A2 - Assignment 2 Winter 2019

Distributed Systems (University of Waterloo)

CS 454/654 Assignments 2 and 3

Deadlines	Assignment 2	Assignment 3
Due	27 Feb 2019 (12 noon)	20 March 2019 (12 noon)
Appeal Deadline	One week from return date	One week from return date

See course webpage for TA contact/office hours

It is imperative that you start these Assignments early!

Section 1) High Level Overview

In these Assignments, you will implement the core components of WatDFS, a simplified distributed file system. WatDFS will act as a transparent layer on top of the local file system to support creating, opening, reading, writing, and closing files on remote machines. You will first implement WatDFS using a remote access model for Assignment 2 (Sections 4-9). You will implement WatDFS using a download/upload model with client-side caching for Assignment 3 (Sections 12-16).

To implement the WatDFS file system, you will integrate with FUSE, a popular library that enables the development of custom file systems. You will be given a library that sets up the FUSE functionality. You will also be given an RPC library that will provide the functionality to make procedure calls on remote servers.

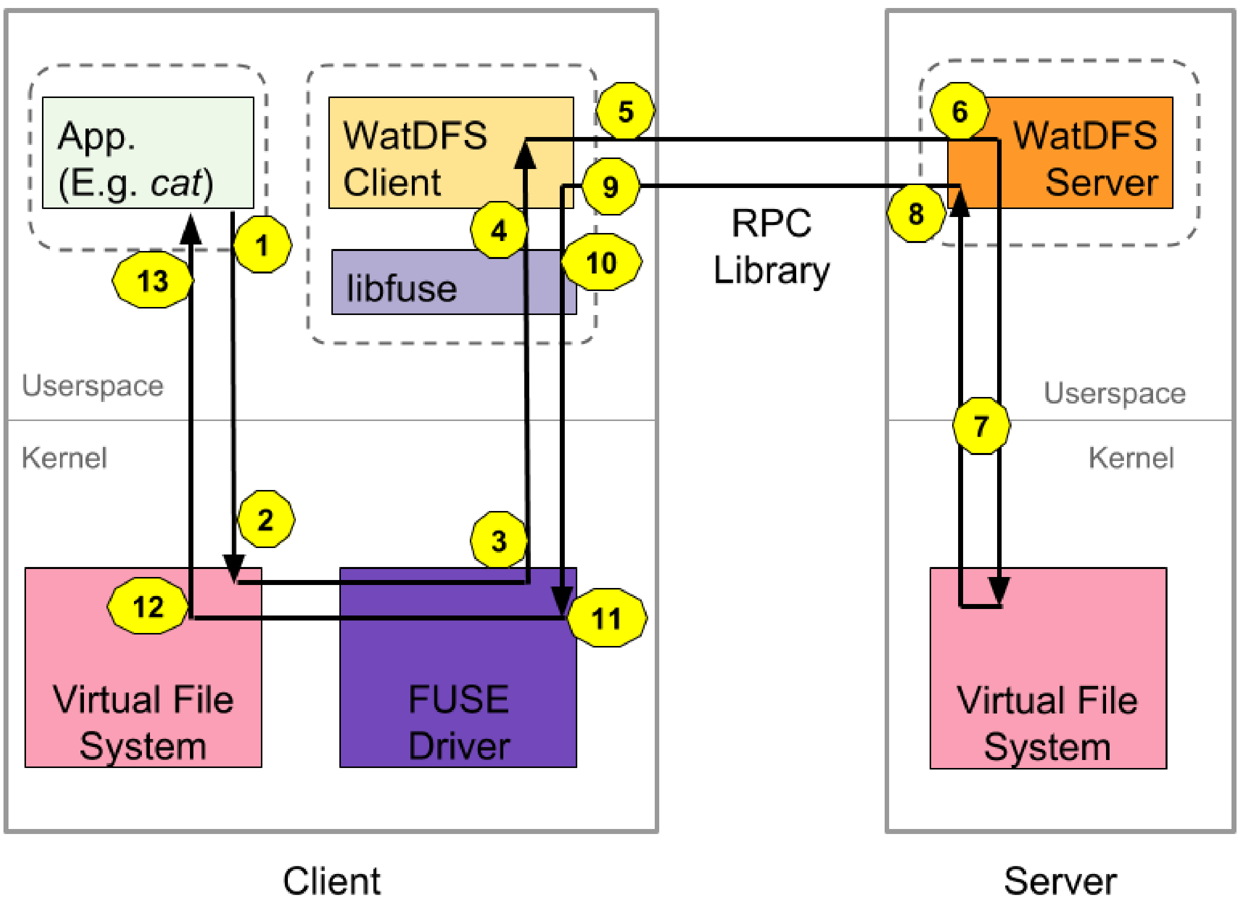
This document presents an overview of FUSE and describes how you should integrate your solution with FUSE (Sections 2-3). It also describes the API of the provided RPC library (Section 10), tips for doing the Assignments, and pointers to more resources (Section 11). ***Ensure that you read the entire document before beginning the Assignments as it contains answers to many frequently asked questions and tips to avoid common pitfalls during implementation.***

