Administrivia

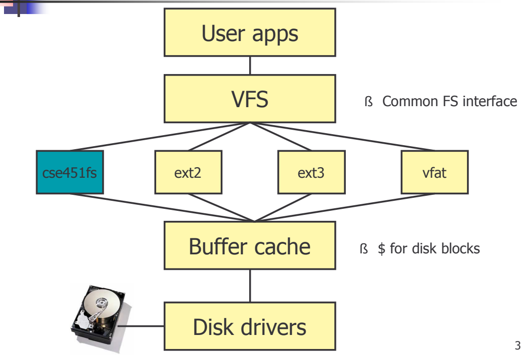
- Project 4 due in a week
  - Turnin only, no report
- Homework 4 due next Wednesday
- EC J

- Today:
  - Project 4 and file system stuff
  - EC questions?

Project 4

- Work with a real file system
- Given:
  - cse451fs: simplified file system for Linux
- Goals:
  - Understand how it works
  - Modify implementation to:
    - Increase maximum size of files (currently 13KB)
    - Allow for longer file names (currently 30 chars)

Linux FS layers



File systems in Linux

- Layered on top of a block device
  - Device provides a big array of blocks
  - Blocks are cached in the *buffer cache*
- Implement a standard interface
  - *file_operations*
    - read/write/seek files; read directory
  - *inode_operations*
    - create / lookup / unlink / mkdir / rmdir / rename
  - *super_operations*
    - read/write inodes
  - *address_space_operations*
    - readpage/writepage for memory-mapped IO
  - *file_system_operations*
    - read in superblock

Project 4 Setup

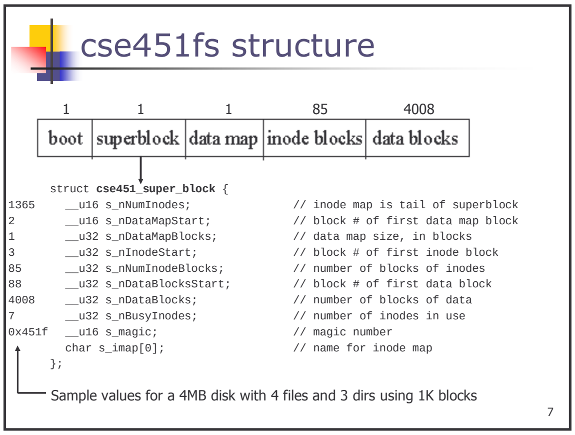
- Build a kernel module for cse451fs (and a kernel supporting cse451fs)
- Transfer it to VMware
- On VMware, use a ramdisk to test your file system.
  - i.e. create a fake disk in memory, create your FS on top, mount, test.
- load cse451fs
- Make a file system using (modified) mkfs tool
- mount, test

- Step 1: try this procedure with given code
- Step 2: read cse451fs.h, then dir.c

cse451fs disk structure

boot	superblock	data map	inode blocks	data blocks

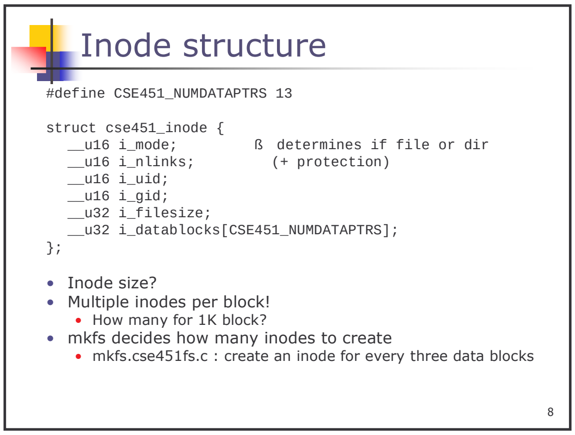
- **Superblock**: tells where all other things are
  - Contains **inode map**:
    - Bit array, tracks which inodes are currently in use
    - E.g. for 3 dirs + 4 files, need 7 inodes
- **Data map**:
  - Bit array, tracks which data blocks are in use



