Operating Systems

Week 10. Assignment 7 Discussion

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File Systems & *Everything is a File*

- File systems
  - Typically used to store & organize data
  - Implemented over block devices (disks and flash memory)

- "Everything is a file"
  - Evolved through the history of UNIX (& BSD, Plan 9, Linux)
  - Devices appear as files
    - Names in the file system name space
    - inode contains major & minor device number
    - Requests are sent to the device driver

Pseudo devices and files

- Device files can refer to software drivers
  - No underlying device

    /dev/zero – read an infinite # of 0 bytes

    /dev/random – return random bytes

- File systems can be software drivers too
  - No underlying block device
  - File system driver under VFS presents something that looks like a file system
  - Example:

    /proc – process file system: get kernel & process information

File Systems as a Name Space

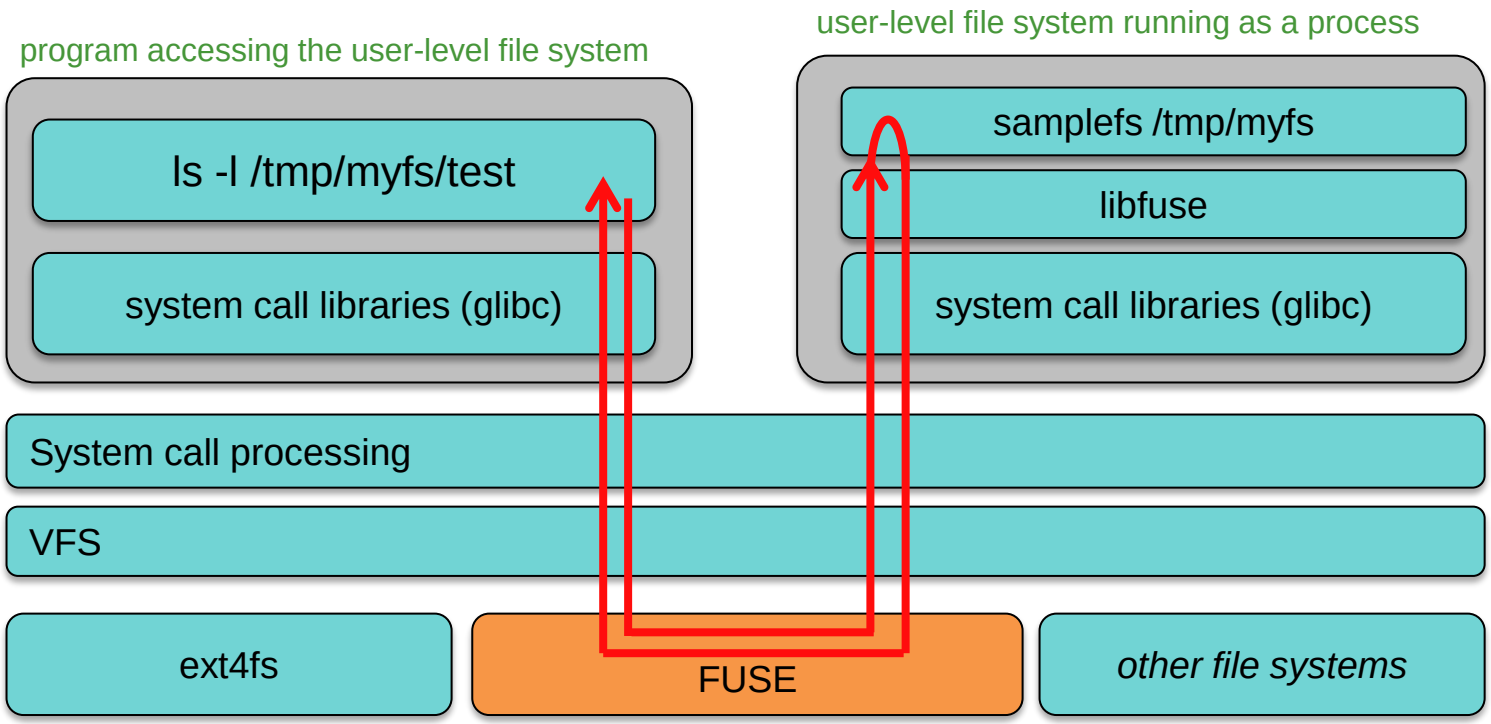
- File system name space is a powerful abstraction
  - Easy to understand: users & programs know how to browse, read, and write files
  - Easy to work with: GUI tools, command-line utilities, scripts, and programming language interfaces