Section 2) Distributed File System Overview

Distributed file systems like Coda and NFS allow a user to interact with files that may be located on a remote server. To do so, the distributed file system must present an interface that acts as though remote files are located on the local file system, and therefore accessible through standard system calls like `open`, `close`, `read`, and `write`.

FUSE presents the interface of a standard file system, and therefore maintains access transparency. Additionally, FUSE requires no kernel code modification. FUSE consists of two parts: the FUSE kernel driver, and the library *libfuse* that integrates with the virtual file system and passes calls on to a users pace library, such as the distributed file system that you will implement.

Below is a diagram that traces the steps, with numbers using arrows, that a file system operation invoked by an application will take to reach WatDFS, as well as the actions WatDFS should take. The dashed lines indicate separate processes, the thick grey lines separate machine boundaries, and the thin grey lines separate user space from the kernel. You will be responsible for implementing the WatDFS Client and WatDFS Server components.



Steps

1) An application (e.g., `cat`) performs a file system operation by making a system call (such as `open(), close(), read(), or write()`). This system call is passed to the Linux kernel.
2) The kernel redirects the system call to the virtual file system (VFS).
3) The VFS transforms the call into an appropriate call against the file system the application wishes to access. The VFS detects the file system call is to be served by WatDFS, a FUSE-based file system. Consequently, the call is passed to the FUSE kernel driver.

4) The FUSE kernel driver delivers the call to the WatDFS client library (*libfuse*/WatDFS client implementation).
5) The WatDFS client library makes an RPC call to the WatDFS server, marshalling and sending appropriate data passed to it by the FUSE kernel driver.
6) The WatDFS server receives the RPC call, unmarshalls the data, and passes it to the WatDFS server implementation.
7) The WatDFS server makes the corresponding system call against the local file system and receives a response from the file system.
8) The WatDFS server responds to the RPC call, sending back any necessary data and a return code from the system call.
9) The RPC response is passed back to the WatDFS client library and the client library generates a response to the FUSE driver's request.
10) The WatDFS client library forwards the FUSE response to the FUSE driver.
11) The FUSE driver passes the response back to the VFS.
12) The VFS translates the file system response back into a system call response for the kernel.
13) The application receives the result of the system call.

To complete Assignments 2 and 3, you must implement steps 5-10 for various functionalities, with the assistance of the provided libraries. To test your system, you should create test applications that perform steps 1 and 13. **We will test the individual components you provide (WatDFS client library and server) in addition to complete end-to-end tests. Most of this testing will be done through automated tests. Consequently, it is imperative that you implement the Assignments *exactly* as this document specifies.**

In these Assignments, there will be only one client application (e.g. `cat`) interacting with a WatDFS client at a time.[1] However, there may be multiple WatDFS client instances that are connected to the same WatDFS server.

Integrating with FUSE requires mapping the FUSE kernel driver's calls to functions in the client WatDFS library. We have implemented this mapping, while filtering out file system calls that are not relevant to the Assignments (e.g. directory operations). Your task is to implement the WatDFS library functions needed to support key FUSE operations, which are detailed below.

Section 3) FUSE Operations to Support

To support opening, reading, writing and closing files, you will be required to support several FUSE functions that are grouped below into categories of related operations. You will need to consult the Linux `man pages` to find the corresponding system call that must be made to support each *libfuse* function. Some pointers on helpful system calls are provided in Section 11.

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[1] This is a simplifying restriction, because FUSE supports multiple client applications interacting with the same user space *libfuse* library.

We also provide links to the related *libfuse* calls that provide more details on the specifications of the functions.

Section 3.1) General Notes
In general, the calls made by FUSE should return `0` on success, or `-errno` if an error occurs.[2] If this is not the case then it will be made clear what should be returned.

The first argument to every function (`void *userdata`) is a global state pointer that can be used to store state. The `userdata` pointer is allocated by `watdfs_cli_init` (detailed below), and should allocate and initialize any global structures that you may need.[3]

libfuse always provides `path` names of the file it wishes to operate on, but using names rather than file descriptors results in more expensive lookups and metadata tracking. Therefore, some functions take a `fuse_file_info` structure. This structure has an integer member variable `fh`, which **should** be filled-in during `open`, and used afterwards to identify the file (i.e. act as a file descriptor).[4]

```
struct fuse_file_info {
     int flags; // open flags, available in open and release.
     /* other fields */
     uint64_t fh; // file handle, may be filled in by open
};
```

The `path` provided in calls is relative to the directory where FUSE is mounted.

The exact arguments to the functions have also been altered so as to add additional information to the call (e.g. `userdata`). If you are uncertain as to the types used in the functions (e.g. `mode_t`) additional information can be found by searching the *libfuse* headers or Linux headers.

Section 3.2) Initialization and Destruction

These functions set up the *libfuse* integration and are called on shutdown, respectively.

watdfs_cli_init

```
void *watdfs_cli_init(struct fuse_conn_info *conn,
```

[2] The return values of calls to libfuse are different from system calls. System calls typically return 0 on success and -1 on error. If an error occurs, then system calls set `errno` to a positive number to indicate what went wrong, and `errno` indicates the error code. (https://github.com/libfuse/libfuse/blob/cece24786e7d0a1cd2a2dc7b84ff54225d2b616f/include/fuse.h#L280-L283, http://man7.org/linux/man-pages/man3/errno.3.html)
[3] `userdata` can be a useful global structure in Assignment 3, but you will not need it in Assignment 2.
[4] Although you could implement these Assignments using only file names, and no `fuse_file_info`, you must use the `fuse_file_info` for performance and compatibility with the automated tests.

```
                             const char *path_to_cache,
                             time_t cache_interval);
```

This function is called during the initialization of the file system. The pointer that is returned will be passed to every other function call as `userdata`. This function can be used to perform a one-time set up and initialization.[5]

watdfs_cli_destroy

```
void *watdfs_cli_destroy(void *userdata);
```

This function is called when the file system is being destroyed, and should clean up any allocated structures during initialization.

Section 3.3) File Attributes

Several file system operations require metadata information about a file (e.g. file size, number of blocks) as defined by the `stat` structure. The functions below fill in the the `stat` structure by getting file attributes given in `path`.
https://github.com/libfuse/libfuse/blob/da29b950bc9d204a93706985255a299f1dfea561/include/fuse.h#L311

Important Note: *libfuse* checks the output `stat` structure (`statbuf`) to determine information about the existence of files. If the file does not exist, it is important not to fill in the `statbuf` structure.

watdfs_cli_getattr

```
int watdfs_cli_getattr(void *userdata, const char *path,
                       struct stat *statbuf);
```

watdfs_cli_fgetattr

```
int watdfs_cli_fgetattr(void *userdata, const char *path,
                        struct stat  *statbuf,
                        struct fuse_file_info *fi);
```

The `watdfs_cli_fgetattr` function differs from `watdfs_cli_getattr` by passing in the `fuse_file_info` structure, so you can use the `fi->fh` variable when making system calls.

Section 3.4) Opening and Closing

watdfs_cli_mknod

```
int watdfs_cli_mknod(void *userdata, const char *path,
```

[5] `watdfs_cli_init` is **not** responsible for starting the file system. Our provided client code will initialize and mount the FUSE file system, and then `watdfs_cli_init` will be called.

```
                      mode_t mode, dev_t dev);
```

This function is called to create a file if it does not exist.
https://github.com/libfuse/libfuse/blob/da29b950bc9d204a93706985255a299f1dfea561/include/fuse.h#L329

Important Note: If an application calls `open` and the file does not exist, `watdfs_cli_mknod` will be called and then `watdfs_cli_open` will be called.

watdfs_cli_open

```
int watdfs_cli_open(void *userdata, const char *path,
                    struct fuse_file_info *fi);
```

This function is called to open a file. As mentioned above, `fi->fh` **must be** filled in with a file handle to identify the file that has been opened. **`watdfs_cli_open` should return `0` or if an error occurs `-errno`. This return value is different from the open system call that returns a file descriptor or `-1`.**

We will only use the following flags during `open`: `O_CREAT, O_APPEND, O_EXCL, O_RDONLY, O_WRONLY, and O_RDWR.`
https://github.com/libfuse/libfuse/blob/da29b950bc9d204a93706985255a299f1dfea561/include/fuse.h#L437

Important Note: The `fuse_file_info` structure contains useful information such as the flags that the file is requested to be opened with.

