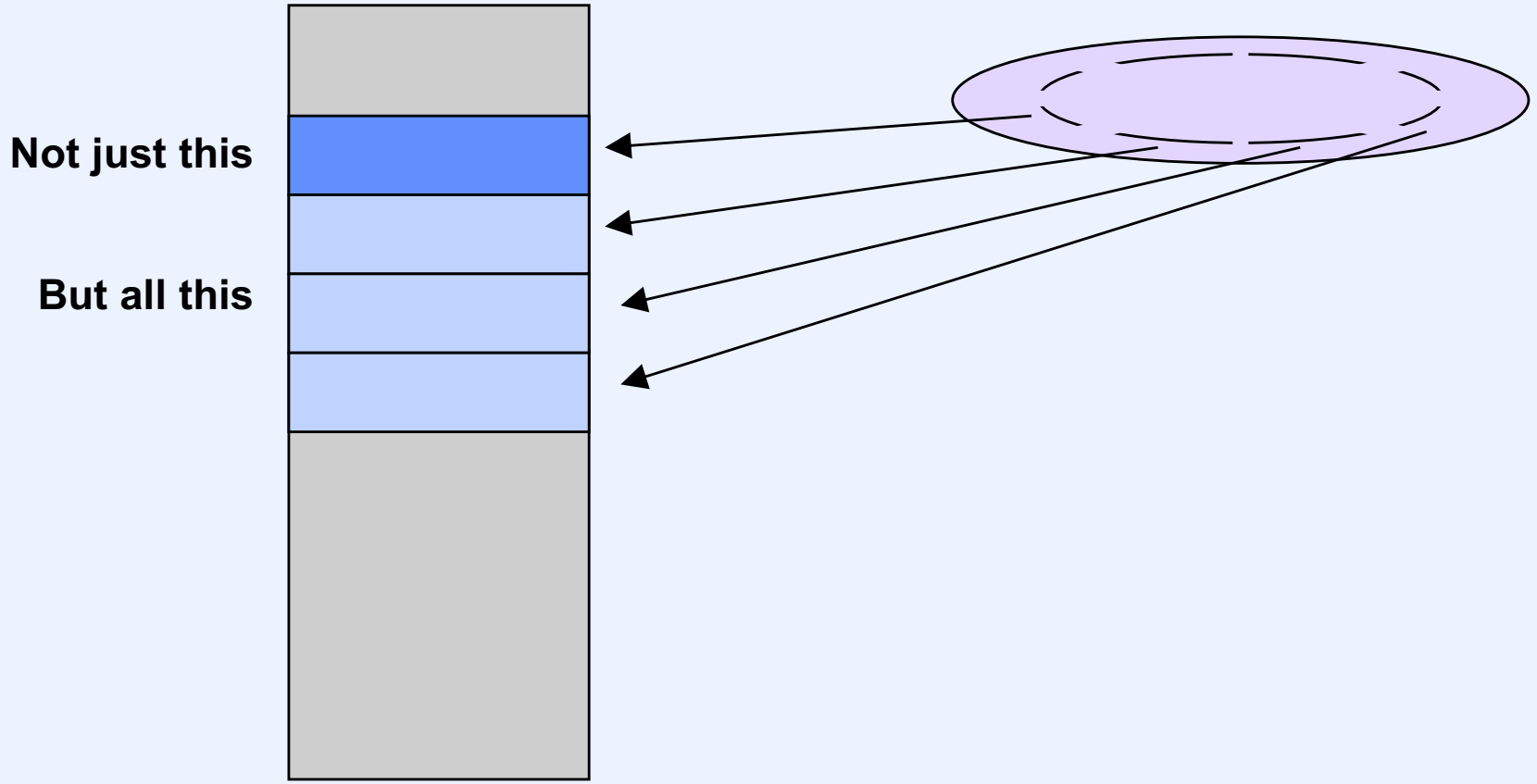
What to Do About It?

- Hardware
  - employ pre-fetch buffer
    - filled by hardware with what's underneath head
    - helps reads; doesn't help writes
- Software
  - better on-disk data structures
    - increase block size
    - minimize seek time
    - reduce rotational latency

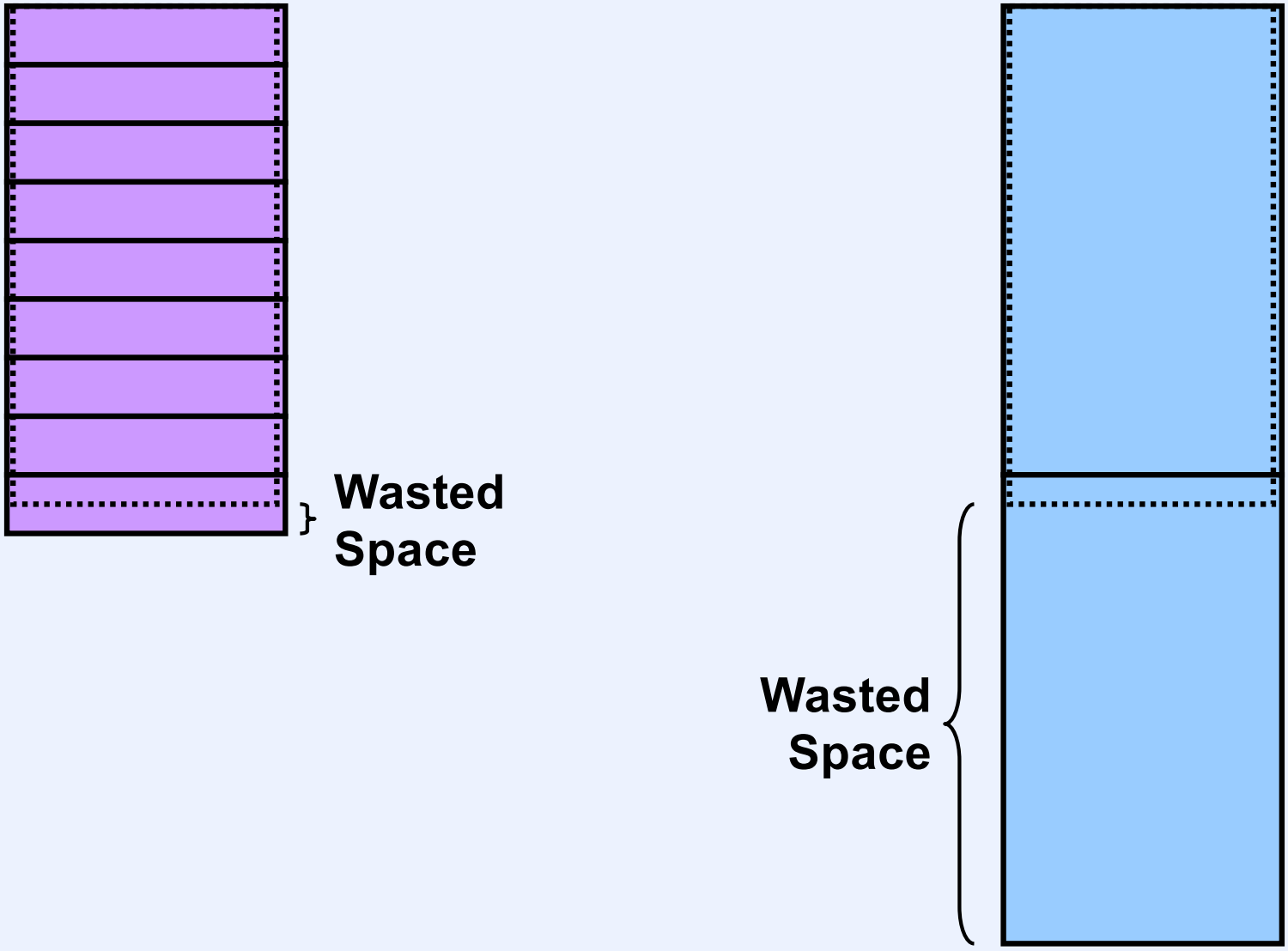
FFS

- Better on-disk organization
- Longer component names in directories
- Retains disk map of S5FS

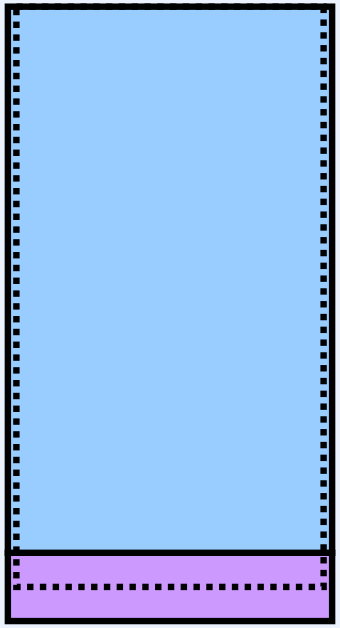
Larger Block Size



The Down Side …



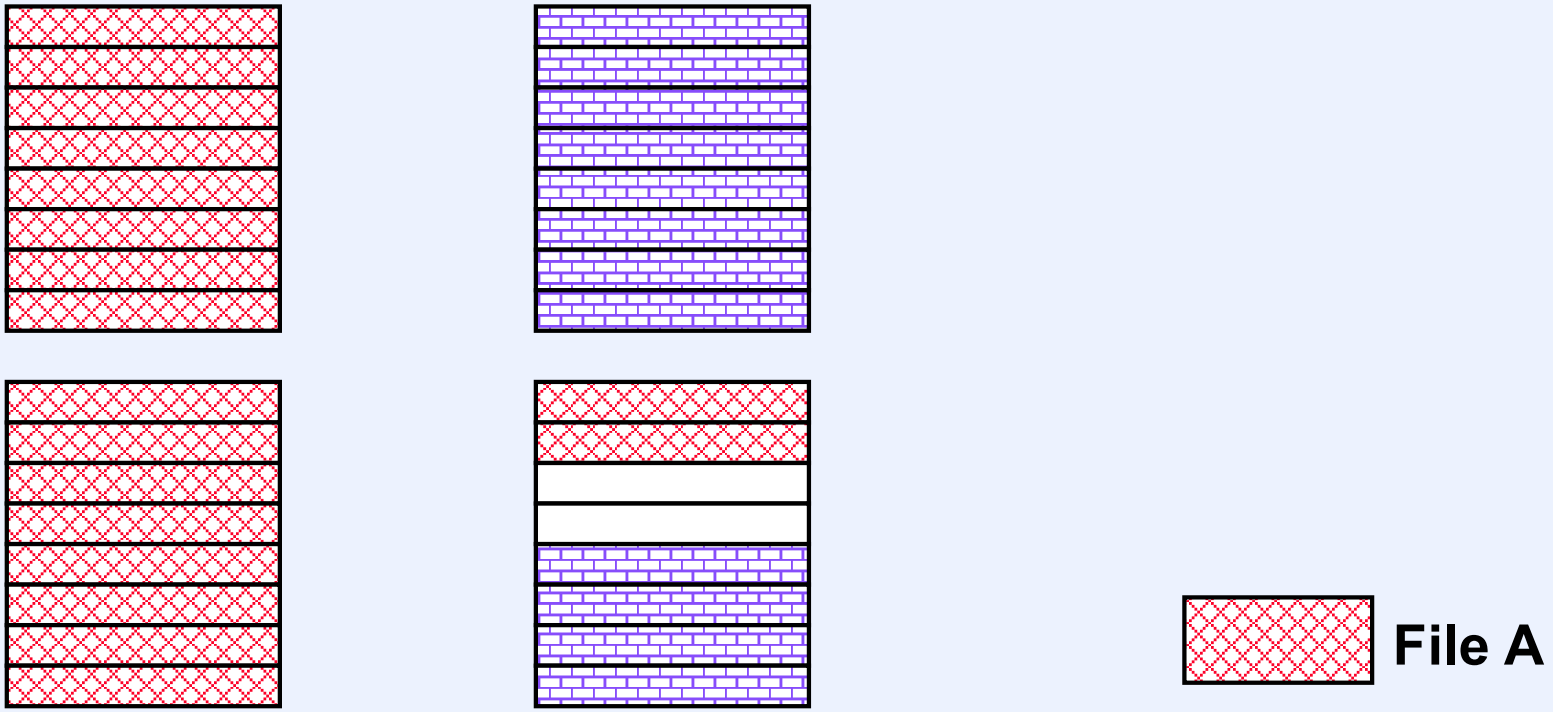
Two Block Sizes …



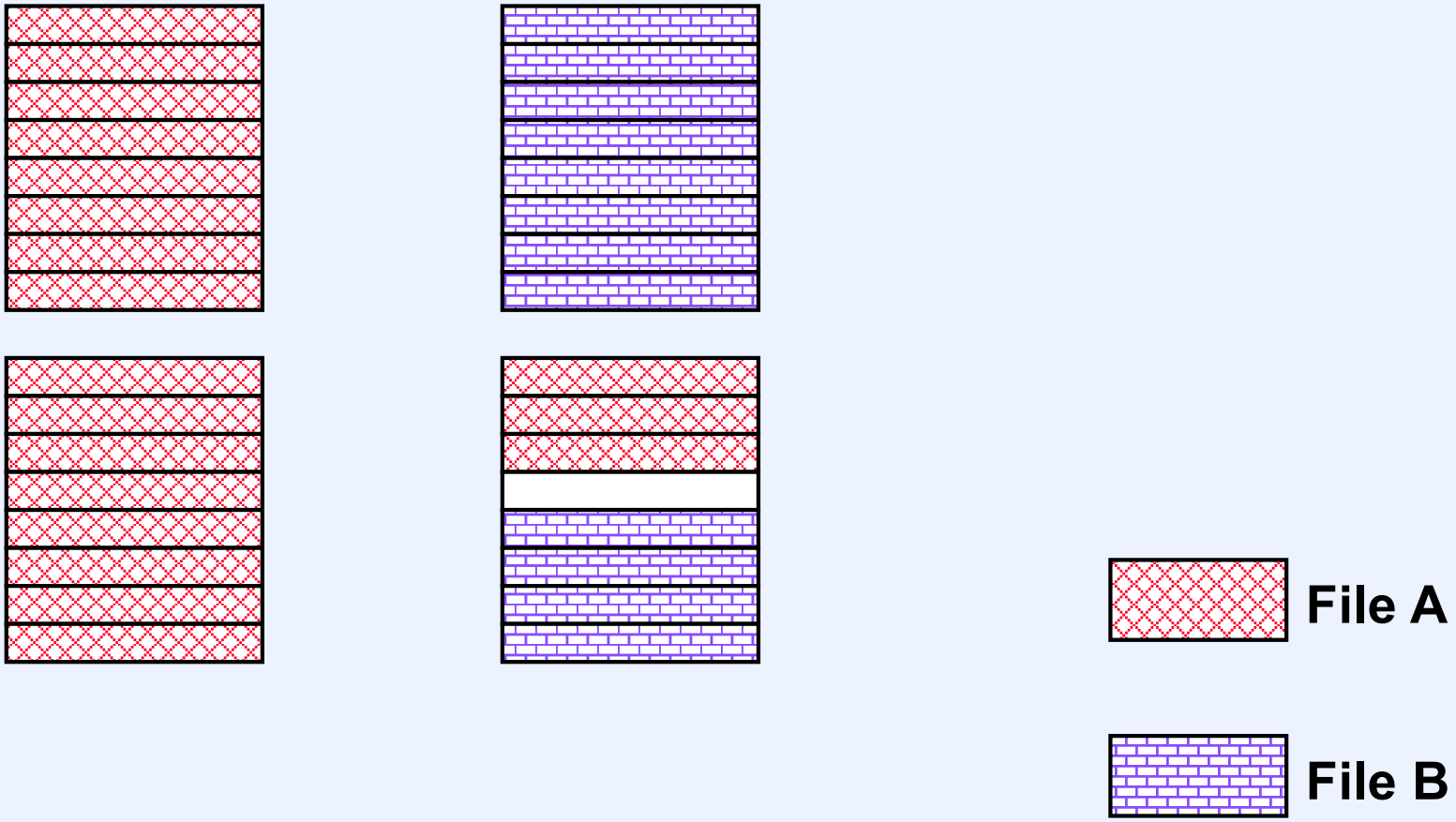
Rules

- File-system blocks may be split into fragments that can be independently assigned to files
  - fragments assigned to a file must be contiguous and in order
- The number of fragments per block (1, 2, 4, or 8) is fixed for each file system
- Allocation in fragments may only be done on what would be the last block of a file, and only for small files

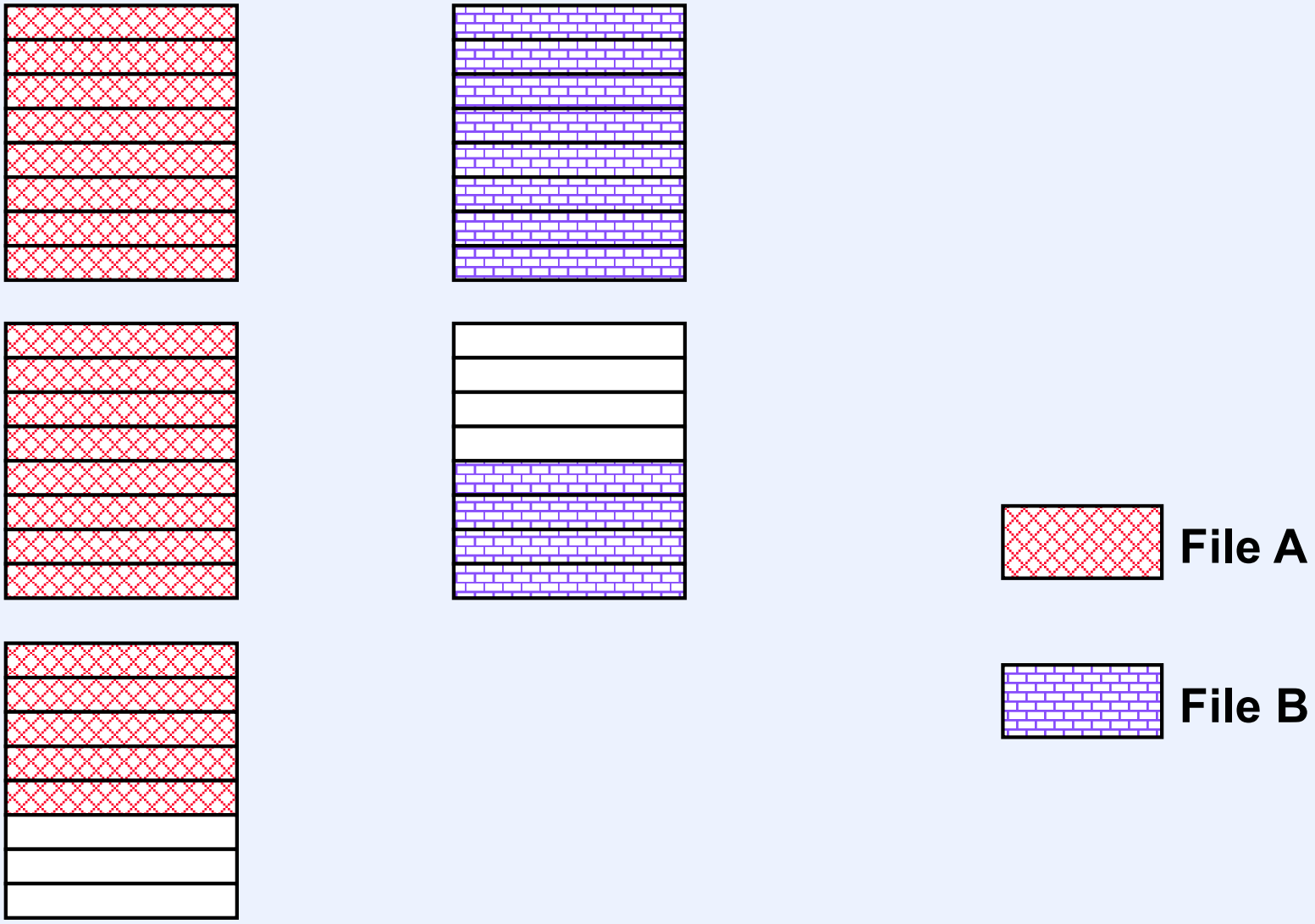
Use of Fragments (1)



Use of Fragments (2)



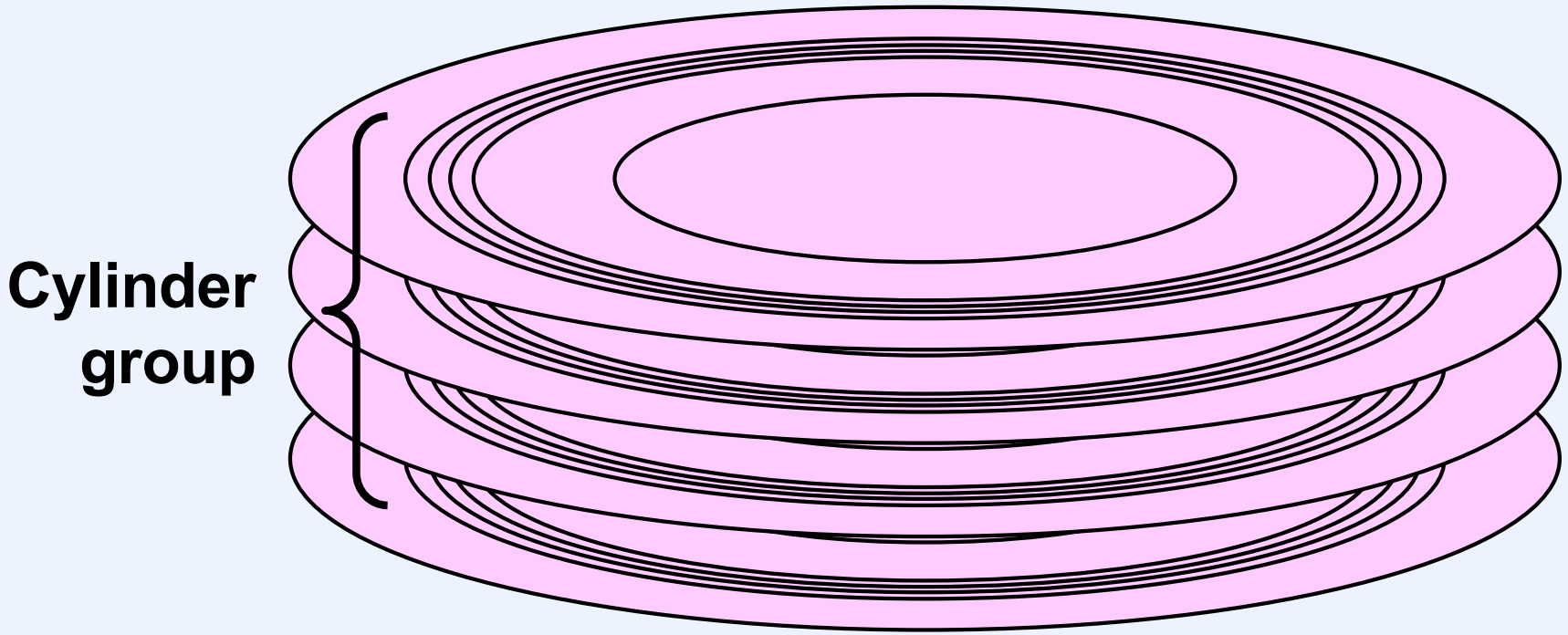
Use of Fragments (3)



Minimizing Seek Time

- Keep related things close to one another
- Separate unrelated things

Cylinder Groups



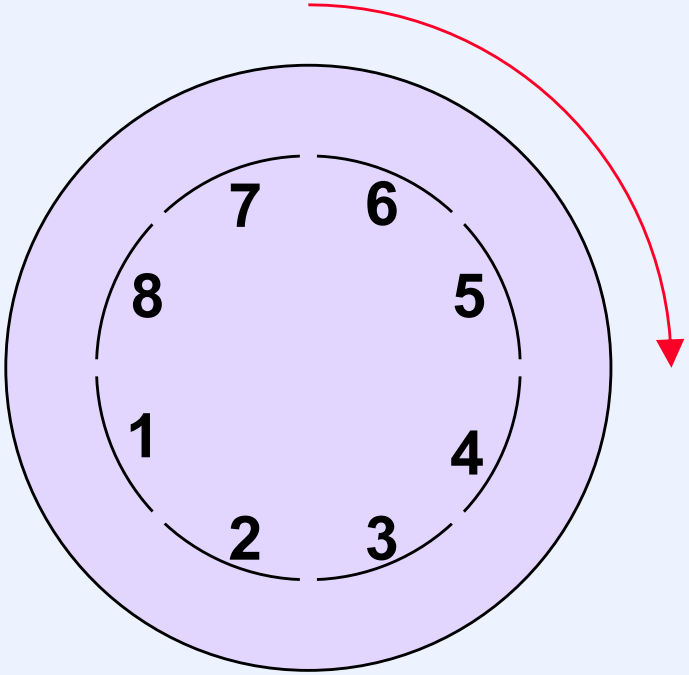
Minimizing Seek Time

- The practice:
  - attempt to put new inodes in the same cylinder group as their directories
  - put inodes for new directories in cylinder groups with "lots" of free space
  - put the beginning of a file (direct blocks) in the inode's cylinder group
  - put additional portions of the file (each 2MB) in cylinder groups with "lots" of free space

How Are We Doing?

