

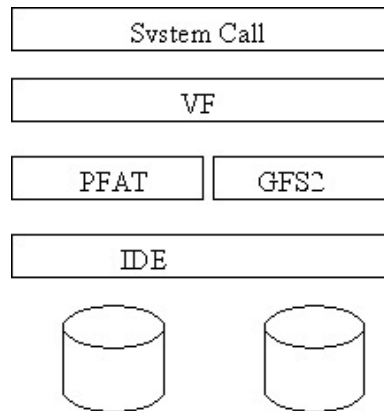
Project 5: GeekOS File System 3

1 Overview

The purpose of this project is to add a writable filesystem, GFS3, to GeekOS. Unlike the existing PFAT, GFS3 includes directories, inodes, direntries, etc. The new filesystem can be bootable, but will for development reside on the second IDE drive in the emulator. The PFAT drive will continue to hold user programs while you format and test your implementation of GFS3.

1.1 VFS Introduction

Since GeekOS will have two types of filesystems (PFAT and GFS3), it will use the virtual filesystem layer (VFS) to direct requests to an appropriate filesystem (see figure below). We have provided an implementation of the VFS layer in the file `vfs.c`. The VFS layer will call the appropriate GFS3 routines when a file operation refers to a file in GFS3.



The implementation of PFAT is in `pfat.c`. You will implement GFS3 in `gfs3.c` and relevant system calls in `syscall.c`.

VFS picks the functions to call based on supplied structures containing function pointers, one for each operation. For example, see `Init_PFAT` in `pfat.c`: this initializes the PFAT filesystem with VFS by passing it a pointer to `s_pfatFilesystemOps`, a structure that contains function pointers to PFAT routines for mounting (and formatting) a filesystem. Other PFAT functions are stored in different structures (e.g., look at the `PFAT_Open` routine, which passes the `gs_pfatFileOps` structure to VFS). You will analogously use `s_gfs3FilesystemOps`, `s_gfs3MountPointOps`, `s_gfs3DirOps`, and `s_gfs3FileOps` in `gfs3.c`. You should also add a call to `Init_GFS3` provided in `gfs3.c` to `main.c` to

register the GFS3 filesystem. In general, use the PFAT implementation as your guide to interfacing GFS3 with VFS.

1.2 GFS3 Filesystem Data

1.2.1 Superblock (gfs3_superblock)

magic: 0x47465333	
version: 0x00000100	
block_with_inode_zero	
number_of_inodes	
blocks_per_disk	
setupStart	setupSize
kernelStart	kernelSize

The superblock contains the file system parameters and is used by the kernel to load and interpret the filesystem. It must be stored at byte offset PFAT_BOOT_RECORD_OFFSET (482) (NOT block offset). You can expect it to be there on mount. If it's not there, the file system is broken and would have to be repaired before being mounted.

You may ignore setupStart, setupSize, kernelStart, and kernelSize, all of which are to support the loading of the kernel when a GFS3 image is made bootable.

1.2.2 Primitive types

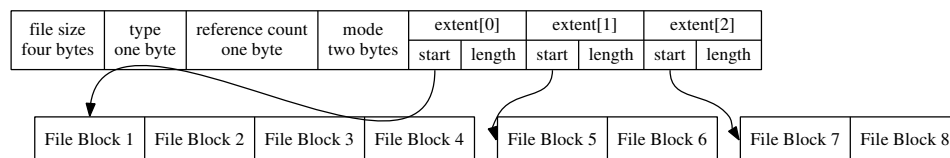
Both primitive types are unsigned integers; the separate data type is meant to ease type checking.

gfs3_blocknum The number of the block (not sector) on disk.

gfs3_inodenum The number of the inode (not the block containing the inode). There are a fixed number of inodes, and thus possible files and directories, in a given disk image.

1.2.3 Inode (gfs3_inode)

Inodes are data structures that store information about a file or directory on the filesystem. Their structure in GFS3 is as follows:



The size of the inode is constrained so that an even number of inodes fit into each block (inodes won't span blocks). The inode does not identify itself; if you need to manipulate an inode, the number is a necessary identifier; the cached inode itself will not have enough information to write it back to disk in the right place.

The type can be either:

GFS3_DIRECTORY It's a directory. It won't be read or written directly by applications.

GFS3_FILE It's a file.

The reference count should be zero in an unused inode. The mode specifies permissions and can be ignored for this project. Each inode stores three extents. This allows the inode to refer to three regions of blocks that are contiguous. Should an application attempt to extend a file that already uses the three extents where the last one cannot be extended (that block is in use), your gfs3 implementation will need to move and coalesce extents to make room.

1.2.4 Dirent (gfs3_dirent)

Dirents are data structures used to store the contents of a directory. This is stored in the data blocks of a GFS3_DIRECTORY's inode.

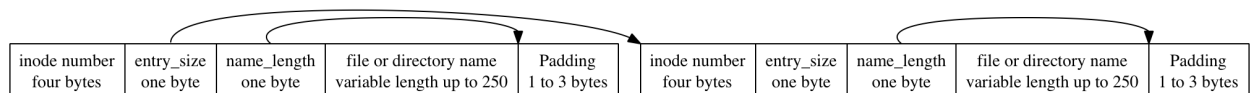


Figure caveat: the lengths are sizes, not pointers and the alignment padding isn't explicit. Figure caveat 2: the entry length of the second dirent will point beyond the end of the second dirent, even if there is nothing there because that's the end of the directory. This is explicit in the example below.

Directories are files consisting of appended records of type gfs3_dirent. Note that you will be overflowing the array to write names of any length; sizeof(struct gfs3_dirent) will very likely confuse. To calculate the size for a new dirent, round $4 + 2 + \text{name_length}$ to the nearest multiple of four. A helper function would be a good idea here.

Some code for seeking through the list in a directory is in lecture notes: to find an entry, first look for entries that match the length.

You must support deletion; We covered three obvious ways to remove from the middle of the list without rewriting the entire directory in class, so I leave it to you to determine.

When creating a directory, it is not entirely empty. Each directory has both '.' and '..' entries. The root directory will have contents:

```
01 00 00 00 04 01 2e 00
01 00 00 00 04 02 2e 2e
```

If you're wondering why inode 1 is represented using 01 00 00 00, smack yourself. (LSB.)

I encourage you to not write these 16 bytes, but instead to write a dirent constructor function to use to build the directory, since that can be reused.

1.2.5 In-use Blocks Bitmap

Track in-use disk blocks using a bit vector. A library called `bitset` is provided (see `bitset.h` and `bitset.c`) that manages a set of bits and provides functions to find bits that are 0, which correspond to free disk blocks. (Note that this is the opposite of the textbook, which uses a 1 to indicate a free block).

The in-use disk blocks map is stored within the file system using inode 2.
Note that `bitset.h` includes a function for finding `N` consecutive free bits.

1.3 Buffer Cache

The buffer cache allows you to keep recently-accessed blocks in memory for a while (for example, the inode for a directory), and hold in-progress modifications to blocks until all the writes to that block are done and can be committed back. This is largely how you will interact with the filesystem in the GeekOS kernel.

Each buffer in the cache has a block number (the backing store block number), the buffer in memory, and two flags:

in use Don't touch it, it's in use. Some thread is reading from it or writing to it. Or it's going to disk. The flag is set when you `Get_FS_Buffer()`, and cleared when you `Release_FS_Buffer()`. (Releasing doesn't remove the buffer from cache, it just marks it not in use.) If the flag has been set when `Get_FS_Buffer()` is called, you'll block, so pretend it is a lock acquisition. If your code appears to hang while the debugger's "thread apply all bt" shows no threads running, that indicates deadlock; your code might have decided to `Get_FS_Buffer()` on the same block twice: e.g., to read the in-use blocks bitmap inode and the root inode, both of which are in the same block.

dirty It has been modified. Mark a buffer dirty using `Modify_FS_Buffer()`. The buffer cache will take care of eventually writing the block back to disk, in whatever order it chooses.

Call `Create_FS_Buffer_Cache()` to make a new buffer cache for the device; it is given a block size (in our case 512 bytes since we will treat disk sectors as file system blocks) at creation time.

Call `Sync_FS_Buffer()` to push back specific blocks, and `Sync_FS_Buffer_Cache()` to push them all back. Ideally, one would use `Sync_FS_Buffer` for flushing the blocks of a file on close or of filesystem metadata eagerly. One would use `Sync_FS_Buffer_Cache` to sync the whole filesystem. (This would be comparable to the "sync" program that administrators worried about a crash or shutdown invoke.)

There's a `Destroy_FS_Buffer_Cache()` function too. I can't see a purpose to it in this assignment.

The buffer cache must be used to prevent too many reads or writes from hitting the virtual disk device. The buffer cache must be sync'd as the shell exits before `Hardware_Shutdown()`.

Some sample images are at:

- <http://www.cs.umd.edu/class/fall2015/cmsc412/gfs3-512k.img.gz> - small, empty
- <http://www.cs.umd.edu/class/fall2015/cmsc412/gfs3-5M.img.gz> - medium, empty
- <http://www.cs.umd.edu/class/fall2015/cmsc412/gfs3-10M-tstprep.img.gz> - this one should be prepared for the gfs3tst read tests.

I expect to add more soon, but this should be enough to start with mount and some simple development.

1.4 Part 1: Mount and Read Functions

The mount system call allows you to associate a filesystem with a place in the file name hierarchy. The Mount call is implemented as part of the VFS code we supply (see Mount function in `vfs.c`); you will implement your `Init_GFS3` function so that VFS's mount code will call your function `GFS3_Mount()` in `gfs3.c`. Among other things, it must ensure that the filesystem being mounted is GFS3.

Open files are tracked by the kernel using a struct `File`. Each user space process will have an associated file descriptor table that records which files the process can currently read and write. A user process can have up to `USER_MAX_FILES` files open at once. The file descriptor table is implemented as a struct `File *file_descriptor_table[USER_MAX_FILES]` array in struct `User_Context`. Not all the entries in the file descriptor table are necessarily open files, since usually a process has less than `USER_MAX_FILES` files open at once. If `fileList[i]` is `NULL`, it represents a free slot (file descriptor is not used). This descriptor will be filled out by the code in VFS; e.g., see `Open` in `vfs.h`, whose `pFile` argument is a pointer to a free slot in the table.

From the list of system calls below, implement all functionality for reading. `Open` (without the create option), `Open_Directory`, `Close`, `Read`, `Readentry`, `Stat`, `FStat`, `Seek`. "All functionality" includes the implementation of these functions for GFS3 in `src/geekos/gfs3.c`. (The syscalls are nearly trivial, since most of the work is done for you in `vfs.c`, and most are implemented for you. Some implementations may not be correct for this assignment, since they are based on another file system design having a different specification.)

Ensure `Makefile.linux` ties the second ide disk to a valid `gfs3` filesystem. (Add `"-hdb gfs3-1500k.img"` to the `qemu` line, for example.)

1.5 Part 2: Write Functions

Implement the rest: the create option to open, delete, write, `create_directory`, `sync`. Deletion should release the blocks to be reused by another file.

1.6 New System Calls

You will implement new system calls as described below. The semantics are very similar to the UNIX file system. Some notes:

- All user-supplied pointers (e.g., strings, buffers) must be checked for validity.
- Some checks are already done by `vfs.c`.

Mount Takes a device name ("`ide1`") to be mounted at a prefix ("`/d`") with a given file system type ("`gfs3`"). `ENOMEM` on a failure to allocate memory. `EINVALIDFS` if not a `gfs3` file system. `ENAMETOOLONG`, `ENOFFILESYS` handled by `vfs`.

Your GFS3 Mount function should not "validate" the filesystem settings except for magic and version fields.

Open Takes a path and a mode, returning a file descriptor. `ENOMEM` on a failure to allocate memory. `EINVALID` if user arguments are incorrect, e.g., bad flags. `ENAMETOOLONG` if the entire path is longer than 1024 bytes or any individual label is longer than 252 bytes. `EMFILE` if no more file descriptors. `ENOTFOUND` if the file does not exist and `O_CREATE`

was not given, or if the containing director does not already exist. Use `Allocate_File` in `vfs.c` to get a `File`. The permissions values are flags that may be or'ed together in a call, e.g., (`O_CREATE` — `O_READ` — `O_WRITE`)

Open_Directory See `Open`, except return `ENOTDIR` if called with the name of a file.

Close `EINVAL` if `fd` out of range.

Delete Takes a path. `ENOTFOUND` if the path is already absent. `EACCESS` if path is a non-empty directory. Let “recursive” always be false (I consider recursive file system operations in the kernel to be an abomination).

Read Acts as `unix read()`. Returns `EACCESS` if file was not opened for reading. `EINVAL` if `fd` out of range, `ENOMEM` if no memory, `ENOTFOUND` if the file descriptor has not been opened or has been closed. It's fine to return fewer bytes than asked for, for example, when near the end of the file. Be sure to advance the file position.

Read_Entry Returns 0 for a valid entry. Returns `VFS_NO_MORE_DIR_ENTRIES` when all entries have been read. (Note: this return convention (zero on something read) is inconsistent with the convention for `Read` (zero on EOF).) Error codes as described for `read`.

Write Acts as `unix write`. Error codes as described for `Read()` above, with obvious edits.

Stat Similar errors as `Open` (except `EMFILE`). `VFS_File_Stat` is defined in `fileio.h`

FStat Similar errors as `Read`, where applicable. `FStat` fills in the `stat` structure given a file descriptor rather than a path name as in `Stat`.

Seek Similar errors as `Read`. Acts as `unix seek`, assuming `SEEK_SET`, that is, an absolute position is the offset. The behavior of `seek()` on `gfs3` directories shall be undefined; the behavior of `readdir` after `seek` equally undefined. (Undefined means do what you want; I don't want to specify.)

Create_Directory Similar errors as `Open`. Should NOT create directories recursively; e.g. `CreateDirectory("/d/d1/d2/d3/d4")`, should fail if `/d/d1/d2/d3` does not exist.

Sync Forces any outstanding operations to be written to disk. That is, flush dirty buffers in the buffer cache to disk.

Format Do not implement. (Other file systems in 412 may implement `Format` as a system call, which permits quick testing but is otherwise atypical.)

2 Testing and Requirements

2.1 Requirements

Here are some must do's for the project:

- Make sure your `Mount()` works well, so that we can test your project. If we cannot `Mount()` a `GFS3`, we cannot grade your project. Do not refuse to mount our valid images.

- You might also want to mount /d to ide1 automatically in main() to speed up your testing, but the code you submit should not mount /d automatically.
- You should support arbitrary file sizes.

You do not need to consider: situations where two processes have the same file open, situations where one process opens the same file twice without closing it in between, or interactions with fork.

2.2 Testing

Finally, in src/user there are some programs that can be used to test your file management system calls: cp.c, ls.c, mkdir.c, mount.c, gfs3tst.c, touch.c, type.c.

There are other test files; these have not been updated for this file system.

Most of the submit server tests are based on gfs3tst.c. Any point values configured in gfs3tst are not necessarily used on submit.

2.3 Study questions

Consider the difference between this mini inode and a more realistic inode; what do others maintain, and why does gfs3 not include it?

Consider the difference between the original unix file system and FFS; in your implementation, how often do you jump between reading inodes and reading data blocks?

Consider readent (SYS_READENTRY); does it make sense to have this be a system call? "strace ls" on a linux machine. What system call does it use instead? Check the man page and explain why that's a better design.

Using your experience from this project, what does it mean for a filesystem to have been cleanly unmounted? How does the kernel know if a filesystem is clean when it is being mounted? What would have to be added to this project to allow that decision? How would one check and repair GFS3?