Hint: You can tell whether a file is requested to be opened read only, write only, or read/write by performing a bitwise and (&) of the flags and `O_ACCMODE`
(https://www.gnu.org/software/libc/manual/html_node/Access-Modes.html)

watdfs_cli_release

```
int watdfs_cli_release(void *userdata, const char *path,
                       struct fuse_file_info *fi);
```

This function is called when FUSE is completely done with a file, generally within the `close` system call. **However, `watdfs_cli_release` is performed asynchronously**; that is, the `close` system call may complete before `watdfs_cli_release` completes. There is exactly one `watdfs_cli_release` per `open`, with the same file name, flags and file handle (`fi->fh`).
https://github.com/libfuse/libfuse/blob/da29b950bc9d204a93706985255a299f1dfea561/include/fuse.h#L504

Section 3.5) Reading and Writing

The following calls correspond to systems calls that support reading and writing data.

watdfs_cli_read

```
int watdfs_cli_read(void *userdata, const char *path, char *buf,
```

```
                         size_t size, off_t offset,
                         struct fuse_file_info *fi);
```

This function reads into `buf` at most `size` bytes **from the specified `offset`** of the file. It should return the number of bytes requested to be read, except on EOF (return the number of bytes actually read), or error (return `-errno`).
https://github.com/libfuse/libfuse/blob/da29b950bc9d204a93706985255a299f1dfea561/include/fuse.h#L448
Hint: The amount of data requested to be read may be larger then the maximum amount of data that can be used as an array argument in our RPC library (Section 10.1). You need to handle this case.
Hint: You should ensure that the buffers are sized exactly as the caller requested, not over or under provisioned.

watdfs_cli_write

```
int watdfs_cli_write(void *userdata, const char *path,
                     const char *buf, size_t size, off_t offset,
                     struct fuse_file_info *fi);
```

This function writes `size` number of bytes from `buf` into the file **at the specified `offset`**. It should return the number of bytes requested to be written, except on error (`-errno`).
https://github.com/libfuse/libfuse/blob/da29b950bc9d204a93706985255a299f1dfea561/include/fuse.h#L460
Hint: The amount of data requested to be written, may be larger than the maximum amount of data that can be used as an array argument in our RPC library (Section 10.1). You need to handle this case.

watdfs_cli_truncate

```
int watdfs_cli_truncate(void *userdata, const char *path,
                        off_t newsize);
```

This function changes the size of the file to `newsize`. If the file previously was larger than this size, the extra data is lost. If the file previously was shorter, it is extended, and the extended part is filled in with null bytes ('\0').
https://github.com/libfuse/libfuse/blob/da29b950bc9d204a93706985255a299f1dfea561/include/fuse.h#L387
Important Note: `truncate` can be called without opening the file, but should succeed if the file has been created with write permissions.

watdfs_cli_fsync

```
int watdfs_cli_fsync(void *userdata, const char *path,
                     struct fuse_file_info *fi);
```

This function should flush the file data specified by the `path` and `fi`.

https://github.com/libfuse/libfuse/blob/da29b950bc9d204a93706985255a299f1dfea561/include/fuse.h#L511

Section 3.6) Changing Metadata

watdfs_cli_utimens

```
int watdfs_cli_utimens(void *userdata, const char *path,
                       const struct timespec ts[2]);
```

This will change the file access and modification time with nanosecond resolution.
https://github.com/libfuse/libfuse/blob/da29b950bc9d204a93706985255a299f1dfea561/include/fuse.h#L650
Important note: There are different semantics based on the `ts` argument; you should read the documentation of `utimensat` http://man7.org/linux/man-pages/man2/utimensat.2.html
Hint: We guarantee that the server runs with an absolute path.