- Example
  - Change the maximum # of file handles the kernel will allocate
    ```
    echo 8192 > /proc/sys/fs/file-max
    ```
  - Look at the computer's name
    ```
    cat /proc/sys/kernel/hostname
    ```
  - Change it
    ```
    echo myname.pk.org > /proc/sys/kernel/hostname
    ```
  - *No need for extra commands or system calls!*

FUSE: Filesystem in USErspace

FUSE enables a file system to run as a normal user process

- FUSE file system module
  - Conduit to pass data between VFS and the user process that implements the file system



Getting information

FUSE is maintained at fuse.sourceforge.net

- Source code
- Documentation
- Examples

FUSE components

- The program that implements the file system links with the FUSE library (libfuse)

- FUSE consists of:
  - Kernel module (fuse.ko)
    - File system module (fusefs) and character device (/dev/fuse)
  - User-space library (libfuse.so)
  - Mount utility (fusermount) to mount the file system onto the namespace

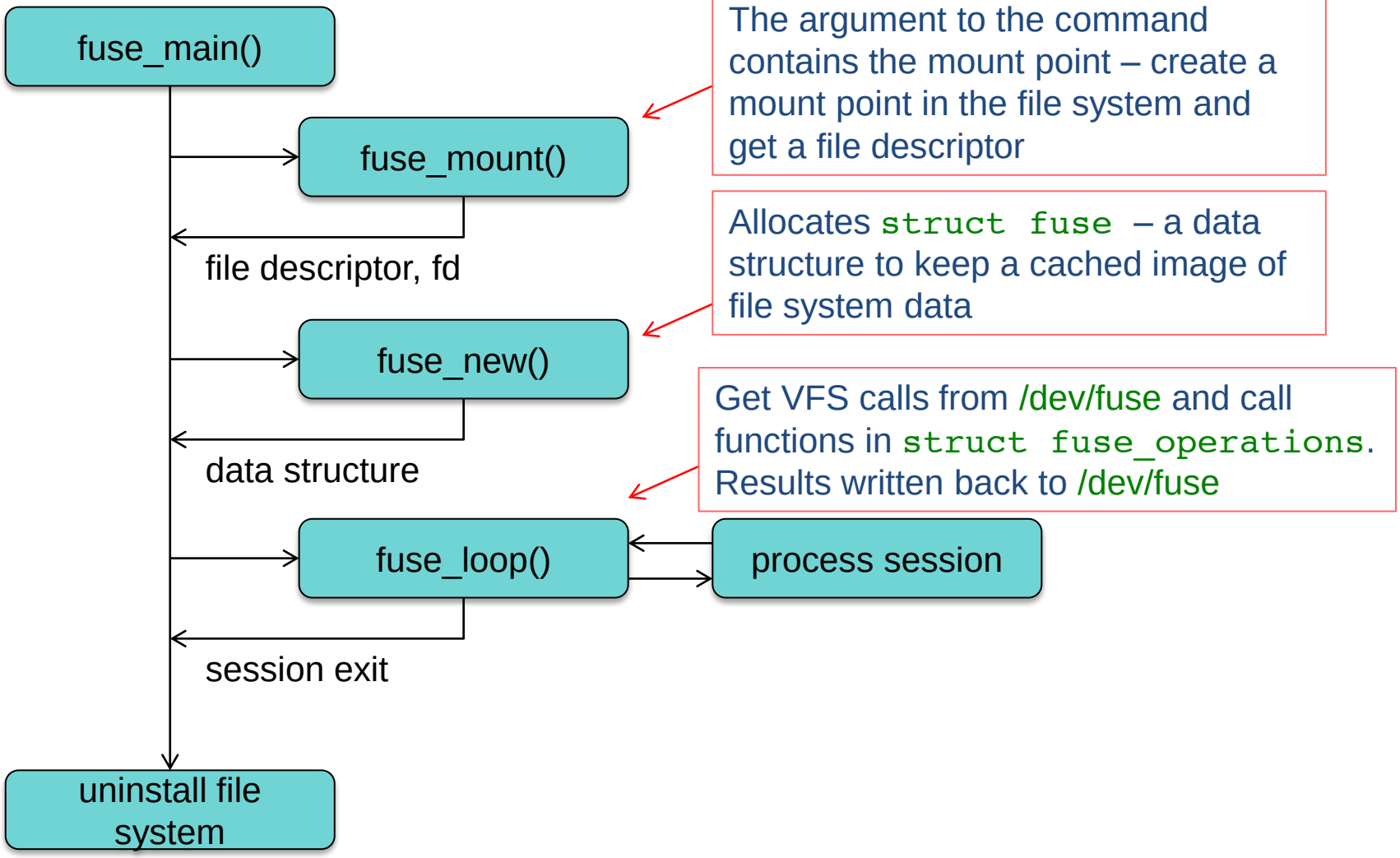
- Your user-level file system is linked with the FUSE library (libfuse.so)

