University of Washington Bothell
CSS503: System Programming
Program 3
C++ Standard I/O Library

1. Purpose

In this programming assignment you will design and implement your own core input and output functions of the C/C++ standard I/O library: stdio.h.

2. Linux I/O

Unix provide system calls for file I/O such as open(), read(), write(), and lseek(). However, these system calls are not supported on non-Unix based systems such as Window. Therefore, the C/C++ standard I/O library was created so that applications which require these functions can be easily ported through recompilation across these systems.

3. C/C++ Standard I/O Library Overview

The standard I/O library is an architecture independent library that allows C/C++ programs to read and write files instead of directly calling the underlying OS system calls. The library's functions add buffering and provide a user-friendly file stream interface (FILE *). The file stream interface is implemented by the standard I/O library utilizing the underlying system calls. When reading and/or writing small byte-counts (e.g., reading one line at a time from a file), buffered functions are faster.

The read() and write() system calls operate on file descriptors and read/write from/to buffers not strings. A file descriptor is just an integer referring to a currently open file. The OS uses that number as an index into the file descriptor table of files currently in use to access the actual device (e.g., disk, network, terminal).

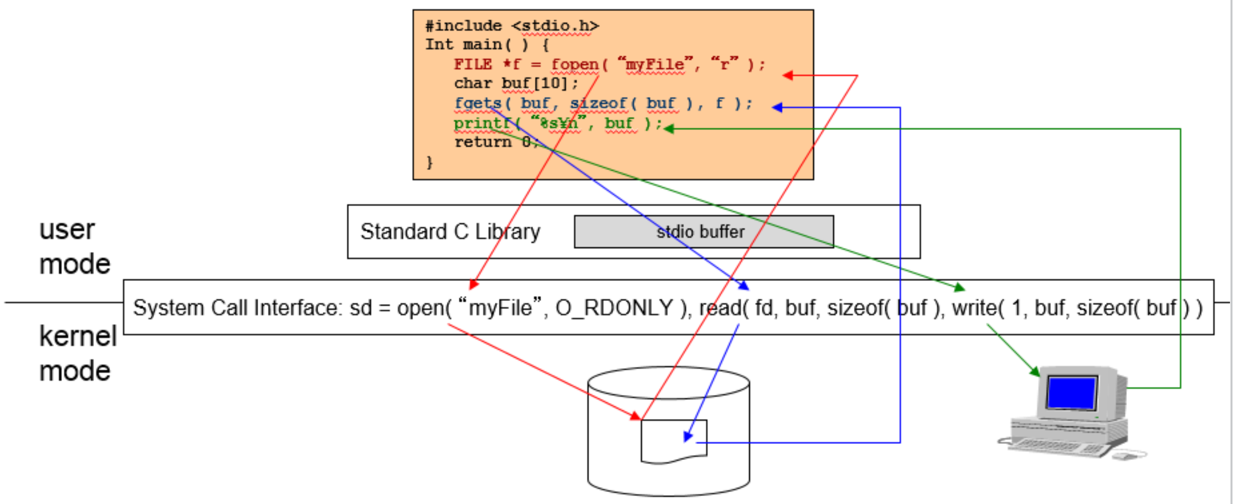
On the other hand, file streams operators (fread/fwrite) interact directly with file streams: FILE *. File streams are dynamically allocated and allow reading/writing raw data. File stream operators, fread() and fwrite(), use the type void * since there are no data-specific requirements.

The core input and output functions defined in <stdio.h> include:

Function name	**Description**
`fopen`	opens a file
`fflush`	synchronizes an output stream with the actual file

`setbuf, setvbuf`	sets the size of an input/output stream buffer
`fpurge`	clears an input/output stream buffer
`fread`	reads from a file
`fwrite`	writes to a file
`fgetc`	reads a character from a file stream
`fputc`	writes a character to a file stream
`fgets`	reads a character string from a file stream
`fputs`	writes a character string to a file stream
`fseek`	moves the file position to a specific location in a file
`feof`	checks for the end-of-file
`fclose`	closes a file
`printf`	prints formatted output to stdout

Figure 1 below shows how the standard I/O library utilizes a buffer to reduce the number of read and write system calls with filestreams.



```
#include <stdio.h>
Int main( ) {
   FILE *f = fopen( "myFile", "r" );
   char buf[10];
   fgets( buf, sizeof( buf ), f );
   printf( "%s¥n", buf );
   return 0;
}
```

Standard C Library
stdio buffer
user mode
kernel mode
System Call Interface: sd = open("myFile", O_RDONLY), read(fd, buf, sizeof(buf), write(1, buf, sizeof(buf))

Figure 1. This figure shows Standard I/O functions using FILE instead of file descriptor.