Assignment 2

Section 4) Remote Access Model (Assignment 2)

In the remote access model, every request is forwarded from the client to the server. A remote file is never stored at the client.[6]

To implement the remote access model in WatDFS, you will transform each of the described FUSE functions (Section 3) into an RPC call from the client to the server. The server will transform the RPC call into a system call and return the result to the client. The server should perform all operations on the files using appropriate system calls and should not buffer writes or cache files in memory.[7]That is, if you receive a write call, the write should be performed on the remote file server and should not be performed by keeping a copy of the file in local memory and writing to it.

In Assignment 2, the client and server should be stateless as all the information needed to perform the required operation is provided by the calling function.

The remote access model will serve as a warm up to familiarize you with FUSE, RPC calls, and the required system calls.

Section 4.1) RPC Protocol

To aid in your testing and development, the RPC calls that you should implement to satisfy the client requests are listed below with their argument types. **Each RPC requires an integer**

[6] The file will also be uncached at the client because we will be disabling client-side kernel caches. (`-o direct_io`).
[7] You do not need to worry about kernel buffering/caching at the server as part of this restriction. Your server code, however, should not buffer or cache files in memory.

(`retcode`) as an output argument, which is the return code of the function call on the WatDFS server, which you must set.

You must exactly follow this protocol specification, as the automated tests will verify it.

Important note: rather than serializing each argument in a structure `T (e.g. fuse_file_info)`, you should simply serialize the entire structure as a character array of `sizeof(T)`.

Function Name
`getattr`
Function types

Arg label	is_input	is_output	is_array	type
`path`	yes	no	yes	ARG_CHAR
`statbuf`	no	yes	yes	ARG_CHAR
`retcode`	no	yes	no	ARG_INT

Function Name
`fgetattr`
Function types

Arg label	is_input	is_output	is_array	type
`path`	yes	no	yes	ARG_CHAR
`statbuf`	no	yes	yes	ARG_CHAR
`fi`	yes	no	yes	ARG_CHAR
`retcode`	no	yes	no	ARG_INT

Function Name
`mknod`
Function types

Arg label	is_input	is_output	is_array	type
`path`	yes	no	yes	ARG_CHAR
`mode`	yes	no	no	ARG_INT
`dev`	yes	no	no	ARG_LONG

`retcode`	no	yes	no	ARG_INT

Function Name
`open`
Function types

Arg label	is_input	is_output	is_array	type
`path`	yes	no	yes	ARG_CHAR
`fi`	yes	yes	yes	ARG_CHAR
`retcode`	no	yes	no	ARG_INT

Important Note: The `retcode` for the `open` RPC call should be `0`, or `-errno`. This return value matches the expected return value of `watdfs_cli_open`, but is different from the system call `open`, which returns a file descriptor.

Function Name
`release`
Function types

Arg label	is_input	is_output	is_array	type
`path`	yes	no	yes	ARG_CHAR
`fi`	yes	no	yes	ARG_CHAR
`retcode`	no	yes	no	ARG_INT

Function Name
`read`
Function types

Arg label	is_input	is_output	is_array	type
`path`	yes	no	yes	ARG_CHAR
`buf`	no	yes	yes	ARG_CHAR
`size`	yes	no	no	ARG_LONG
`offset`	yes	no	no	ARG_LONG
`fi`	yes	no	yes	ARG_CHAR
`retcode`	no	yes	no	ARG_INT

Function Name
`write`
Function types

Arg label	**is_input**	**is_output**	**is_array**	**type**
`path`	yes	no	yes	ARG_CHAR
`buf`	yes	no	yes	ARG_CHAR
`size`	yes	no	no	ARG_LONG
`offset`	yes	no	no	ARG_LONG
`fi`	yes	no	yes	ARG_CHAR
`retcode`	no	yes	no	ARG_INT

Function Name
`truncate`
Function types

Arg label	**is_input**	**is_output**	**is_array**	**type**
`path`	yes	no	yes	ARG_CHAR
`newsize`	yes	no	no	ARG_LONG
`retcode`	no	yes	no	ARG_INT

Function Name
`fsync`
Function types

Arg label	**is_input**	**is_output**	**is_array**	**type**
`path`	yes	no	yes	ARG_CHAR
`fi`	yes	no	yes	ARG_CHAR
`retcode`	no	yes	no	ARG_INT

Function Name
`utimens`
Function types

Arg label	is_input	is_output	is_array	type
`path`	yes	no	yes	ARG_CHAR
`ts`	yes	no	yes	ARG_CHAR
`retcode`	no	yes	no	ARG_INT

Section 4.2) Notes

Recall from Section 3.2 the definition of `watdfs_cli_init:`

```
void *watdfs_cli_init(struct fuse_conn_info *conn,
                      const char *path_to_cache,
                       time_t cache_interval);
```

In Assignment 2, `path_to_cache` and `cache_interval` are not used, and should be ignored.

