PERSISTENCE: FAST FILE SYSTEM

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Administrivia

P5 release tonight, due April 23rd, 10pm

Attend the discussion section for more details!

AGENDA / LEARNING OUTCOMES

How does file system represent files, directories?

What steps must reads/writes take?

How does FFS improve performance?

RECAP

FILE API WITH FILE DESCRIPTORS

```
int fd = open(char *path, int flag, mode_t mode)
read(int fd, void *buf, size_t nbyte)
write(int fd, void *buf, size_t nbyte)
close(int fd)
```

advantages:

- string names
- hierarchical
- traverse once
- offsets precisely defined

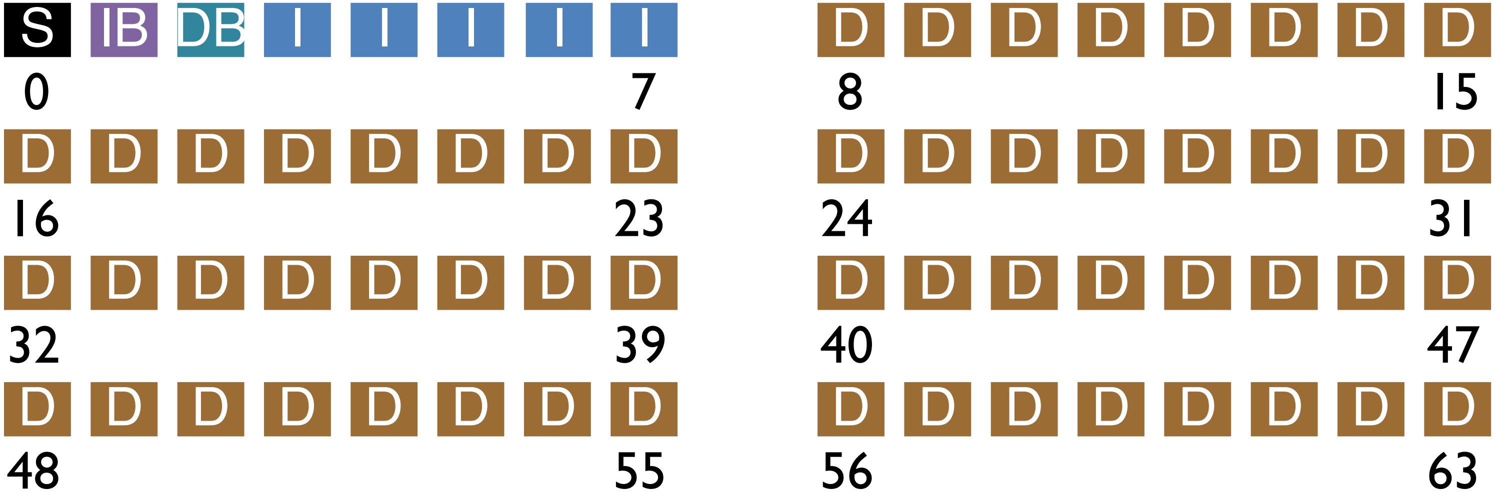
FILE API SUMMARY

Using multiple types of name provides convenience and efficiency

Hard and soft link features provide flexibility.

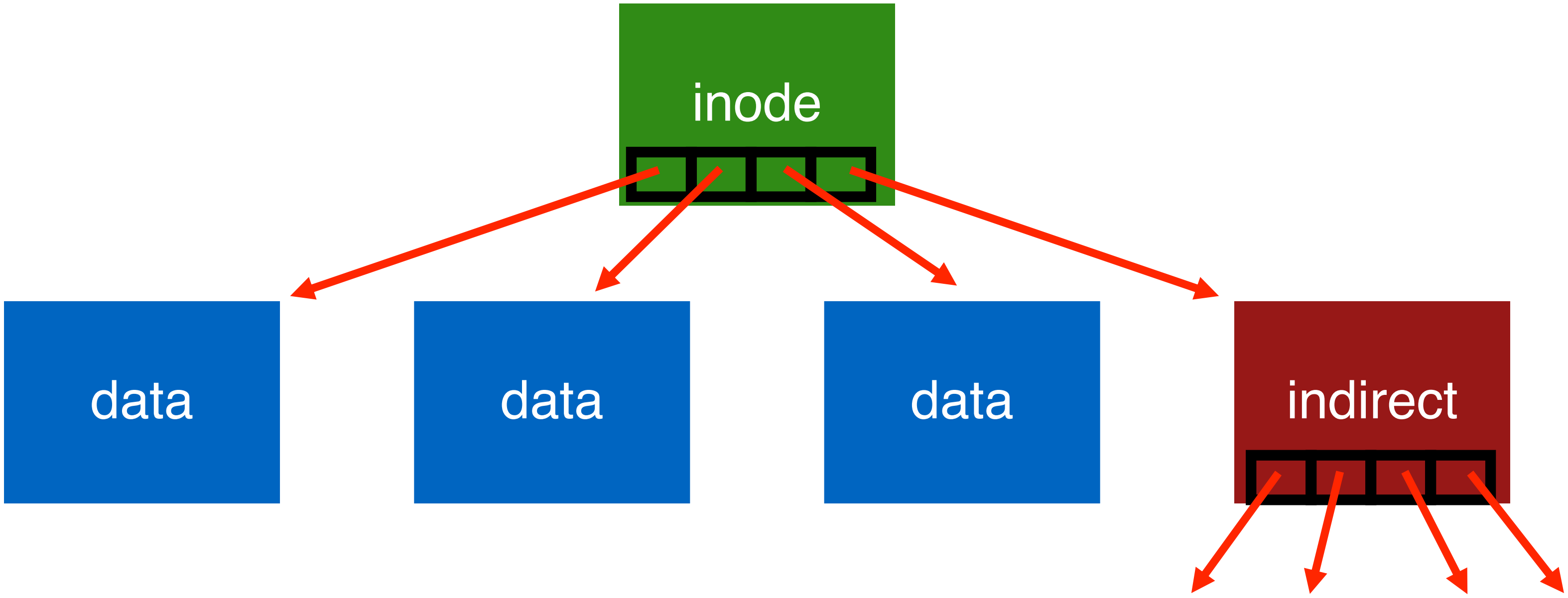
Special calls (fsync, rename) let developers communicate requirements to file system

FILE SYSTEM LAYOUT



INODE

type (file or dir?)
uid (owner)
rwx (permissions)
size (in bytes)
Blocks
time (access)
ctime (create)
links_count (# paths)
addrs[N] (N data blocks)



Better for small files!
How to handle even larger files?

SIMPLE DIRECTORY LIST EXAMPLE

valid	name	inode
1	.	134
1	..	35
1	foo	80
1	bar	23

unlink("foo")

FS OPERATIONS

- open
- read
- close
- create file
- write

open /foo/bar

TIME ↓

data bitmap	inode bitmap	root inode	foo inode	bar inode	root data	foo data	bar data
		(1) read					
					(2) read		
			(3)read				
						(4)read	
				(5)read			

read /foo/bar – assume opened

TIME

data bitmap	inode bitmap	root inode	foo inode	bar inode	root data	foo data	bar data
				(1) read			
							(2) read
				(3)write			

close /foo/bar

data bitmap	inode bitmap	root inode	foo inode	bar inode	root data	foo data	bar data

nothing to do on disk!

create /foo/bar

TIME

data bitmap	inode bitmap	root inode	foo inode	bar inode	root data	foo data
		1. read				
					2. read	
			3. read			
						4. read
	5.read 6.write					
						7.write
				8.read 9.write		
			10.write			

write to /foo/bar (assume file exists and has been opened)

TIME ↓

data bitmap	inode bitmap	root inode	foo inode	bar inode	root data	foo data	bar data
				(1) read			
(2)read							
(3)write							
							(4)write
				(5)write			

EFFICIENCY

How can we avoid this excessive I/O for basic ops?

Cache for:

- reads
- write buffering

WRITE BUFFERING

Overwrites, deletes, scheduling

Shared structs (e.g., bitmaps+dirs) often overwritten.

Tradeoffs: how much to buffer, how long to buffer

QUIZ 26

https://tinyurl.com/cs537-sp20-quiz26

```
inode bitmap   ????????
inodes         [d a:0 r:3] [d a:1 r:2] [] [] [] [] [] []
data bitmap    11000000
data           [(.,0) (..,0) (n,1)] [(.,1) (..,0)] [] [] [] [] [] []
```

```
inode bitmap   11000000
inodes         [d a:0 r:2] [f a:- r:1] [] [] [] [] [] []
data bitmap    10000000
data           [CORRUPT!] [] [] [] [] [] [] []
```

QUIZ 26

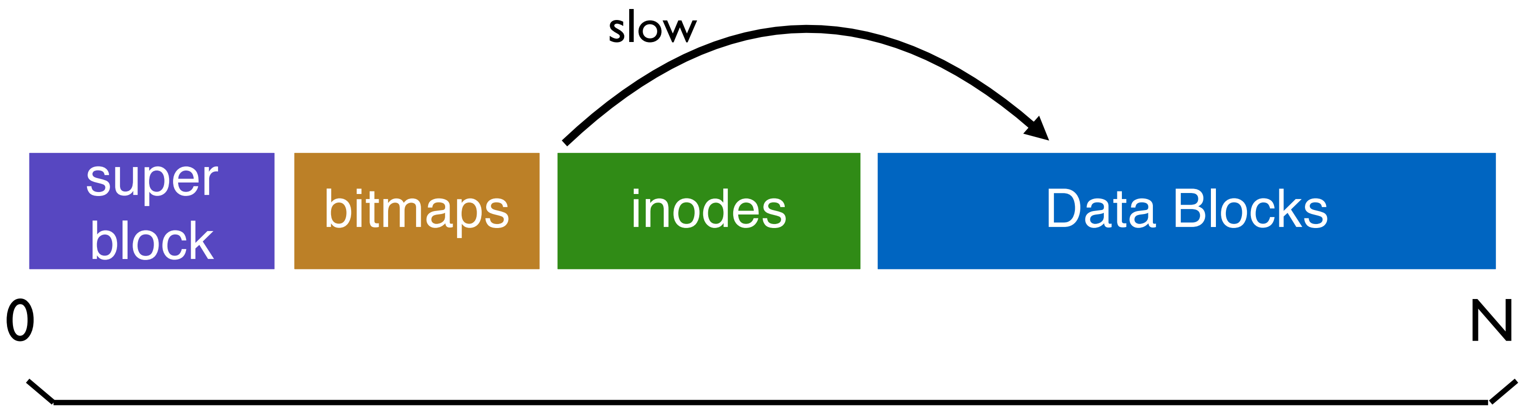
https://tinyurl.com/cs537-sp20-quiz26

```
inode bitmap 11100000
inodes       [d a:0 r:4] [d a:1 r:2] [d a:2 r:2] [] [] [] [] []
data bitmap  11100000
data         [(.,0) (..,0) (d,1) (w,2)] [????] [(.,2) (..,0)] [] [] [] [] []
```

```
inode bitmap  11000000
inodes        [d a:0 r:2] [f a:1 r:2] [] [] [] [] [] []
data bitmap   ????????
data          [(.,0) (..,0) (c,1) (m,1)] [foofoofoo] [] [] [] [] [] []
```

FAST FILE SYSTEM

FILE LAYOUT IMPORTANCE



Layout is not disk-aware!

DISK-AWARE FILE SYSTEM

How to make the disk use more efficient?

Where to place meta-data and data on disk?

PLACEMENT TECHNIQUE: GROUPS

Key idea: Keep inode close to data

Use groups across disks;

Strategy: allocate inodes and data blocks in same group.

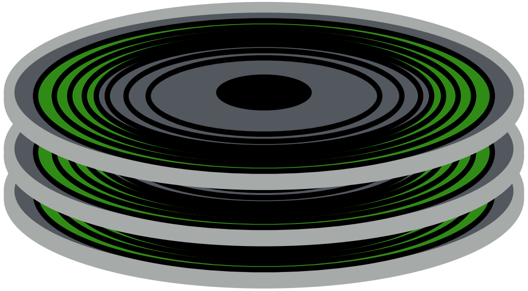
PLACEMENT TECHNIQUE: GROUPS

In FFS, groups were ranges of cylinders

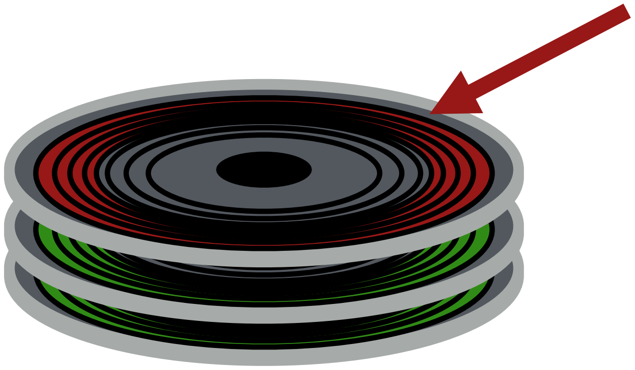
called cylinder group

In ext2, ext3, ext4 groups are ranges of blocks

called block group



REPLICATED SUPER BLOCKS



top platter damage?

solution: for each group, store super-block at different offset

SMART POLICY

Where should new inodes and data blocks go?

PLACEMENT STRATEGY

Put related pieces of data near each other.

Rules:

1. Put directory entries near directory inodes.
2. Put inodes near directory entries.
3. Put data blocks near inodes.

Problem: File system is one big tree

All directories and files have a common root.

All data in same FS is related in some way

Trying to put everything near everything else doesn't make any choices!

REVISED STRATEGY

Put more-related pieces of data near each other

Put less-related pieces of data **far**

```
/a/b
/a/c
/a/d
/b/f
```

```
group inodes     data
    0 /--------- /---------
    1 acde------ accddee---
    2 bf-------- bff-------
    3 ---------- ----------
    4 ---------- ----------
    5 ---------- ----------
    6 ---------- ----------
    7 ---------- ----------
  ...
```

POLICY SUMMARY

File inodes: allocate in same group with dir

Dir inodes: allocate in new group with fewer used inodes than average group

First data block: allocate near inode

Other data blocks: allocate near previous block

PROBLEM: LARGE FILES

Single large file can fill nearly all of a group

Displaces data for many small files

```
group inodes     data
    0 /a-------- /aaaaaaaaa aaaaaaaaaa aaaaaaaaaa a---------
    1 ---------- ---------- ---------- ---------- ----------
    2 ---------- ---------- ---------- ---------- ----------
    ...
```

Most files are small!

Better to do one seek for large file than

one seek for each of many small files

SPLITTING LARGE FILES

```
group inodes      data
    0 /a--------- /aaaaa---- ---------- ---------- ----------
    1 ---------- aaaaa----- ---------- ---------- ----------
    2 ---------- aaaaa----- ---------- ---------- ----------
    3 ---------- aaaaa----- ---------- ---------- ----------
    4 ---------- aaaaa----- ---------- ---------- ----------
    5 ---------- aaaaa----- ---------- ---------- ----------
    6 ---------- ---------- ---------- ---------- ----------
    ...
```

Define "large" as requiring an indirect block

Starting at indirect (e.g., after 48 KB) put blocks in a new block group.

Each chunk corresponds to one indirect block
Block size 4KB, 4 byte per address => 1024 address per indirect
1024*4KB = 4MB contiguous "chunk"

POLICY SUMMARY

File inodes: allocate in same group with dir

Dir inodes: allocate in new group with fewer used inodes than average group

First data block: allocate near inode

Other data blocks: allocate near previous block

Large file data blocks: after 48KB, go to new group.

Move to another group (w/ fewer than avg blocks) every subsequent 1MB.

OTHER FFS FEATURES

FFS also introduced several new features:

- large blocks (with libc buffering / fragments)
- long file names
- atomic rename
- symbolic links

FFS SUMMARY

First disk-aware file system

- Bitmaps
- Locality groups
- Rotated superblocks
- Smart allocation policy

Inspired modern files systems, including ext2 and ext3

NEXT STEPS

P5 will be released later today
Details in the discussion section

Next class: Filesystem consistency