How it works (at the simplest level!)

- FUSE kernel module
  - Redirects VFS calls to the user-level library via the /dev/fuse character device

- The main program in your file system (fuse_main):
  - Parses arguments and calls fuse_mount()
  - Opens /dev/fuse
    - Each process that opens /dev/fuse gets a different file descriptor
  - Reads VFS file system calls from /dev/fuse
  - Calls file system functions stored in fuse_operations struct
    - These are functions you write to implement the file system
  - Results written back to /dev/fuse via the file descriptor

The life of a user-level file system



FUSE Operations

- Defined in `struct fuse_operations`
  - Not all of these need to be implemented – depends on what the file system needs to do
  - This is a high-level overview & not a complete list
    Read the documentation!

- Operations: file system
  - **`void *(*init) (struct fuse_conn_info *conn);`**
    - Initialize your file system
  - **`int (*statfs) (const char *, struct statvfs *);`**
    - Provide file system statistics
  - **`void (*destroy) (void *);`**
    - Clean up your file system – free any allocated data

File & Directory create/move/delete

- `int (*mknod) (const char *, mode_t, dev_t);`
  - Create a file node (device file or named pipe)
- `int (*mkdir) (const char *, mode_t);`
  - Create a directory
- `int (*unlink) (const char *);`
  - Remove a file
- `int (*rmdir) (const char *);`
  - Remove a directory
- `int (*symlink) (const char *, const char *);`
  - Create a symbolic link (pointer to a file or directory)
- `int (*rename) (const char *, const char *);`
  - Rename a file or directory
- `int (*link) (const char *, const char *);`
  - Create a hard link to a file (alias)

Directory data operations

- **`int (*opendir) (const char *, struct fuse_file_info *);`**
  - Open directory
  - Unless the 'default_permissions' mount option is given, this method should check if *opendir* is permitted for this directory
  - *opendir* may return an arbitrary `filehandle` in the `fuse_file_info` structure
    - This will be passed to *readdir*, *closedir* and *fsyncdir*.