cse451fs structure

```
        struct cse451_super_block {
1365      __u16 s_nNumInodes;            // inode map is tail of superblock
2         __u16 s_nDataMapStart;         // block # of first data map block
1         __u32 s_nDataMapBlocks;        // data map size, in blocks
3         __u32 s_nInodeStart;           // block # of first inode block
85        __u32 s_nNumInodeBlocks;       // number of blocks of inodes
88        __u32 s_nDataBlocksStart;      // block # of first data block
4008      __u32 s_nDataBlocks;           // number of blocks of data
7         __u32 s_nBusyInodes;           // number of inodes in use
0x451f    __u16 s_magic;                 // magic number
          char s_imap[0];                // name for inode map
        };
```

Sample values for a 4MB disk with 4 files and 3 dirs using 1K blocks

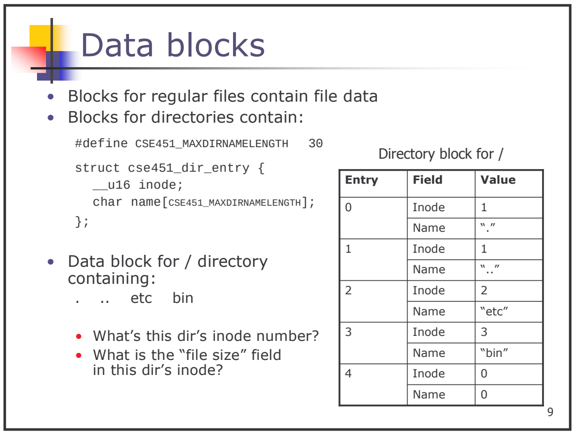


Inode structure

```
#define CSE451_NUMDATAPTRS 13

struct cse451_inode {
   __u16 i_mode;          ß determines if file or dir
   __u16 i_nlinks;          (+ protection)
   __u16 i_uid;
   __u16 i_gid;
   __u32 i_filesize;
   __u32 i_datablocks[CSE451_NUMDATAPTRS];
};
```

- Inode size?
- Multiple inodes per block!
  - How many for 1K block?
- mkfs decides how many inodes to create
  - mkfs.cse451fs.c : create an inode for every three data blocks



Data blocks

- Blocks for regular files contain file data
- Blocks for directories contain:

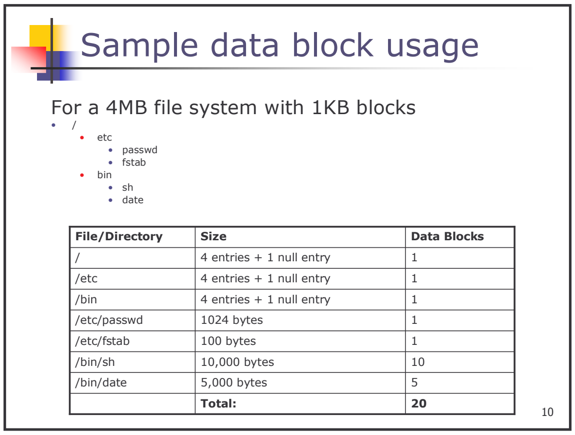
```
#define CSE451_MAXDIRNAMELENGTH   30

struct cse451_dir_entry {
   __u16 inode;
   char name[CSE451_MAXDIRNAMELENGTH];
};
```

- Data block for / directory containing:
  . .. etc bin
  - What's this dir's inode number?
  - What is the "file size" field in this dir's inode?

Directory block for /

Entry	Field	Value
0	Inode	1
	Name	“.”
1	Inode	1
	Name	“..”
2	Inode	2
	Name	“etc”
3	Inode	3
	Name	“bin”
4	Inode	0
	Name	0

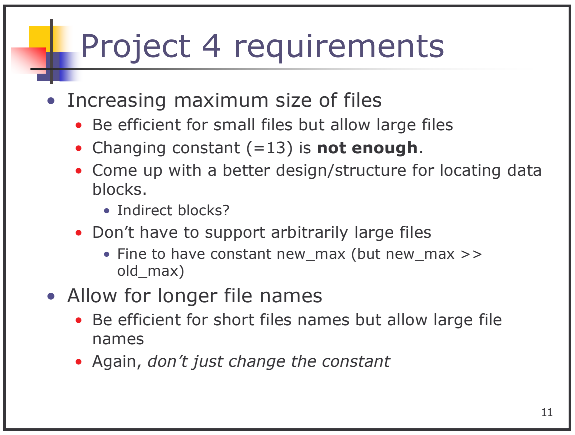


Sample data block usage

For a 4MB file system with 1KB blocks

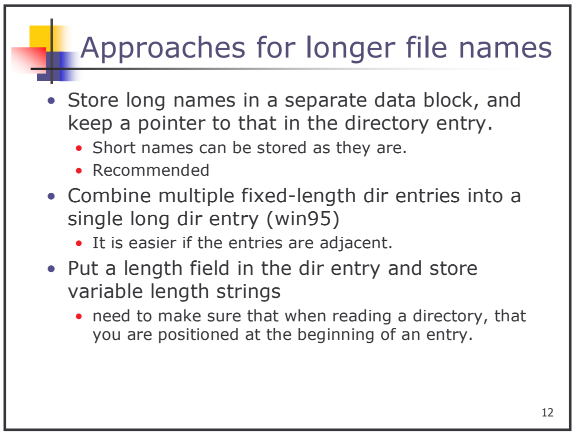
- /
  - etc
    - passwd
    - fstab
  - bin
    - sh
    - date

File/Directory	Size	Data Blocks
/	4 entries + 1 null entry	1
/etc	4 entries + 1 null entry	1
/bin	4 entries + 1 null entry	1
/etc/passwd	1024 bytes	1
/etc/fstab	100 bytes	1
/bin/sh	10,000 bytes	10
/bin/date	5,000 bytes	5
	Total:	**20**



Project 4 requirements

- Increasing maximum size of files
  - Be efficient for small files but allow large files
  - Changing constant (=13) is **not enough**.
  - Come up with a better design/structure for locating data blocks.
    - Indirect blocks?
  - Don't have to support arbitrarily large files
    - Fine to have constant new_max (but new_max >> old_max)
- Allow for longer file names
  - Be efficient for short files names but allow large file names
  - Again, *don't just change the constant*



Approaches for longer file names

- Store long names in a separate data block, and keep a pointer to that in the directory entry.
  - Short names can be stored as they are.
  - Recommended
- Combine multiple fixed-length dir entries into a single long dir entry (win95)
  - It is easier if the entries are adjacent.
- Put a length field in the dir entry and store variable length strings
  - need to make sure that when reading a directory, that you are positioned at the beginning of an entry.

Getting started with the code

- Understand the source of the limits in the existing implementation
  - Look at the code that manipulates dir entries
    - mkfs code
    - dir.c in the file system source code
- Longer file names:
  - The code for will largely be in dir.c: add_entry() and find_entry()
  - In mkfs, change how the first two entries (for "." and "..") are stored
- Bigger files:
  - super.c:get_block()
  - References to i_datablock[] array in an inode will have to change

VFS vs cse451fs

- Don't conflate VFS structures and cse451fs structures!
  - inodes, superblocks
- E.g., there are "two" inodes:
  - VFS `struct inode`
    - Generic inode used in Linux source (works for any FS)
    - Lives in memory
  - cse451 `struct cse451_inode`
    - Actual inode representation on disk
  - **`inode.c`**:`cse451_read_inode` converts from `cse451_inode` to `struct inode`
    - Copies over mode, size, etc
    - Copies over i_datablocks[] to `struct inode`'s `generic_ip` field (which will now be used as type `cse451_inode_info`)
  - **`inode.c`**:`cse451_write_inode` converts the other way

Linux Buffer Manager Code

- To manipulate disk blocks, you need to go through the buffer cache
- Linux buffer cache fundamentals:
  - blocks are represented by buffer_heads
    - Just another data structure
  - Actual data is in buffer_head->b_data
  - For a given disk block, buffer manager could be:
    - Complete unaware of it
      - no buffer_head exists, block not in memory
    - Aware of block information
      - buffer_head exists, but block data (b_data) not in memory
    - Aware of block information and data
      - Both the buffer_head and its b_data are valid ("$ hit")

Accessing blocks

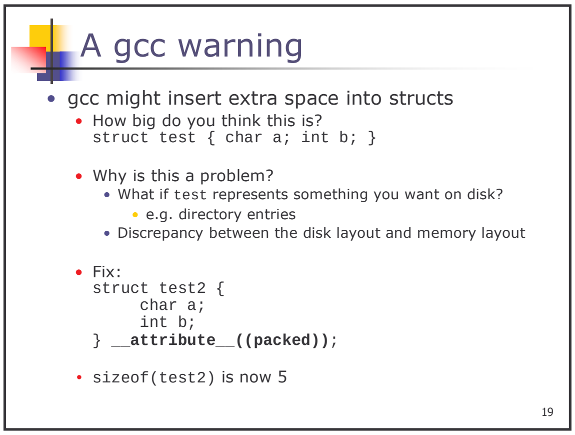
- To read a block, FS uses bread(…):
  - Find the corresponding buffer_head
    - Create if doesn't exist
  - Make sure the data is in memory (read from disk if necessary)
- To write a block:
  - mark_buffer_dirty() + brelse() - mark buffer as changed and release to kernel (which does the writing)

Some buffer manager functions

cse451_bread(inode, block, create)	Get the buffer_head for the given disk block, ensuring that the data is in memory and ready for use. Increments ref count; always pair with a brelse.
bh = **cse451_getblk**(inode, block, create)	Get the buffer_head for the given disk block. Does not guarantee anything about the state of the actual data. Increments ref count; always pair with a brelse. Zeros out new blocks (required for security).
brelse(bh)	Decrement the ref. count of the given buffer.
mark_buffer_dirty(bh)	Mark the buffer modified, meaning needs to be written to disk at some point.
mark_buffer_uptodate(bh)	Indicate that the data pointed to by bh is valid.

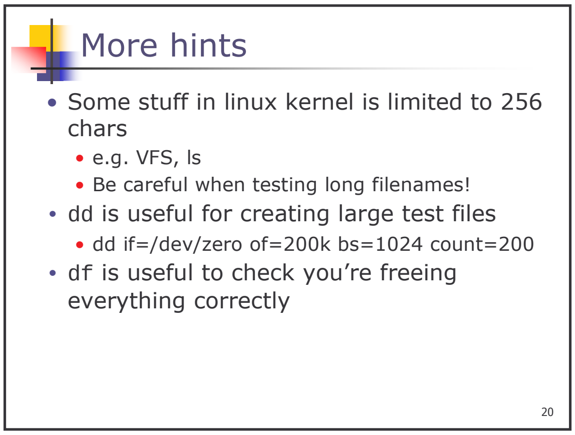
Hints

- Learn how to use bread/brelse and other buffer cache stuff by looking at provided code
- All printk messages stored in /var/log/messages
  - Can view to examine long debug outputs
- Q: "It is extremely frustrating not to be able to read debug messages because they scroll off screen in vmware so quickly :("
  - A: Use Shift-pageup and Shift-pagedown
- Q: "How does ls get its entries?"
  - dir.c:readdir()



A gcc warning

- gcc might insert extra space into structs
  - How big do you think this is?
    ```
    struct test { char a; int b; }
    ```
  - Why is this a problem?
    - What if `test` represents something you want on disk?
      - e.g. directory entries
    - Discrepancy between the disk layout and memory layout
  - Fix:
    ```
    struct test2 {
          char a;
          int b;
    } __attribute__((packed));
    ```
  - `sizeof(test2)` is now 5



More hints

- Some stuff in linux kernel is limited to 256 chars
  - e.g. VFS, ls
  - Be careful when testing long filenames!
- dd is useful for creating large test files
  - dd if=/dev/zero of=200k bs=1024 count=200
- `df` is useful to check you're freeing everything correctly