Project report on Implementation of File System on Raspberry Pi.

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Course: CS 630 - Operating Systems Design

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1. Introduction

Nowadays Linux is an operating system of choice for many computing systems ranging from personal computers (PC), servers, mainframe computers and supercomputers to electronic devices known as embedded systems. Linux is a highly portable operating system; it can run on a variety of hardware architectures such as x86, PowerPC, MIPS, H8, SPARC, or ARM, to name just a few.

This portability also comes with limitations, however. It is no doubt that while the modular architecture of Linux makes it easy when porting to different types of architectures, a great deal of effort is required to build new kernel components in order to support a target platform. The Raspberry Pi platform is an example of a target device that Linux can be ported to run on it. General file system is one of the kernel modules that can be developed and mounted on Linux platform. Thus the goal of this project was to implement a File System on Raspberry Pi.

The intended result of this work was to get a deeper understanding on the Raspberry Pi platform, to learn what Linux file systems does and how it works, and finally to mount a file system for the Raspberry Pi platform which was coded from its scratch.

2. Raspberry Pi Model B Rev 2.0 Platform

The Raspberry Pi model B rev 2.0 platform was chosen for this project to implement the File System. This is due to the fact that Raspberry Pi is a low-cost Linux computer which costs approximately $35 from the Farnell distributor. The platform is widely used by hobbyists and professional embedded developers around the world. Therefore, there is a large support from the community when it comes to getting help or information. For convenience, Raspberry Pi will be used when referring to the Raspberry Pi model B rev 2.0 platform throughout this report.

3. Milestones

In order to complete our project on time, we used Agile framework and broke the tasks down into 5 milestones. Our process is shown below.

Step	Milestones	Duration
1	Learning and preparing Raspberry Pi environment	3 weeks
2	Understanding the Linux Kernel	2 weeks
3	Implementing simple kernel module	1 weeks
4	File System coding and mounting	5 weeks
5	Testing and Reporting	2 week

4. VFS:

The Linux VFS supports multiple file systems. The kernel does most of the work while the file system specific tasks are delegated to the individual file systems through the handlers. Instead of calling the functions directly the kernel uses various Operation Tables, which are a collection of handlers for each operation (these are actually structures of function pointers for each handlers/callbacks). The kernel calls the handler present in the table for the operation. This enables different file systems to register different handlers. This also enables the common tasks to be done before calling the handlers. This reduces the burden on the handlers which can then focus on the operations that are only specific to that file system.

File systems are identified by their names. The supported file systems can be seen using 'cat /proc/filesystems'. The first step is to register the file system with the kernel. Since we are using a kernel module, the file system registration is done during the module initialization. This registers a handler which will be called to fill the super block structure while mounting, a handler to do the cleanup during unmounting the file system. These are other handlers but these two are essential.

The super block operations are set at the time of mounting. The operation tables for inodes and files are set when the inode is opened. The first step before opening an inode is lookup. The inode of a file is looked up by calling the lookup handler. The root-most inode of the new file system has to be allocated at the time of mounting i.e., during the super block initialization.

Once the operation tables are set on the data structures, the kernel calls the handlers depending on the operation.

5. Data structures used in our project:

This is a brief description about the data structures used in implementing our file system.

a. File System Type (struct file_system_type)

This structure is used to register the filesystem with the kernel. This data structure is used by the kernel at the time of mounting a file system. We have to fill the 'name' field with the name of our file system and the handlers to allocate and release the super block objects.

b. Super Block (struct super_block)

This stores the information about the mounted file system. The important fields to be filled are the operation table (s_ops field) and the root dentry (s_root). At the time of mounting a file system, the kernel calls the mount field of the file_system_type object to get a super block object.

c. Super Block Operations (struct super_operations)

Super block operations table.

d. Inode (struct inode)

Inode object is the kernel representation of the low level file. We return the dentry of the root of our file system. We have to attach a proper inode also to the dentry. This structure has two operation tables inode operations and file operations respectively.

e. Inode Operations (struct inode_operations)

This is the inode operations table with each field corresponding to a function pointer to handle the task. It has fields like mkdir, lookup etc.

f. Address Space Operations (struct address_space_operations)

Address space operations table.

g. DEntry (struct dentry)

The kernel uses dentries to represent the file system structure. dentries point to inode objects. This has pointers to store the parent-child relationship of the files. Inodes and files do not store any information about the hierarchy.

h. File (struct file)

File object is used to store the information about the file. The kernel takes care of filling the proper fields but we have to implement the file operation callbacks.

i. File Operations (struct file_operations)

This is the file operations table.