4. FILE Data Structure and fopen()

Upon a file open, fopen() returns a pointer to a FILE object that maintains the attributes of the opened file.

On canvas is posted a version of the header file we will use for the project. The following shows the class FILE definition :

```
#ifndef _MY_STDIO_H_
#define _MY_STDIO_H_

#define BUFSIZ 8192 // default buffer size
#define _IONBF 0    // unbuffered
#define _IOLBF 1    // line buffered
#define _IOFBF 2    // fully buffered
#define EOF -1      // end of file

class FILE
{
 public:
  FILE() :
    fd(0), pos(0), buffer((char *)0), size(0 , actual_size(0),
    mode(_IONBF), flag(0), bufown(false), lastop(0), eof(false) {}

  int fd;           // a Unix file descriptor of an opened file
  int pos;          // the current file position in the buffer
  char *buffer;     // an input or output file stream buffer
  int size;         // the buffer size
  int actual_size;  // actual buffer size when read() returns # bytes smaller than size
  int mode;         // _IONBF, _IOLBF, _IOFBF
  int flag;         // O_RDONLY
                    // O_RDWR
                    // O_WRONLY | O_CREAT | O_TRUNC
                    // O_WRONLY | O_CREAT | O_APPEND
                    // O_RDWR   | O_CREAT | O_TRUNC
                    // O_RDWR   | O_CREAT | O_APPEND
  bool bufown;      // true if allocated by stdio.h or false by a user
  char lastop;      // 'r' or 'w'
  bool eof;         // true if EOF is reached
};
#include "stdio.cpp"
#endif
```

When opening a file, the fopen() function receives not only the file name to open but also various file access modes:

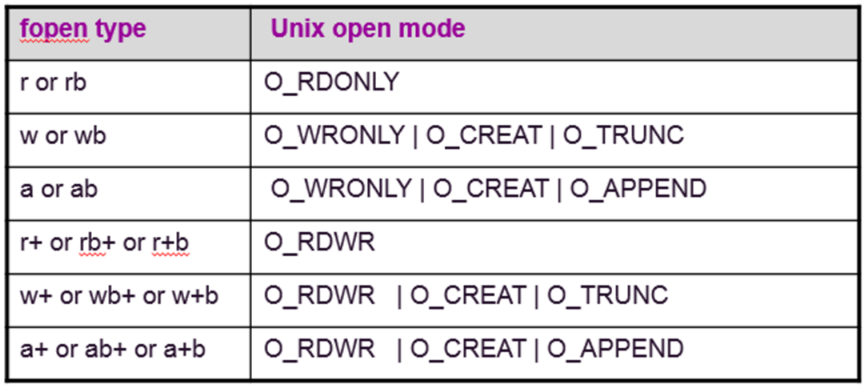
r	Open text file for reading.
r+	Open for reading and writing.
w	Truncate file to zero length or create text file for writing.
w+	Open for reading and writing. The file is created if it does not exist, otherwise truncated.
a	Open for appending (writing at end of file). The file is created if it does not exist.
a+	Open for reading and appending (writing at end of file). The file is created if it does not exist. The initial file position for reading is at the beginning of the file, but output is always appended to the end of the file.

The fopen() function must:

- instantiate a FILE object
- initialize it according to the file modes
- allocate a file stream buffer within the FILE object

- open a file using the corresponding OS system call, (e.g., open in Unix)

Binary vs. text files: Linux doesn't differentiate between text and binary files, so 'b' type for fopen() has no effect



fopen type	Unix open mode
r or rb	O_RDONLY
w or wb	O_WRONLY | O_CREAT | O_TRUNC
a or ab	O_WRONLY | O_CREAT | O_APPEND
r+ or rb+ or r+b	O_RDWR
w+ or wb+ or w+b	O_RDWR | O_CREAT | O_TRUNC
a+ or ab+ or a+b	O_RDWR | O_CREAT | O_APPEND

Figure 2. Differences between file-opening modes using stdio.h functions vs. system calls.

5. Our stdio.cpp File

In addition to stdio.h, you will also find stdio_template.cpp on Canvas to support with this program. The file stdio_template.cpp has already implemented: **printf, setvbuf, setbuf, fopen,** and **feof**.

Note that printf accepts only %d, and that the other functions are partially implemented -- just enough to be able to run the driver and performance test programs. No need to implement the rest of the function.

Also on canvas are the files driver.cpp and eval.cpp. These should not be modified and are only used to test your implementation of stdio. They should include “stdio.h”; they don't need to be aware of the existence of “stdio.cpp”. Note that “stdio.cpp” is included at the bottom of “stdio.h”, so that it is possible to compile a user program like this:

```
% g++ driver.cpp
% g++ eval.cpp
```

6. Statement of Work

Step 1: Copy the source code and compile script from canvas to a Linux system.
Files: compile.sh, eval.cpp, driver.cpp, stdio.h and stdio_template.cpp

Step 2: Rename stdio_template.cpp to stdio.cpp. Implement all missing functions; noted by, “//complete it” in the file.

