CS2106: Operating Systems
Lab 5 – USFAT File System

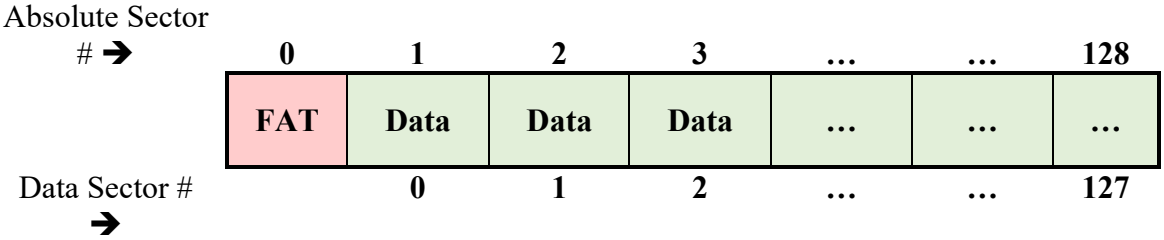
Important:
- The deadline of submission on LumiNUS is **May 6th 2020, 8pm**
- The total weightage is 4 marks:
  - Exercise 1: 1.5 marks
  - Exercise 2: 2.5 marks

This is an easy lab with a relaxed deadline to celebrate the end of an unusually hectic semester. Students interested in more challenging work should try to solve optional (not graded) exercises in Section 2.4.

Section 1. USFAT File System Overview

USFAT is a **fictional** file system invented for CS2106 that draws inspirations from the basic FAT-based file allocation scheme and the MS-DOS FAT16 file system. Your task in this lab is to understand and provide functionalities that interact with the underlying USFAT file system.

1.1 USFAT File System Layout



Note that a "logical block" is the same size as a "sector" in USFAT and we use the two terms interchangeably.

There are a total of 129 sectors (with absolute index 0 to 128) and each sector contains 256 bytes. So, a typical USFAT file system is 129 * 256 = 33,024 bytes in size. The FAT table **occupies one sector** and is located at sector 0. All remaining sectors (128) are used for data storage.

Each FAT entry is **2 bytes** in size, i.e., the FAT contains 256 / 2 = 128 entries. Note that the FAT index refers only to blocks in the file data region. For ease of reference (and coding), we will use **data sector number** to indicate sectors in the data region. For example, the status of data sector 2 can be found in FAT[2], but the actual storage on the "hard disk" is at sector 3. So, pay attention to whether you are using the data

sector number or the absolute sector number in your code to avoid "off-by-one" errors. Each FAT entry can contain one of the following values:

Values	Meaning
0xFFFA	The sector is **free**.
0xFFF7	The sector is **bad** (i.e. not working, don't store any content here).
0xFFFF	The sector is the **END** of a linked sector chain.
0x0000 to 0x007F	The sector leads to the indicated sector as part of a linked sector chain.

Here's a sample FAT printout:

```
offset: +00  +01  +02  +03   +04  +05  +06  +07
-----------------------------------------------
0x0000: FREE FREE FREE FREE  FREE END* FREE 003f
0x0008: 0009 000a 0056 FREE  FREE FREE FREE 0010
0x0010: 0011 0012 0013 0014  0008 FREE FREE FREE
0x0018: FREE FREE FREE FREE  END* FREE FREE 0020
0x0020: 006e FREE FREE FREE  FREE FREE FREE FREE
0x0028: FREE FREE FREE FREE  FREE FREE FREE FREE
0x0030: FREE FREE FREE FREE  FREE FREE FREE FREE
0x0038: FREE FREE FREE FREE  0055 003e 001c 0040
0x0040: 0041 0042 000f FREE  FREE FREE 0047 0048
0x0048: 0049 004a 004b 004c  END* FREE FREE FREE
0x0050: FREE FREE FREE FREE  FREE 005c 0057 0058
0x0058: 0059 005a 005b 003c  005d 005e 005f 0060
0x0060: 0062 END* 0063 0064  0065 0066 0067 0068
0x0068: 0069 006a 006b 006c  006d 001f 006f 0070
0x0070: 0071 0072 0073 0074  END* FREE FREE FREE
0x0078: FREE FREE FREE 007c  003d FREE FREE FREE
```

From the FAT printout above, we can see that the data sector 0x0000 is free; the data sectors 0x004a→0x004b→0x004c (end) is **part** of a linked sector chain, etc.

1.2 Directory (Folder) and File under USFAT

Under USFAT, directory and file both use the file data sectors to store information. For a directory, the data sector stores **directory entries**, which contains information about **files under** that directory. For a file, the data sector stores the **actual file content**.

For simplicity, the USFAT media provided in this lab has the following limitations:

- There is only one directory, the **Root Directory**. It is located at **data sector 5**.
- Directory uses **only 1** sector for its directory entries, which place an upper limit on the number of files it can store.
- Your code only needs to work with these limitations in place.

Note: the above limits are imposed to simplify the exercises, the design of the USFAT is much more general / flexible.

Each of the directory entry in a directory's data sector occupies **32 bytes** and has the following layout:

Offset	**0**	**…**	**10**	**11**	**12**	**…**	**25**	**26**	**27**	**28**	**…**	**31**
Usage	**Name**			**Attr**	**<not used>**			**Start Sector**		**File Size**		

The name uses the old "8+3" format, where the file name is 8 characters long and the extension takes up 3 characters, e.g., a file with name "`sample.cc`" is stored as:

0	1	2	3	4	5	6	7	8	9	10
␣	␣	**S**	**a**	**m**	**p**	**l**	**e**	**c**	**c**	␣

Note that the filename is right-aligned to the "." while the extension is left-aligned. The "." itself is **not stored**. We use '␣' to represent a blank space (' ').

The attribute is a single byte (8 bits):

Bit	7	6	5	4	3	2	1	0
Usage				**Is directory?**		**Is System?**	**Is Hidden?**	**Is Readable?**

For our exercises, you can assume that **all files have an attribute value of 0x01**, which stands for readable, not hidden, not a system file and not a directory.

Since each directory entry is 32 bytes and the directory in USFAT can utilize only 1 sector for directory entries, this gives us 256 bytes / 32 bytes = 8 files under a single directory **at most**.

1.3 USFAT "Media", Library Calls and Utility Program

There are a number of “disk image” files provided for this lab, e.g. ***4files.img, empty.img***, etc. Each of the file represents a complete USFAT file system. You can imagine they represent simulated storage media like a hard disk, etc.

A **large number** of library calls are provided for you to focus on “high-level” file system functionalities. In the common/ directory, take a look at the **`USFAT.h`** header files which defines all important system parameters and the available library calls. Essentially, “low-level” functionalities that deals with reading/writing information from/to the media (e.g., sector/FAT reading/writing) are available for use.

In addition, a “debug inspector” program, known as USFATI (USFAT *Inspector*) is also available so that you can view the raw content on a USFAT media easily. Instructions to setup the *Inspector* is given in Section 2.

Section 2. Exercises for USFAT

2.1 Directory structure of the skeleton code

There is one additional folder ***common/*** with the following files:

Filename	Purpose
`USFAT.h`	USFAT header file with all key definitions and declarations.
`USFAT_Util.c`	Implementation of all USFAT library functions.
`USFAT_Insepct.c`	The debug inspector utility program. Compiles into the "`USFATI`" executable.
Various `*.img`	Backup copies of all USFAT disk images. **In exercise 2, your program will modify the USFAT disk image**, so if you ever need to "reset" the disk images, copy the backup over.
`makefile`	For compiling the USFATI debug inspector as mentioned above. reset.sh: A simple script file to copy the backup images to the exercise directories.

Preparation:

1. Go into the common/ folder and type "`make`" to produce the USFATI executable.
2. Enable the "`reset.sh`" script file by "`chmod 700 reset.sh`"
3. Execute the "`reset.sh`" script file "`./reset.sh`", this copy a fresh set of disk images to the exercise directories. Use this step whenever you need to reset your disk images.

2.2 Exercise 1 (1.5 marks)

Main task: Display the file content of a file under the root directory.

The main function is already written for you. The main function will repeatedly print the directory content of the root directory (i.e. similar to a "`ls`"), then prompt the user for a file to display (i.e. similar to a "`cat`" / "`less`" command). Your task is to implement the function "`read_file( FAT_RUNTIME* rt, char filename[])`" which returns:

- **0** if the file with `filename` cannot be found under the root directory.
- **1** if the operation is successful.

This function attempts to locate the directory entry for the file *filename*, then read **all** data sectors of this print and print them to the screen. **Note: use the** *`print_as_text()`* **function when you need to print out the content of a file data sector.** This ensure your output format is exactly the same as ours to facilitate checking.

Key criteria for evaluation:

- Entire content of the file should be shown. This requires you to follow the "*linked sector chain*" by traversing in the FAT……
- Note that the last sector may not be full! You need to print out **only the valid content**. (hint: use file size…..).
- You are allowed to define as many helper functions as you need.
- You can add / change the parameter(s) of the *`read_file()`* function if needed.
- The main function should not be changed except the function call to *`read_file()`* can be modified with new parameters if you change them.

Sample Output (using **4files.img**, user input in **bold**, file content in **red**):

```
  Filename      Attr      Start      Size
-------------------------------------
     fat.txt 01 <file> [0x0067]   1563
 mystery.abc 01 <file> [0x003a]   1092
   hello.c   01 <file> [0x007e]     74
    rain.txt 01 <file> [0x0042]  12194
Read File ("DONE" to quit) > hello.c
#include <stdio.h>

int main()
{
        printf("Hello World!\n");

        return 0;
}

  Filename      Attr      Start      Size
-------------------------------------
     fat.txt 01 <file> [0x0067]   1563
```

Note that only 74 bytes of "`hello.c`" are valid out of 256 bytes in the sector.

```
 mystery.abc 01 <file> [0x003a]   1092
   hello.c   01 <file> [0x007e]     74
    rain.txt 01 <file> [0x0042]  12194
Read File ("DONE" to quit) > hi.txt
"hi.txt" not found!
  Filename     Attr     Start     Size
--------------------------------------
     fat.txt 01 <file> [0x0067]   1563
 mystery.abc 01 <file> [0x003a]   1092
   hello.c   01 <file> [0x007e]     74
    rain.txt 01 <file> [0x0042]  12194
Read File ("DONE" to quit) > mystery.abc
#include <stdio.h>
#include <stdlib.h>
#include <string.h>
...... <Some file content omitted to save space> ......
        }

        fclose(fat_rt.media_f);

        return 0;
}

  Filename     Attr     Start     Size
--------------------------------------
     fat.txt 01 <file> [0x0067]   1563
 mystery.abc 01 <file> [0x003a]   1092
   hello.c   01 <file> [0x007e]     74
    rain.txt 01 <file> [0x0042]  12194
Read File ("DONE" to quit) > DONE
```

There is no "hi.txt" in the root

The entire "mystery.abc" is printed.

To aid your checking, the original files "fat.txt", "mystery.abc", "hello.c" and "rain.txt" (as well as a number of other text files) are included in the exercise folder.

2.3 Exercise 2 (2.5 marks)

Main task: Import a normal file into the USFAT file system.

Similar to exercise 2, the main function is already coded for you. You only need to provide the implementation of the `import_file()` function. This function returns:

- **-1:** if there is any error. Full error lists is given below. OR
- **Non-negative value:** Actual number of bytes copied over.

To facilitate explanation, let us assume we make the following call using the given function prototype:

```
import_file( &runtime, "example.txt",  25 );
```

The function should perform the following checks:

- Ensure the normal file "`example.txt`" can be opened. You can assume the filename given by user follows the "8+3" filename restriction.
- Ensure the root directory of the USFAT media **does not** have another file with the same filename as "`example.txt`" as filename should be unique under a directory.
- Ensure the root directory is **not full**, i.e. has less than 8 files currently.
- If any of the above fails, the function returns "`-1`".
- Once checks are all cleared, the function will now attempt to copy the "`example.txt`" into the data sectors.
- The function will **try** to use the first sector as specified (data sector `25`) in this example. If the sector is free, copying can start there. Otherwise, you should check subsequent data sectors (e.g. `26`, `27`, `28` …..) and wraps around if needed. If there are no free data sector, the function terminates and return `-1`.
- Once copying starts, data sector chain needs to be constructed if you need more than one data sector. The logic for getting the next sector is the same: look for the free data sector in the subsequent indices and wrap around if needed. **Remember to modify the FAT entries accordingly as you move along**.
- Copy stops when i) the input file e.g. "`example.txt`" has been copied fully OR, ii) there are no more free data sectors. **Remember to "terminate" your sector chain by setting the END flag in the FAT.**
- The function will also add a new directory entry with the right information into the root directory.
- **Don't forget to flush the FAT into the actual USFAT media.**
- Finally, the function returns the total number of bytes copied to the caller.
- Note that this exercise **changes the disk images**. Use "`common/reset.sh`" to restore the images if needed.

Hints and Tips:

- Browse the library calls. You have **many** helpful functions.
- Define useful helper functions to keep your code manageable.
- Our sample solution is only about 120+lines (with newlines, debug code, comments included).
- You can use your `ex1.c` to check whether the files are imported properly.
- Use the utility program `USFATI` to monitor the changes of sectors.

Sample Output (using **`empty.img`**, user input in **bold**, notable key info in **red**).

The **`empty.img`** is an empty USFAT media with **only the root directory taking up data sector 5** at the beginning.

```
  Filename      Attr      Start      Size
--------------------------------------
Import File ("DONE" to quit) > hi.c
Start sector (in Hex) > 0x0
Import "hi.c" to [0x0000] Data Sector...FAILED!
  Filename      Attr      Start      Size
--------------------------------------

Import File ("DONE" to quit) > hello.c
Start sector (in Hex) > 0x5
Import "hello.c" to [0x0005] Data Sector...Written 74 bytes.
  Filename      Attr      Start      Size
--------------------------------------
   hello.c    01 <file> [0x0006]      74

Import File ("DONE" to quit) > hello.c
Start sector (in Hex) > 0x4A
Import "hello.c" to [0x004a] Data Sector...FAILED!
  Filename      Attr      Start      Size
--------------------------------------
   hello.c    01 <file> [0x0006]      74

Import File ("DONE" to quit) > fat.txt
Start sector (in Hex) > 0x2f
Import "fat.txt" to [0x002f] Data Sector...Written 1563 bytes.
  Filename      Attr      Start      Size
--------------------------------------
   hello.c    01 <file> [0x0006]      74
     fat.txt  01 <file> [0x002f]    1563

Import File ("DONE" to quit) > mystery.abc
Start sector (in Hex) > 0x0
```

"**`Hi.c`**" doesn't exist.

Data sector 5 is occupied, so next available sector (i.e. 6) is used.

There is already a "**`hello.c`**" ➔ import failed.

```
Import "mystery.abc" to [0x0000] Data Sector...Written 1092
bytes.
  Filename      Attr      Start      Size
-------------------------------------------
   hello.c    01 <file> [0x0006]      74
     fat.txt  01 <file> [0x002f]    1563
 mystery.abc  01 <file> [0x0000]    1092

Import File ("DONE" to quit) > alice.txt
Start sector (in Hex) > 0x4A
Import "alice.txt" to [0x004a] Data Sector...Written 29184
bytes.
  Filename      Attr      Start      Size
-------------------------------------------
   hello.c    01 <file> [0x0006]      74
     fat.txt  01 <file> [0x002f]    1563
 mystery.abc  01 <file> [0x0000]    1092
   alice.txt  01 <file> [0x004a]   29184

Import File ("DONE" to quit) > DONE
```

Both "**fat.txt**" and "**mystery.abc**" are imported fully. You can verify their file size.

The USFAT disk is almost full at this point and can only stores 29,184 bytes out of the full 177,428 bytes for "**alice.txt**"

The FAT table (use USFATI to inspect) should looks like the following afterwards:

```
Offset: +00  +01  +02  +03   +04  +05  +06  +07
-----------------------------------------------
0x0000: 0001 0002 0003 0004  END* END* END* 0008
0x0008: 0009 000a 000b 000c  000d 000e 000f 0010
0x0010: 0011 0012 0013 0014  0015 0016 0017 0018
0x0018: 0019 001a 001b 001c  001d 001e 001f 0020
0x0020: 0021 0022 0023 0024  0025 0026 0027 0028
0x0028: 0029 002a 002b 002c  002d 002e 0036 0030
0x0030: 0031 0032 0033 0034  0035 END* 0037 0038
0x0038: 0039 003a 003b 003c  003d 003e 003f 0040
0x0040: 0041 0042 0043 0044  0045 0046 0047 0048
0x0048: 0049 END* 004b 004c  004d 004e 004f 0050
0x0050: 0051 0052 0053 0054  0055 0056 0057 0058
0x0058: 0059 005a 005b 005c  005d 005e 005f 0060
0x0060: 0061 0062 0063 0064  0065 0066 0067 0068
0x0068: 0069 006a 006b 006c  006d 006e 006f 0070
0x0070: 0071 0072 0073 0074  0075 0076 0077 0078
0x0078: 0079 007a 007b 007c  007d 007e 007f 0007
```

Some notable observations:

- "**Hello.txt**" is in sector 6, where the FAT entry is indicated with the END flag as it occupies only 1 sector.
- "**Mystery.abc**" starts from sector 0, follow the linked sector list to understand the requirement better (use adjacent if possible, otherwise search forward for free sector).

2.4 Optional exercises for your exploration (not graded)

If you have the curiosity (and time) to explore further, we suggest a few exercises:

1. Expand the directory to use multiple sectors. This removes the 8 files per directory limitation. Your code in ex2 can help.
2. Implement subdirectory (rather straightforward actually).
3. With (2), extend ex2 and ex3 to support subdirectory, i.e. read file with full path "**`/dir1/dir2/example.txt`**", import file for deeper directory structure etc.
4. Extend the USFAT interface and implementation to support the following RAID schemes, and analyze their benefits and shortcomings:
    a. 2 disks of same capacity in a RAID-0 setup
    b. 2 disks of same capacity in a RAD-1 setup
    c. 3 disks of same capacity in a RAID-5 setup

Section 3. Submission

Zip the following files as E0123456.zip (**use your NUSNET user id!**):

`a. ex1.c` (Remember to remove all debug messages)
`b. ex2.c` (Remember to remove all debug messages)

Do not include any folder structures. Upload the zip file to the "Files → Lab Assignments → **lab5-submissions**" folder on LumiNUS. The deadline for the submission is **May 6th, 8pm**.

Please ensure you follow the instructions carefully (**output format**, how to zip the files, etc). **Deviations will be penalized.**

Reference:

1. "Design of the FAT file system" (a nice read – much deeper than you'll need) https://en.wikipedia.org/wiki/Design_of_the_FAT_file_system
2. "Standard RAID levels" https://en.wikipedia.org/wiki/Standard_RAID_levels