- Configure Rhinopias with 20 cylinders per group
  - 2-MB file fits entirely within one cylinder group
  - average seek time within cylinder group is ~.3 milliseconds
  - average rotational delay still 3 milliseconds
  - .12 milliseconds required for disk head to pass over 8KB block
  - 3.42 milliseconds for each block
  - 2.4 million bytes/second average transfer time
    - 20-fold improvement
    - 3.7% of maximum possible

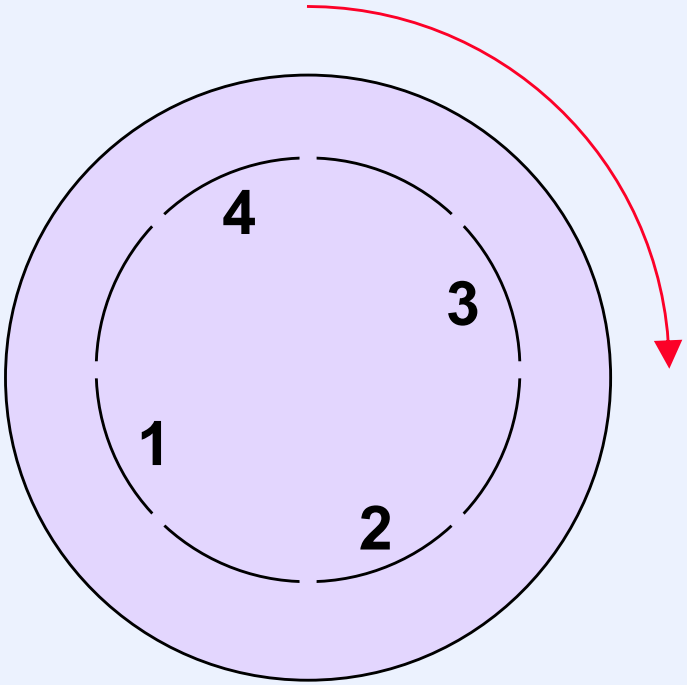
Minimizing Latency (1)

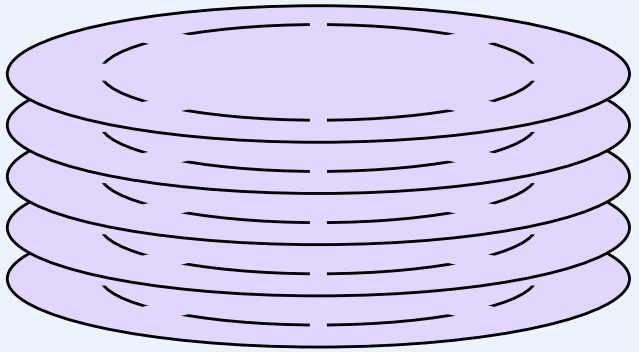


Numbers

- Rhinopias spins at 10,000 RPM
  - 6 milliseconds/revolution
- 100 microseconds required to field disk-completion interrupt and start next operation
  - typical of early 1980s
- Each block takes 120 microseconds to traverse disk head
- Reading successive blocks is time-consuming!

Minimizing Latency (2)





How’re We Doing Now? (part 1)

- Time to read successive blocks (two-way interleaving):
  - after request for second block is issued, must wait 20 microseconds for the beginning of the block to rotate under disk head
    - factor of 300 improvement!

How’re We Doing Now? (part 2)

- Same setup as before
  - 2-MB file within one cylinder group
  - actually fits in one cylinder
  - block interleaving employed: every other block is skipped
  - .3-millisecond seek to that cylinder
  - 3-millisecond rotational delay for first block
  - 50 blocks/track, but 25 read in each revolution
  - 10.24 revolutions required to read all of file
  - 32.4 MB/second (50% of maximum possible)

Quiz 3

If file access is one (8KB) block at a time and we employ block interleaving, can we do better than the 50% of maximum transfer speed achieved by FFS?

a) **yes – we can get arbitrarily close to 100%**

b) **yes, but the limit is somewhere between 50% and 100%**

c) **no – we've reached the limit**

Further Improvements?

- S5FS: 0.16% of capacity
- FFS without block interleaving: 3.8% of capacity
- FFS with block interleaving: 50% of capacity
- What next?

Larger Transfer Units

- Allocate in whole tracks or cylinders
  - too much wasted space
- Allocate in blocks, but group them together
  - transfer many at once

Block Clustering

- Allocate space in blocks, eight at a time
- Linux's Ext2 (an FFS clone):
  - allocate eight blocks at a time
  - extra space is available to other files if there is a shortage of space
- FFS on Solaris (~1990)
  - delay disk-space allocation until:
    - 8 blocks are ready to be written
    - or the file is closed