Section 5) Tips

You should implement functions in the following order: `getattr, mknod, open, release, fgetattr.` These will allow you to support opening and creating a file. Next you should implement: `write, read, truncate`. These will allow you to read and write data to a file. Finally implement: `utimens, fsync.`

To assist you in seeing when calls into your library have been made, we log before your functions are called, and log the return value of your calls. The logfile is stored as watdfs.log in the directory where you start your client.

Recall from Section 3.1 that *libfuse* expects functions to return `0` or `-errno`. However, most system calls (e.g. `stat`) return `0` or `-1`, and set `errno`. If a system call returns `-1`, your WatDFS server should set the retcode in the RPC call to `-errno`, and return that error to libfuse from the WatDFS client.

Section 6) Requirements (Assignment 2)

Code with Makefile and README

You are required to implement WatDFS using the Remote/Access Model as described in this specification (Section 4). In particular, you are required to implement a client library, and the server. **You must use C++ to implement your solution.**

You should write a `Makefile` that produces:

1. `libwatdfs.a:` a library containing the implementation of your client side library.
    a. **Important Note**: you should not have a `main` routine in your library; we provide it in `libwatdfsmain.a`
2. `watdfs_server:` an executable of your server

a. Your server executable should have a main function.
b. Your server must parse the command line arguments to read the directory of where to persist data (`persist_path` in the examples in Section 6.1).
c. Your server should register and execute RPC functions.

We will provide:

1. `rpc.h, watdfs_client.h`
   a. **Important Note**: you must not change these headers
2. `librpc.a`: which contains the RPC library
3. `libwatdfsmain.a`: which implements the client main and sets up FUSE

We will also provide starter code to assist you in beginning the Assignment:

1. `watdfs_client.c`: with function definitions for the required methods, and some comments.
2. `watdfs_server`.c: with a starter `main` method, and some comments
3. `Makefile` that will compile the starter code

Section 6.1) Example Test

To compile your code for a test, we will:

```
# Compile libwatdfs.a and watdfs_server
$ make
# Compile watdfs_client
$ g++ -o watdfs_client -L. -lwatdfsmain -lwatdfs -lrpc -lfuse -pthread
```

To run your code for a test, we will:

Run your server:

```
$ ./watdfs_server <server_persist_dir>
# The persist_path should be where you persist file data, this
# directory should not be located in your home directory which is
# replicated. Instead use a directory local to the machine, e.g.
# /tmp/$USER/server
# when you call rpcExecute it should print
export SERVER_ADDRESS=ubuntu1604-006
export SERVER_PORT=12345
```

Run your client:

```
$ export SERVER_ADDRESS=ubuntu1604-006
$ export SERVER_PORT=12345
$ ./watdfs_client -s -f -o direct_io <path_to_cache>
<client_mount_dir>
# path_to_cache is the directory you should cache files (A3 only)
```

```
# it is passed as path_to_cache in watdfs_cli_init.
# client_mount_dir is the directory that the system is mounted as
# all operations to this directory will flow through your library.
# As with the server, these directories should be local to the
# machine, e.g. /tmp/$USER/cache /tmp/$USER/mount
```

You can test your client with bash commands like:

```
$ touch client_mount_dir/454.txt
$ echo “454 is great!” > client_mount_dir/454.txt
$ cat client_mount_dir/454.txt # should print “454 is great!”
$ stat client_mount_dir/test.txt # should print info about the file
```

Important Note: FUSE can run a client multi-threaded. We will always run your client single threaded (-s) and with the -o direct_io flag (to disable kernel caching). Run `./watdfs_client` (no args) to see more options. For example without the (-f) flag, the client will run in the background.

Important Note: If you cannot start your client and get a mount-point error, execute the following:

```
$ fusermount -u <client_mount_dir>
```

Section 7) Submission

You should submit your Assignment on Marmoset as a single zip file for automated testing. