FUSE

Developing filesystems in userspace

Mads D. Kristensen

`mads@oejlug.dk`

OEJLUG - Oestjyllands Linux-brugergruppe

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What is a filesystem?

"... a method for storing and organizing computer files and the data they contain to make it easy to find and access them." [wikipedia].

From this description we can deduce two important things about a filesystem:

1. It must provide a method for storing the data; be it on disk, CD or something other, and
2. it must provide an interface for the user to make it possible to navigate through the stored data.

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Storing file data.

Well known *regular* filesystems are ext2, ext3, reiserfs, xfs etc. These filesystems specify the layout of data on disk.

Filesystems does not *have* to be this low-level. For example a typical network filesystem does not specify such things but just depends on the local filesystem on the server for storing the data. Examples are NFS, Samba and AFS.

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Filesystem meta data.

Apart from defining how file data is stored some meta data must be stored as well. This meta data represents things like:

- Filename in human-readable form.
- Directory structure.
- Access rights.
- Ownership.
- Timestamps.

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The Virtual File Switch (VFS).

In Linux the meta data of the filesystem must be fed to VFS so that it may present the user with a common interface for all filesystems. This means that, if your meta data matches with VFS's demands, you can use standard commands like `chmod`, `chown` and `cp`.

Furthermore, when using VFS, you can use all the standard commands to read/manipulate the file data as well (eg. `cat`, `sed`, `grep`).

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VFS continued.

All this works because VFS defines the basic system calls for opening and closing files (`open`, `close`), reading from/writing to files (`read`, `write`), getting/setting rights and ownership (`stat`, `chown`, `chmod`, `umask`), creating and deleting directories (`mkdir`, `rmdir`), reading directory contents and more (`utime`, `truncate`, ...).

This means that all applications will work with your filesystem, for example: `emacs /mnt/myfs/foo.txt`.

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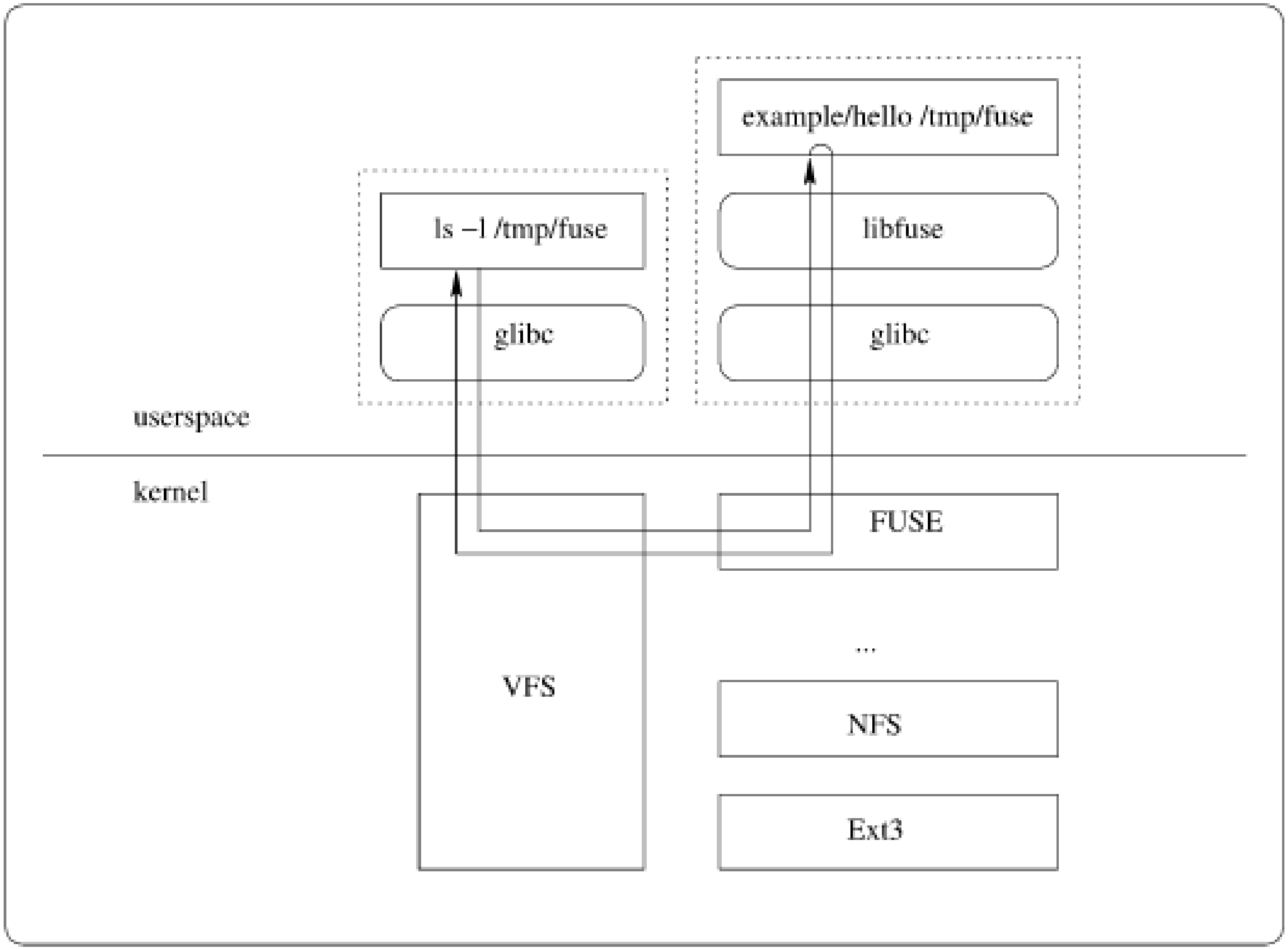
How does FUSE work?



How does FUSE work? (continued)

As the figure showed FUSE is separated into two parts:

1. A kernel module that hooks up to the VFS inside the kernel.
2. A userspace library that communicates with the kernel module.

A related system call is then first passed to the kernel by the calling application, VFS passes the request on to the FUSE kernel module which in turn passes the request on to the FUSE library in userspace. The FUSE library then calls the associated function for that specific system call.

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Installing FUSE.

Gentoo	`sys-fs/fuse`
Ubuntu	`fuse-source`
	`fuse-utils`
	`libfuse2`
	`libfuse2-dev`
Source	`./configure`
	`make`
	`make install`

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Getting started.

This is all well and good, but how do we get started implementing a filesystem?

As mentioned FUSE works by passing system calls from the kernel and back into userspace so we need to implement some functions to take care of the different system calls.

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System calls in FUSE.

`getattr`	Get file attributes - similar to `stat()`.
`readlink`	Read the target of a symbolic link.
`mknod`	Create a file node.
`mkdir`	Create a directory.
`unlink`	Remove a file.
`rmdir`	Remove a directory.
`symlink`	Create a symbolic link.
`rename`	Rename a file.
`link`	Create a hard link to a file.
`chmod`	Change the permission bits of a file.

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System calls in FUSE. (continued)

`chown`	Change the owner and group of a file.
`truncate`	Change the size of a file.
`open`	Open a file.
`release`	Close an open file.
`read`	Read data from an open file.
`write`	Write data to an open file.
`fsync`	Synchronize file contents (ie. flush dirty buffers).
`opendir`	Open directory.
`readdir`	Read directory - get directory listing.
`releasedir`	Close directory.

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System calls in FUSE. (continued)

`utime`	Change the access and/or modification times of a file.
`statfs`	Get file system statistics.
`init`	Initialize filesystem (FUSE specific).
`destroy`	Clean up filesystem (FUSE specific).

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A first example.

This first example defines a flat (ie. no directories) in-memory filesystem.

The implementation can be found in `example1.c` and it can be compiled by typing `make ex1`.

The helper class `dlist` just defines a doubly linked list and it should be obvious what the different functions does.

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What is missing?

This simple example are missing a lot of features that a regular filesystem needs, but it might be enough for *your* specific filesystem needs.

We will continue with the example by adding functionality to properly initialize the access bits, timestamps and ownership of files and by adding functions to change these settings.

These additions can be found in `example2.c`.

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How about delete and rename?

It would be nice if it was also possible to rename and delete files stored in or filesystem; so that functionality is added in the third iteration of our example.

These additions can be seen in `example3.c`.

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Adding hierarchy (directories).

Now is the time to remove the *flatness* from our example filesystem by adding some hierarchy.

Directories are represented in a lot of different ways in different filesystems. In most *regular* filesystems a directory is just an ordinary file that contains information about the files and directories that reside in it; this is why a directory has a size in a Linux system, because a directory with at lot of files in it needs more than one page (4096 bytes) for its list.

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Directory size example.

Example:

```
mdk@tux ~/docs/foredrag/fuse $ ls /usr/ -la
total 144
drwxr-xr-x   14 root    root      4096 Jul 25 21:37 .
drwxr-xr-x   19 root    root      4096 Aug  2 10:19 ..
-rw-r--r--    1 root    root         0 Jul 25 21:37 .keep
lrwxrwxrwx    1 root    root         6 Jul  9 15:44 X11R6 -> ../usr
drwxr-xr-x    2 root    root     40960 Aug  4 10:05 bin
lrwxrwxrwx    1 root    root         9 Jul  9 00:41 doc -> share/doc
drwxr-x---    3 root    games     4096 Jul 10 19:16 games
drwxr-xr-x    7 root    root      4096 Jul 14 20:16 i686-pc-linux-gnu
drwxr-xr-x  182 root    root     12288 Aug  2 14:58 include
lrwxrwxrwx    1 root    root        10 Jul  9 00:41 info -> share/in
drwxr-xr-x   89 root    root     49152 Aug  3 17:18 lib
...
```

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Directories (continued).

So, we could represent directories in our example filesystem by creating regular files that contains the inode numbers of the files that reside in them.

But, directories does no *have* to be represented as regular files, in fact there are a lot of other possibilities all depending on the specific filesystem that you are designing.

How we choose to represent directories can be seen in the fourth iteration of our filesystem, `example4.c`.

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Now we've got everything, right?

The short answer: "No.".

There are still some important filesystem functions missing from our filesystem; things such as hard links and symbolic links.

Actually we are still missing all these calls: `readlink`, `releasedir`, `symlink`, `link`, `statfs`, `release` and `fsync`.

These calls will not be presented in this talk - wait for the tutorial ;-)

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FUSE options.

```
usage: ./example4 mountpoint [FUSE options]

FUSE options:
    -d                     enable debug output (implies -f)
    -f                     foreground operation
    -s                     disable multithreaded operation
    -r                     mount read only (equivalent to '-o ro')
    -o opt,[opt...]        mount options
    -h                     print help

Mount options:
    default_permissions    enable permission checking
    allow_other            allow access to other users
    allow_root             allow access to root
    kernel_cache           cache files in kernel
    large_read             issue large read requests (2.4 only)
```

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FUSE options (continued).

direct_io	use direct I/O
max_read=N	set maximum size of read requests
hard_remove	immediate removal (don't hide files)
debug	enable debug output
fsname=NAME	set filesystem name in mtab
use_ino	let filesystem set inode numbers
readdir_ino	try to fill in d_ino in readdir

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Concurrency.

Concurrent filesystem requests may come in any ordering so you have to make sure that your filesystem is ready for this.

The example filesystem we have seen thus far does not support multithreading because the datastructures are not protected at all. This would be fairly easy to do by adding mutexes.

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Other FUSE based filesystems.

- SSHFS
- EncFS
- GmailFS
- Wayback Filesystem
- ... and others.

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Questions?