- **`int (*readdir) (const char *, void *, fuse_fill_dir_t, off_t, struct fuse_file_info *);`**
  - Read directory

- **`int (*releasedir) (const char *, struct fuse_file_info *);`**
  - Release directory

- **`int (*fsyncdir) (const char *, int, struct fuse_file_info *);`**
  - Synchronize directory contents

File attribute operations

- `int (*getattr) (const char *, struct stat *);`
  - Get file attributes
- `int (*setxattr) (const char *, const char *, const char *, size_t, int);`
  - Set extended attributes
- `int (*getxattr) (const char*, const char*, char*, size_t);`
  - Get extended attributes
- `int (*listxattr) (const char *, char *, size_t);`
  - List extended attributes
- `int (*removexattr) (const char *, const char *);`
  - Remove extended attributes
- `int (*readlink) (const char *, char *, size_t);`
  - Read the target of a symbolic link
- `int (*chmod) (const char *, mode_t);`
  - Change the permission bits of a file
- `int (*chown) (const char *, uid_t, gid_t);`
  - Change the owner and group of a file

File operations

- `int (*open) (const char *, struct fuse_file_info *);`
  - Open a file

- `int (*flush) (const char *, struct fuse_file_info *);`
  - Flush any cached data for an open file
  - Called when a file is closed

- `int (*fsync) (const char *, int, struct fuse_file_info *);`
  - Synchronize file contents

- `int (*create) (const char *, mode_t, struct fuse_file_info *);`
  - Create and open a file. If the file does not exist, first create it with the specified mode, and then open it.

File data operations

- `int (*truncate) (const char *, off_t);`
  - Change the file size to a given offset

- `int (*read) (const char *, char *, size_t, off_t, struct fuse_file_info *);`
  - Read bytes of data from an open file

- ```
  int (*write) (const char*, const char*, size_t, off_t,
                struct fuse_file_info *);
  ```
  - Write bytes of data to an open file

- `int (*flush) (const char *, struct fuse_file_info *);`
  - Flush any cached data for an open file
  - Called when a file is closed
  ```

Assignment 7 Overview

- Create a user-level **math file system (mathfs)**
  - Runs via FUSE
- The root of mathfs comprises seven directories
- Each directory represents a mathematical function:
  1. /factor - Computes the prime factors of a number.
  2. /fib - Computes the first n fibonacci numbers.
  3. /add - Adds two numbers
  4. /sub - Subtracts two numbers.
  5. /mul - Multiplies two numbers.
  6. /div - Divides two numbers.
  7. /exp - Raises a number to a given exponent.

Assignment 7 Overview

- Suppose you mount your file system on /tmp/math
  - Create a directory /tmp/math: `mkdir /tmp/math`
  - Run the program, giving it the mount point: `./mathfs /tmp/math`
- The command

  ```
  cat /tmp/math/factor/12782
  ```

  will produce the prime factors of 12782:

  ```
  2
  7
  11
  83
  ```

- The command

  ```
  cat /tmp/math/add/6/4
  ```

  will produce the sum of 6+4

  ```
  10
  ```

First, run the demo: get it

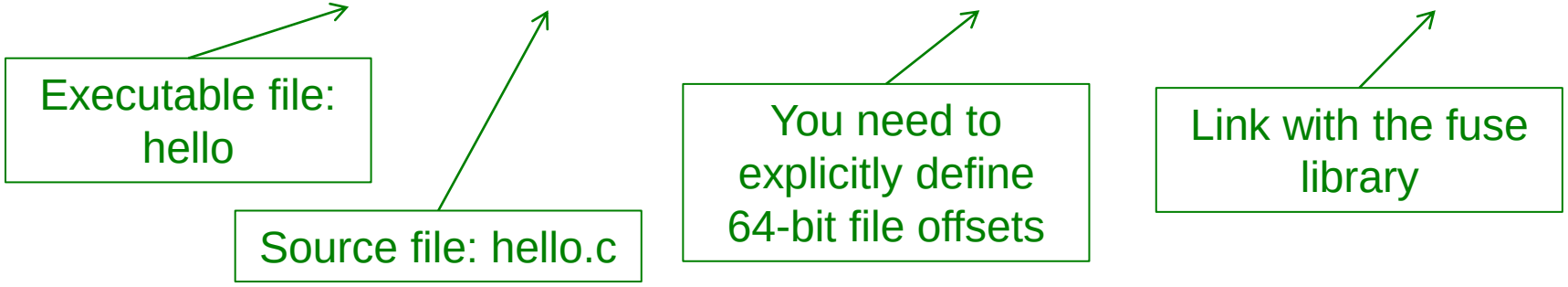
Before starting the assignment, be sure that you can use FUSE and run the “hello, world” demo

- See fuse.sourceforge.net

Running the demo: compile it

- The “hello, world” file system is < 100 lines long
- Download hello.c
  - `http://fuse.sourceforge.net/helloworld.html`
- Compile it:

```
cc -o hello hello.c -D_FILE_OFFSET_BITS=64 –lfuse
```



Running the demo: run it

- Create a mount point: any directory

```
mkdir hitest
```

- Run the hello file system, telling it to use hitest as the mount point

```
./hello hitest
```

- hello runs in the background
  - Be aware of this when debugging your program!
  - You have to remember to *unmount* the file system when done!

```
./fusermount –u hitest
```

Running the demo: test it

We now have the file system running. Test it out:

```
$ ls -l hitest
total 0
-r--r--r-- 1 root root 13 Dec 31  1969 hello
```

There's just one file in there called `hello`. Let's look at it:

```
$ cat hitest/hello
Hello World!
```

It doesn't do much but it works!

We can see the process *hello* is still running

```
$ ps x |grep hello
15806 ?        Ssl    0:00 ./hello hitest
```

Running the demo: stop it

When we're done, unmount the file system

```
$ fusermount –u hitest
```

this is our mount point

This causes the process to exit

Running the demo: debugging

Running *hello* with a -d flag enables debug logging

```
$ ./hello hitest -d
```

- Use another window for typing commands since log output goes to the screen
- Great way to see what functions are being called

`ls` calls:
- *getxattr* (not implemented)
- *readdir*
- *releasedir*

`cat hello` calls:
- *lookup*
- *open*
- *read*
- *getattr*
- *flush* (not implemented)
- *release*

Minimal implementation

- FUSER passes in dozens of VFS functions
- You don't need to implement those you don't use
- The "Hello, World!" demo implements only four!

```
static struct fuse_operations hello_oper = {
    .getattr  = hello_getattr,
    .readdir  = hello_readdir,
    .open     = hello_open,
    .read     = hello_read,
};
```

Minimal implementation

- Some implementations can be hard-coded
  - Everything in the “Hello, World!” demo is
  - Example, *readdir* returns a directory listing
    - The demo supports only one directory with one file

```
static const char *hello_path = "/hello";
static int hello_readdir(const char *path, void *buf,
        fuse_fill_dir_t filler, off_t offset, struct fuse_file_info *fi)
{
    (void) offset;
    (void) fi;

    if (strcmp(path, "/") != 0)
        return -ENOENT;

    filler(buf, ".", NULL, 0);
    filler(buf, "..", NULL, 0);
    filler(buf, hello_path + 1, NULL, 0);

    return 0;
}
```

Assignment 7 Implementation

Implement & debug each of the 7 math functions

- Make sure they work before plugging them into the file system
- Handle ALL errors: overflow, divide by 0, bad data
- You can always return an error message but don't die!

Assignment 7 Implementation

- Then, create a basic file system that doesn't implement the operations but parses pathnames & returns dummy data
- At a minimum, you will need to implement
  - *getattr*: get attribute of a file; don't bother with timestamps
  - *readdir*
    - At the top level, you should show these directories
      - `factor fib add sub mul div exp`
    - Within each directory, you should show just one directory
      - `doc`: contains usage info for that function
  - *open*
    - Parses the pathname to get the operation & numbers and produce the results

Assignment 7 Implementation

- Finally, tie the implementation of the functions into the file system and test everything!

The End