Step 3: Build the eval and driver executables using the compile.sh build script.

Step 4: Test your implementation of stdio.h using the driver executable and the texts provided on canvas: hamlet.txt, othello.txt, test1.txt, test2.txt, test3.txt.

- Execute: `./driver hamlet.txt > output_hamlet.txt`
  Compare output_hamlet.txt, test1.txt, test2.txt, test3.txt to versions on canvas
- Execute: `./driver othello.txt > output_othello.txt`
  Compare output_othello.txt, test1.txt, test2.txt, test3.txt to versions on canvas

Step 5: Test your implementation of stdio.h using the eval executable by running the following commands:

./eval r u a hamlet.txt	read hamlet.txt with unix I/O at once.
./eval r u b hamlet.txt	read hamlet.txt with unix I/O every 4096 bytes.
./eval r u c hamlet.txt	read hamlet.txt with unix I/O one by one character.
./eval r u r hamlet.txt	read hamlet.txt with unix I/O with random sizes.
./eval r f a hamlet.txt	read hamlet.txt with your stdio.cpp at once.
./eval r f b hamlet.txt	read hamlet.txt with your stdio.cpp every 4096 bytes.
./eval r f c hamlet.txt	read hamlet.txt with your stdio.cpp one by one character.
./eval r f r hamlet.txt	read hamlet.txt with your stdio.cpp with random sizes.
./eval w u a test.txt	write to test.txt with unix I/O at once.
./eval w u b test.txt	write to test.txt with unix I/O every 4096 bytes.
./eval w u c test.txt	write to test.txt with unix I/O one by one character.
./eval w u r test.txt	write to test.txt with unix I/O with random sizes.
./eval w f a test.txt	write to test.txt with your stdio.cpp at once.
./eval w f b test.txt	write to test.txt with your stdio.cpp every 4096 bytes.
./eval w f c test.txt	write to test.txt with your stdio.cpp one by one character.
./eval w f r test.txt	write to test.txt with your stdio.cpp with random sizes.

Step 6: Replace the first line of the eval.cpp, (i.e., "stdio.h") with <stdio.h> to use the Unix-original stdio.h rather than your own, recompile it with "./compile.sh", and rerun the eval program with the following test cases:

./eval r f a hamlet.txt	read hamlet.txt with the unix-original stdio.cpp at once.
./eval r f b hamlet.txt	read hamlet.txt with the unix-original stdio.cpp every 4096 bytes.
./eval r f c hamlet.txt	read hamlet.txt with the unix-original stdio.cpp one by one character.
./eval r f r hamlet.txt	read hamlet.txt with the unix-original stdio.cpp with random sizes.
./eval w f a test.txt	write to test.txt with the unix-original stdio.cpp at once.
./eval w f b test.txt	write to test.txt with the unix-original stdio.cpp every 4096 bytes.
./eval w f c test.txt	write to test.txt with the unix-original stdio.cpp one by one character.
./eval w f r test.txt	write to test.txt with the unix-original stdio.cpp with random sizes.

7. What to Turn in

	Criteria	**Grade**
Code	**Source code** that adheres good modularization, coding style, and an appropriate amount of comments.	5 pts

	Correctness
	Execution output that verifies the correctness of your implementation and compares your own and the Unix-original stdio.h.
	• Correct screenshots of the diff command in Step 4 comparing your output files vs. the originals
	`diff output_hamlet.txt Originals/output_hamlet.txt`
	`diff output_othello.txt Originals/output_othello.txt`
	`diff test1.txt Originals/test1.txt`
	`diff test2.txt Originals/test2.txt`
	`diff test3.txt Originals/test3.txt`
	• Screenshots of all 16 test cases in Step 5
	• Screenshots of all 8 test cases in Step 6
	
	NOTE: make sure you rename the original test files to avoid overwriting them, or place them in a subfolder, e.g., Originals
		15 pts

Report	**Documentation** of your stdio.cpp implementation including explanations and illustration in <u>one or two pages</u>.	5 pts
	Discussions <u>in one or two pages</u>. • Limitation and possible extension of your program • Performance consideration between your own stdio.h and Unix I/O • Performance consideration between your own stdio.h and the Unix-original stdio.h	5 pts
	Total	30 pts

Notes/FAQ

1) Question: How are we to handle the myriad of potential errors when implementing these functions? Are we supposed to output specific error codes in line with how <stdio.h> does?
Answer: You don't need to handle all the errors stdio.h does, this is a minimalistic version of stdio.h

2) Question: Both reference files *output_hamlet.txt* and *output_othello.txt* files have multiple lines containing **writeBuffer = 8192.** Is this correct? Should my stdio library generate that line?
Answer: The "writeBuffer = 8192" is just for reference; you do not need to print it out. There is no requirement that your output contain any "writeBuffer" lines. If you want you can add them in just to make it easier to compare with the sample output, but this is not necessary. If you do add it in, it doesn't need to reflect anything about the state of the program - you can just add some hardcoded "cout << "writeBuffer = 8192";" lines to wherever you need to to replicate the sample output.