6. Code Snippets

The following table shows the fields we need to fill in the above data structures.

File System Type	DEntry	Super Block	Inode
• name • mount • kill_sb • fs_flags	• d_inode	• s_root	• i_ino • i_mode • i_op • i_fop

The following table shows the operation tables and the handlers used.

Super Operations	Inode Directory Operations	Inode File Operations	Address Space Operations	File Operations
• statfs • drop_inode	• lookup • link • mkdir • rmdir	• setattr • getattr	• readpage • write_begin • write_end	• read_iter • write_iter • splice_read • splice_write • open • llseek

```
static struct file_system_type osfs_type = {
.owner = THIS_MODULE,
.name = "fscjs",
.mount = &osfs_mount,
.kill_sb = kill_block_super,
.fs_flags        = FS_USERNS_MOUNT,
};
```

Fig 1: File System Type

```
static struct dentry *osfs_mount(struct file_system_type *type, int flags,
                                  char const *dev, void *data)
  {
      return mount_nodev(type, flags, data, osfs_fill_sb);
  }
```

Fig 2: The mount function returning a dentry

```c
static int osfs_fill_sb(struct super_block *sb, void *data, int silent)
 {
        struct inode * inode;
        struct osfs_fs_info *fsi = kzalloc(sizeof(*fsi), GFP_KERNEL);


        sb->s_fs_info = fsi;
        if (!fsi)
                return -ENOMEM;
        sb->s_maxbytes          = MAX_LFS_FILESIZE;
        sb->s_blocksize         = PAGE_SIZE;
        sb->s_blocksize_bits    = PAGE_SHIFT;
        sb->s_magic             = OSFS_MAGIC;
        sb->s_op                = &osfs_super_ops;
        sb->s_time_gran         = 1;

        inode = osfs_get_inode(sb, NULL, S_IFDIR | fsi->mount_opts.mode, 0);
        sb->s_root = d_make_root(inode);
        if (!sb->s_root)
                return -ENOMEM;

        return 0;
}
```

Fig 3: Filling super block fields like s_root etc.

```c
struct inode *osfs_get_inode(struct super_block *sb,
                                const struct inode *dir, umode_t mode, dev_t dev)
{
        struct inode * inode = new_inode(sb);
        if (inode) {
                inode->i_ino = get_next_ino();
                inode_init_owner(inode, dir, mode);
                inode->i_atime = inode->i_mtime = inode->i_ctime = current_time(inode);
                switch (mode & S_IFMT) {
                default:
                        init_special_inode(inode, mode, dev);
                        break;
                case S_IFREG:
                        inode->i_op = &osfs_file_inode_operations;
                        inode->i_fop = &osfs_file_operations;
                        break;
                case S_IFDIR:
                        inode->i_op = &osfs_dir_inode_operations;
                        inode->i_fop = &simple_dir_operations;
                        inc_nlink(inode);
                        break;
                case S_IFLNK:
                        inode->i_op = &page_symlink_inode_operations;
                        inode_nohighmem(inode);
                        break;
                }
        }
        return inode;
}
```

Fig 4: Filling inode fields like i_op, i_fop etc.

```
static const struct super_operations osfs_super_ops= {
        .statfs         = simple_statfs,
        .drop_inode     = generic_delete_inode,
};
```

Fig 5: Superblock Operations.

```
static const struct inode_operations osfs_dir_inode_operations = {
        .lookup         = simple_lookup,
        .link           = simple_link,
        .mkdir          = osfs_mkdir,
        .rmdir          = simple_rmdir,
};
```

Fig 6: Inode Directory Operations.

```
static const struct inode_operations osfs_file_inode_operations = {
        .setattr        = simple_setattr,
        .getattr        = simple_getattr,
};
```

Fig 7: Inode File Operations.

```
static const struct address_space_operations osfs_aops = {
        .readpage       = simple_readpage,
        .write_begin    = simple_write_begin,
        .write_end      = simple_write_end,
};
```

Fig 8: Address Space Operations.

```
static const struct file_operations osfs_file_operations = {
        .open           = generic_file_open,
        .read_iter      = generic_file_read_iter,
        .write_iter     = generic_file_write_iter,
        .splice_read    = generic_file_splice_read,
        .splice_write   = iter_file_splice_write,
        .llseek         = generic_file_llseek,
};
```

Fig 9: File Operations.

7. Mounting/Unmounting:

Step 1: Creating a Makefile

```
obj-m += fscjs.o

all:
	make -C /lib/modules/$(shell uname -r)/build M=$(PWD) modules

clean:
	make -C /lib/modules/$(shell uname -r)/build M=$(PWD) clean
```

Step 2: This generates a file fscjs.o. Loading the file system is same as loading a module.
insmod fscjs.o

Step 3: Mount the file system.

```
pi@raspberrypi:~/Desktop/filesystem $ touch image
pi@raspberrypi:~/Desktop/filesystem $ mkdir FSCJS
pi@raspberrypi:~/Desktop/filesystem $ ls
FSCJS    fscjs.ko      fscjs.mod.o  image     modules.order
fscjs.c  fscjs.mod.c   fscjs.o      Makefile  Module.symvers
pi@raspberrypi:~/Desktop/filesystem $ sudo mount -o loop -t fscjs ./image ./FSCJS
```

Step 4: Check if the file system is mounted

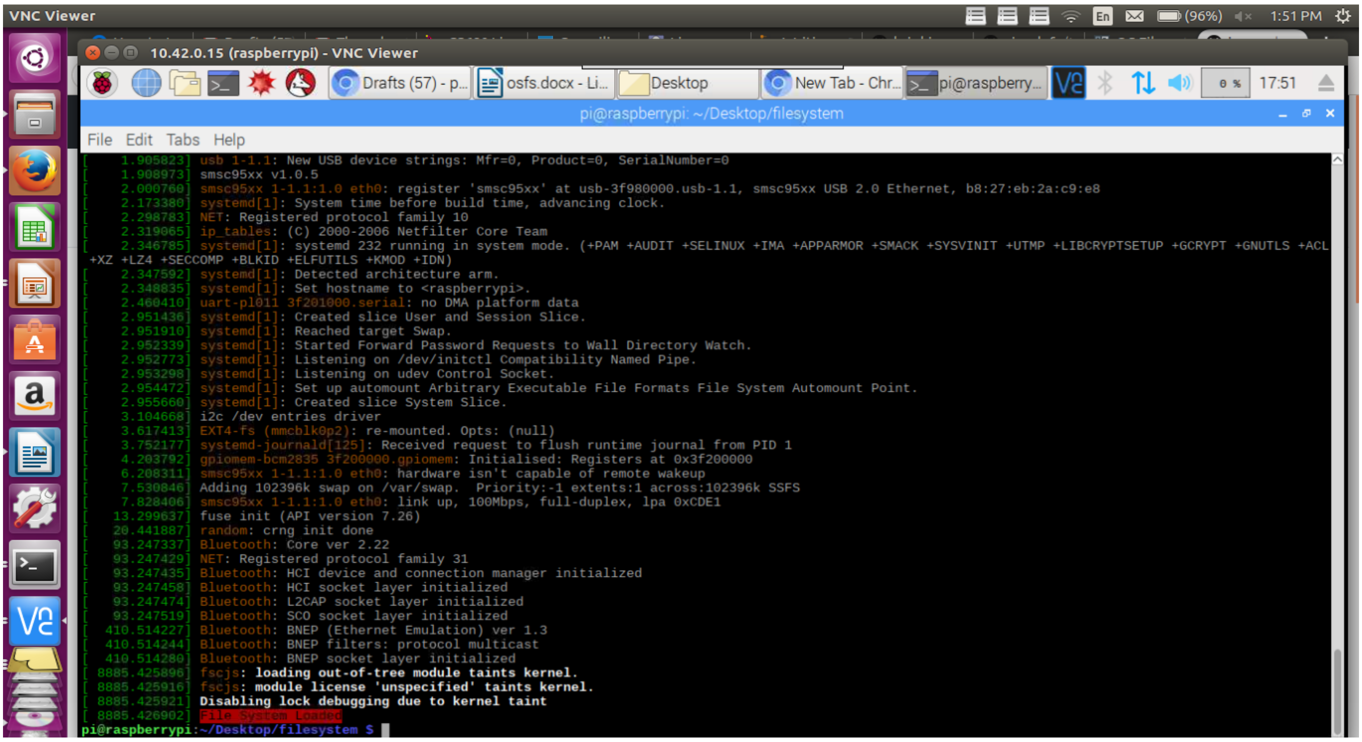
```
pi@raspberrypi:~/Desktop/filesystem $ cat /proc/filesystems
nodev   sysfs
nodev   rootfs
nodev   ramfs
nodev   bdev
nodev   proc
nodev   cpuset
nodev   cgroup
nodev   cgroup2
nodev   tmpfs
nodev   devtmpfs
nodev   configfs
nodev   debugfs
nodev   tracefs
nodev   sockfs
nodev   pipefs
nodev   rpc_pipefs
nodev   devpts
        ext3
        ext2
        ext4
        vfat
        msdos
nodev   nfs
nodev   nfs4
nodev   autofs
        f2fs
nodev   mqueue
        fuseblk
nodev   fuse
nodev   fusectl
        fscjs
pi@raspberrypi:~/Desktop/filesystem $ cat /proc/filesystems|grep fscjs
        fscjs
pi@raspberrypi:~/Desktop/filesystem $
```

Step 5: Unmount
umount /mnt/rkfs

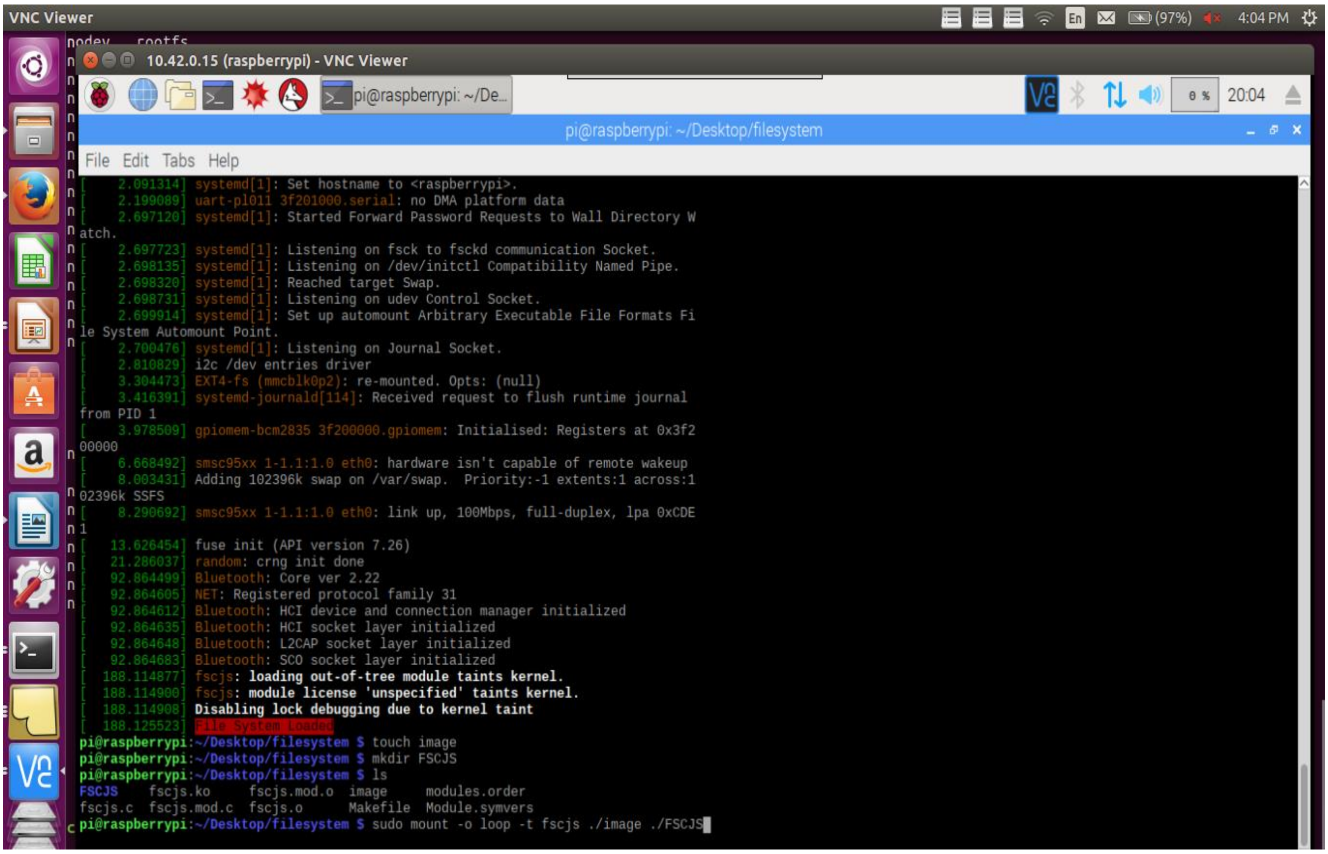
Step 6: Unload the module
rmmod rkfs

8. Working Screenshots

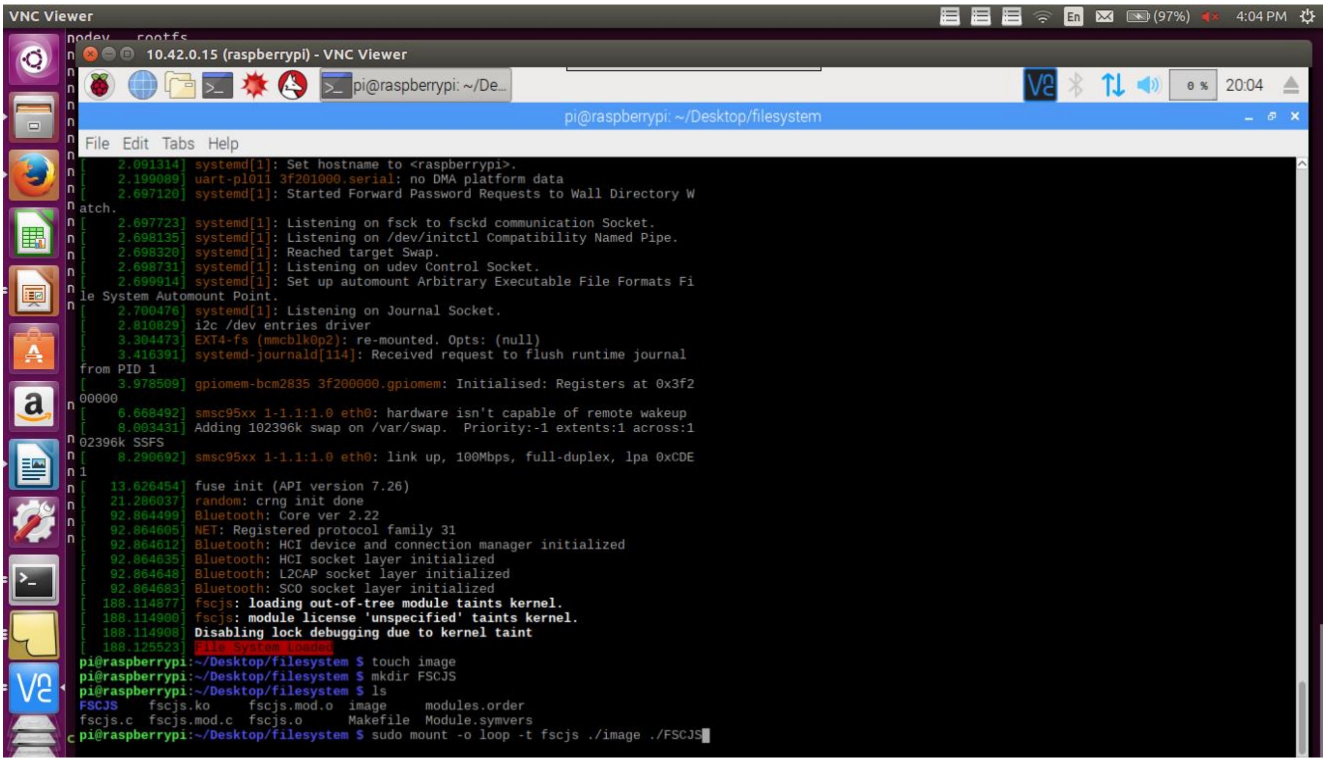
a. Loading filesystem



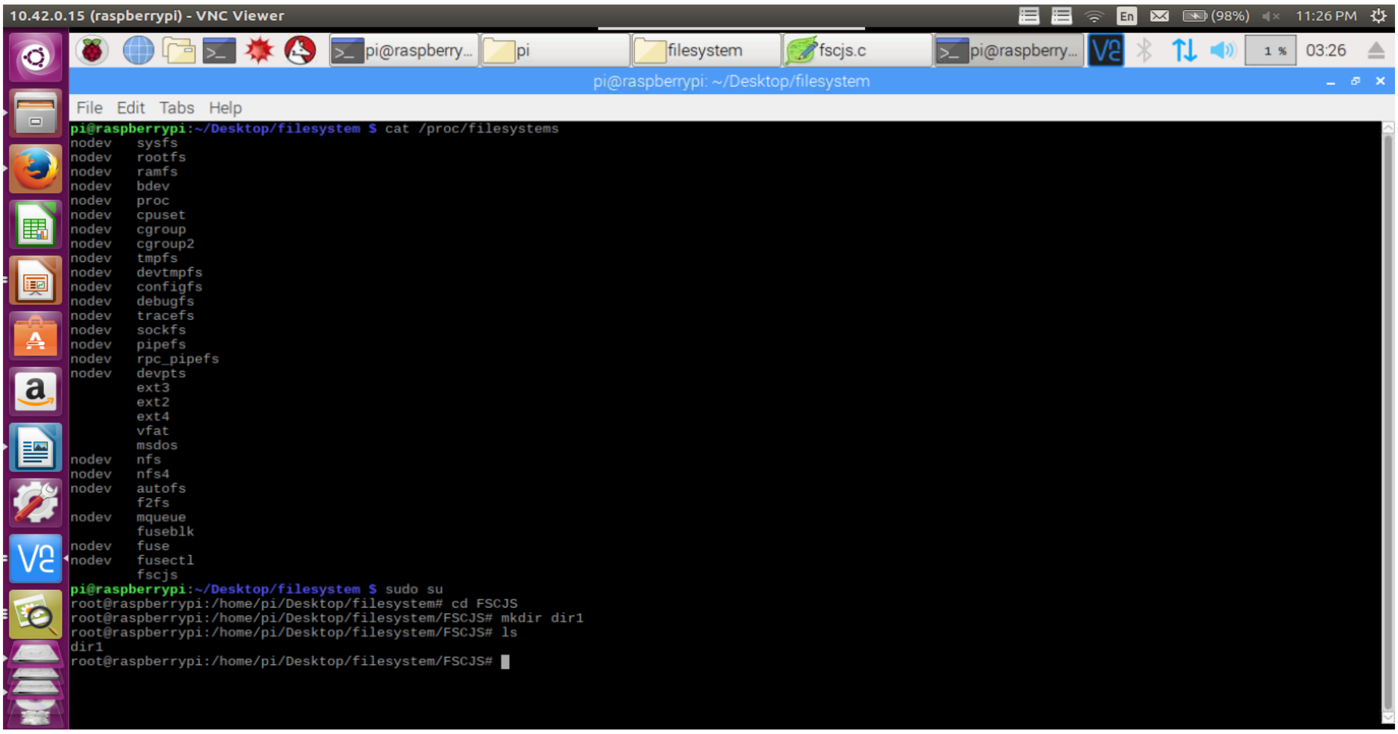
b. Inserting module.



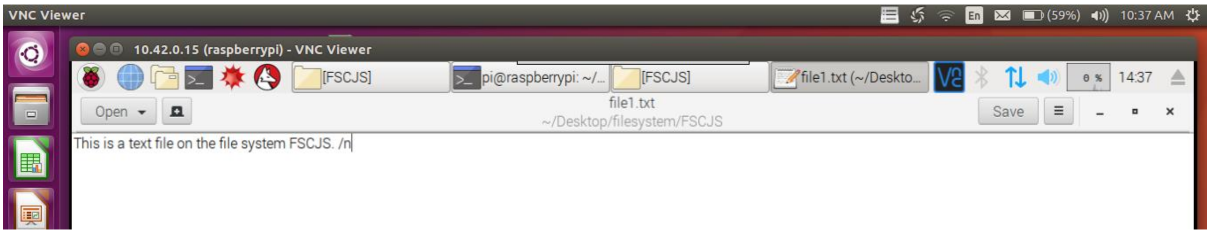
c. Mounting on kernel

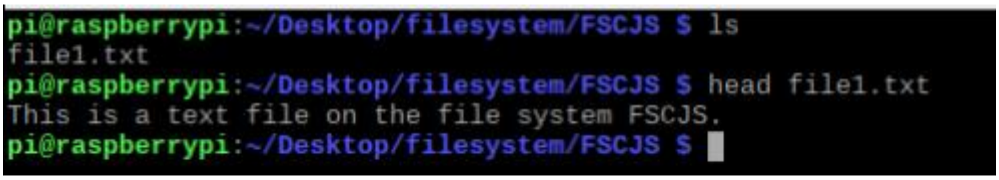


d. Creating a directory

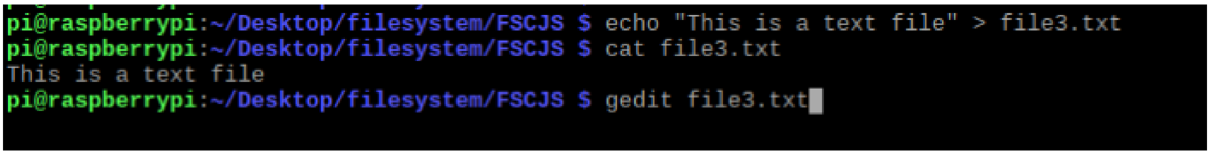


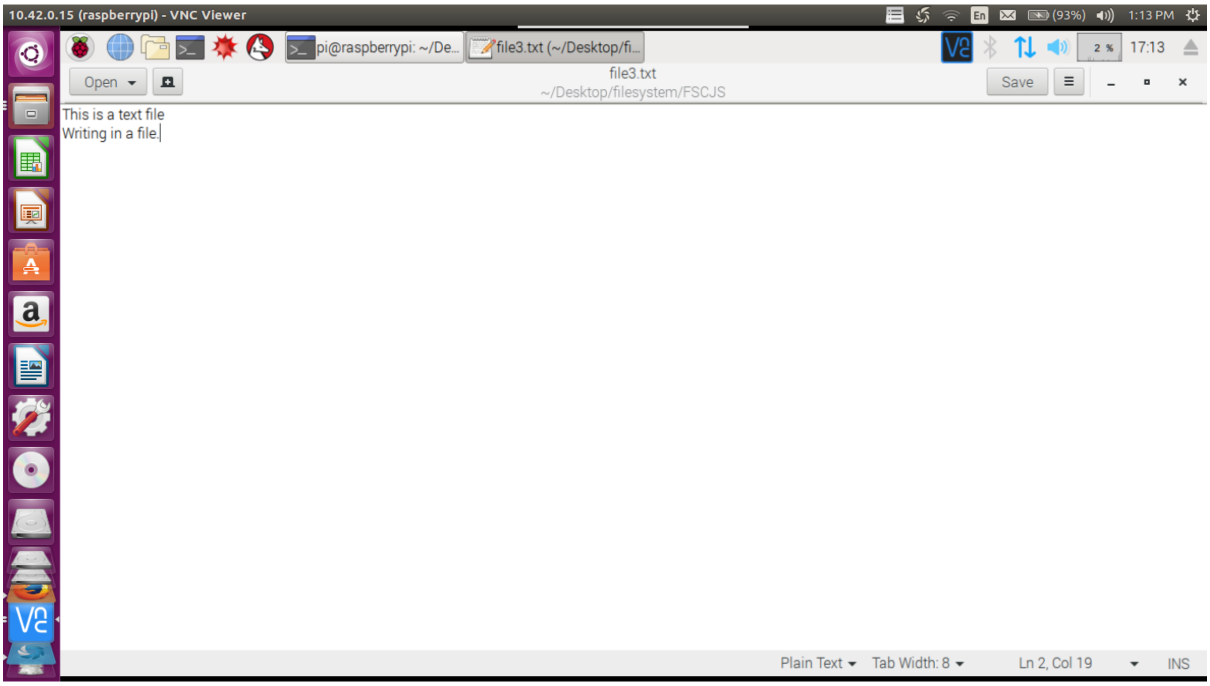
e. Creating and Reading file:





f. Writing on file:





9. Summary:

We familiarized ourselves with creation of loadable kernel modules and main structures of the file system. We also wrote a real file system, which makes use of Linux's page caching mechanisms and mounted it on Raspberry Pi.

10. References

https://www.tldp.org/LDP/lkmpg/2.6/html/lkmpg.html
https://kukuruku.co/post/writing-a-file-system-in-linux-kernel/
http://www.cse.wustl.edu/~cdgill/courses/cse422/studios/01_RPi3_setup.html
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http://www.cse.wustl.edu/~cdgill/courses/cse422//studios/21_vfs.html