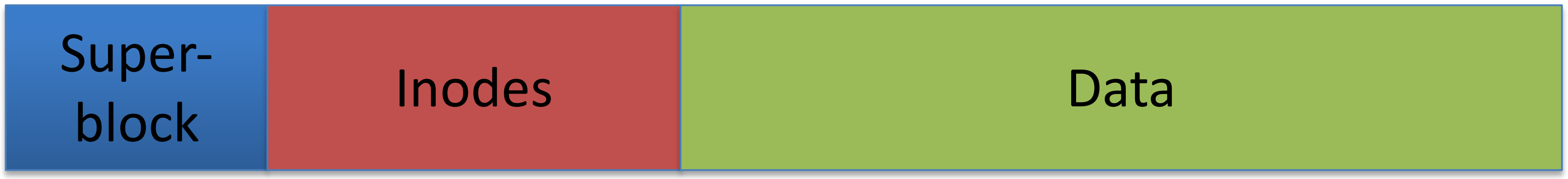
Fast File System

Don Porter

How to place a file system on disk?

- Let's assume we have the following:
  - Super block (allocation bitmap, FS-level metadata)
  - Inodes (file-level metadata)
  - Data blocks
- Thoughts?

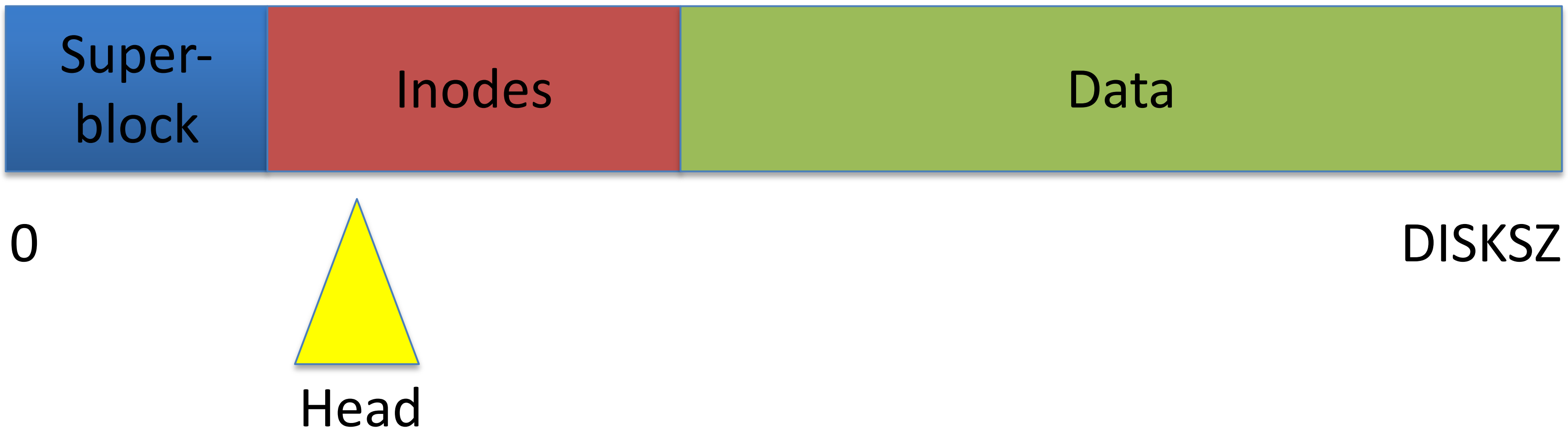
Strawman



0 DISKSZ

- Problems?

Typical file access pattern



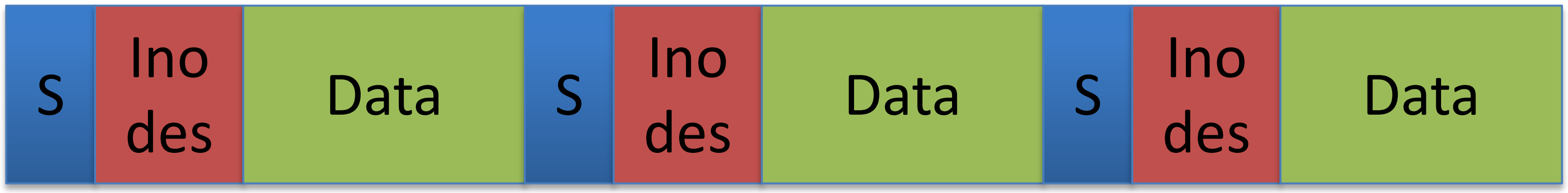
- cat a
- cat b
- cat c

Lots of seeking – no locality for head across files

Metadata locality

- File data and metadata (inode) are frequently accessed together
- Simple design fails to capture this pattern
- Any ideas?

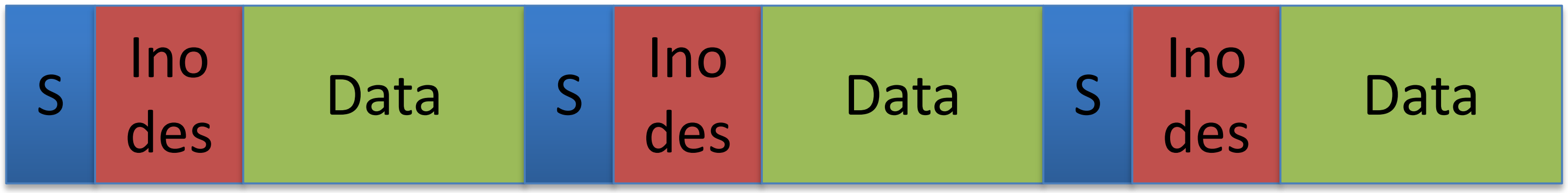
Block (or Cylinder) Group



0 DISKSZ

- Stripe smaller chunks of these triples across disk
- Superblock:
  - Some data replicated (good for crash tolerance)
  - Some data distributed (free block bitmap)
- Per-group inodes and blocks

Block (or Cylinder) Group



0 DISKSZ

- What does this give you?
  - Average case: Inode + data relatively close
    - Reduce average-case seek time
- Performance goal:
  - Put things together that are accessed together
  - How?

FFS data placement heuristics

- Keep related things together
- Keep unrelated things far apart

- Directories:
  - New directories placed in least-utilized cylinder group
    - Low number of total directories + plenty of free inodes
    - Why?
- Files:
  - Blocks of files should be allocated in same group as inode
  - Place files in same directory in same group

Edge cases?

Edge case 1: Large files

- Where to place a big file (e.g., movie download)?
  - Option 1: Fill up 1+ entire block groups (best fit)
    - Pro: Data is close together
    - Con: Wastes inodes in block group (or causes them to be far apart
    - Requires a lot of free space in 1+ groups to work
      - Degenerate case: only a few blocks free in each group
  - Option 2: Spread data across many block groups (worst fit)
    - Pro: Tries to keep larger regions of free space
    - Cons: Can end up seeking across many block groups

Amortizing seeks

- Seeks have a fixed cost
  - Let’s say 10 ms on a current HDD
- Transfer time is proportional to amount of contiguous data moved
  - Let’s say 125 MB/s on a current HDD

- Insight: We can control fraction of time spent seeking by data allocation size

Amortizing seeks

- Suppose we want to spend half of our time seeking:
  - I.e., we want to spend 10 ms in transfer time

$$\frac{125MB}{1s} * \frac{1\text{s}}{1000ms} * 10ms = 1.25MB$$

- Suppose we want to spend 10% of our time seeking

$$\frac{125MB}{1s} * \frac{1\text{s}}{1000ms} * 90ms = 11.25MB$$

Caveat: You need to actually use this much data

Fragmentation

- Not fragmenting free space becomes very important to performance
- Internal: Lots of files smaller than 1.25 MB
  - Idea: pack multiple small files into one 1.25 MB chunk
    - Called sub-blocking
- External: Need to keep enough free space in a block group for a directory
  - Approach: load balance across block groups
  - No good solution when disk is nearly full

Edge case 2: Renaming

- How does rename work?
  - Change the pointer from name to inode
- Implication for locality if you move files across directories?
  - Create in one block group
  - Rename to directory in a different block group
  - Directory contents no longer in same group

Edge case 2: Renaming

- What to do?
  - Live with it (one of several was a file system *ages*)
  - Move the data (slow):
    - BetrFS v.1 does this; takes 5 minutes to rename a 4 GB file

FFS Summary

- First file system designed for good performance
- Design principles still in use today
  - Ext* family on Linux
  - FFS still used in BSD
- Key ideas:
  - Block/cylinder groups
  - Data placement heuristics
  - Amortizing seeks