3) Question: I'm getting all kinds of "redefinition" compiler errors. For example, "Redefinition of printf". Should I be renaming my stdio.cpp and stdio.h to mystdio.cpp and mystdio.h to avoid these errors?
Answer: No, you can just do the following in your stdio.h

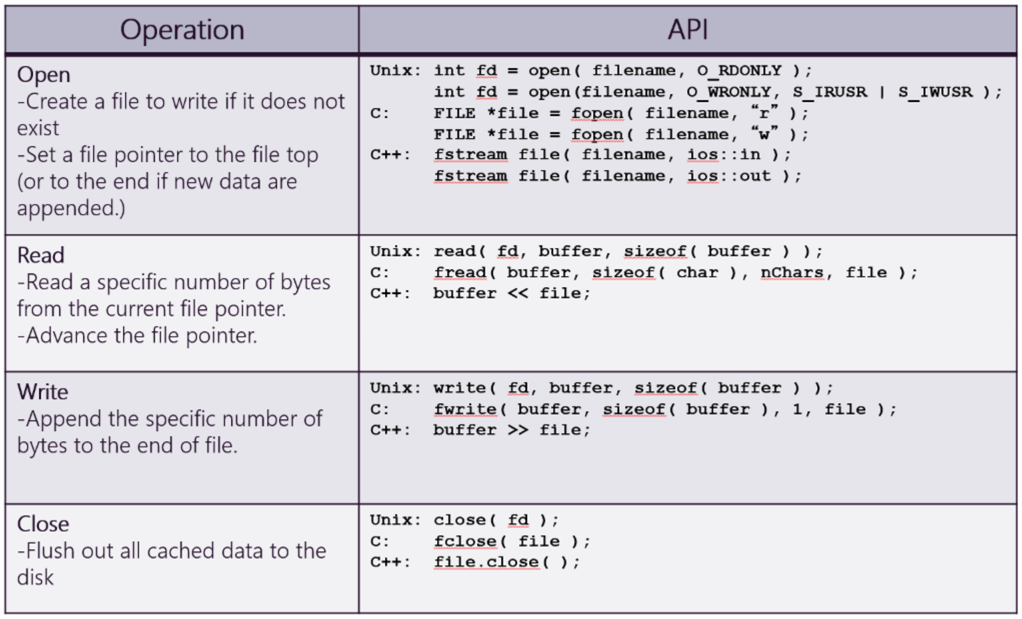
```
#ifndef _MY_STDIO_H_
#define _MY_STDIO_H_
```

And don't forget to include it `#include "stdio.h" // my stdio.h file`

4) Question: Is there only one buffer for both reading and writing or can we have 2 buffers?
Answer: Only one buffer is used

5) Question: Are the files test1, test2, test3 the same.
Answer: yes (it is weird but historically, they've always been like this), so use them as they are. The only difference is at the bottom of test3

6) Question: What are the common I/O system calls?
Answer: The following table shows a summary of common I/O operations open, read, write and close and their corresponding APIs as system calls and C/C++.



Operation	API

Open
-Create a file to write if it does not exist
-Set a file pointer to the file top (or to the end if new data are appended.)
	`Unix: int fd = open( filename, O_RDONLY );`
	`      int fd = open(filename, O_WRONLY, S_IRUSR | S_IWUSR );`
	`C:    FILE *file = fopen( filename, “r” );`
	`      FILE *file = fopen( filename, “w” );`
	`C++:  fstream file( filename, ios::in );`
	`      fstream file( filename, ios::out );`

Read
-Read a specific number of bytes from the current file pointer.
-Advance the file pointer.
	`Unix: read( fd, buffer, sizeof( buffer ) );`
	`C:    fread( buffer, sizeof( char ), nChars, file );`
	`C++:  buffer << file;`

Write
-Append the specific number of bytes to the end of file.
	`Unix: write( fd, buffer, sizeof( buffer ) );`
	`C:    fwrite( buffer, sizeof( buffer ), 1, file );`
	`C++:  buffer >> file;`

Close
-Flush out all cached data to the disk
	`Unix: close( fd );`
	`C:    fclose( file );`
	`C++:  file.close( );`

Figure 3: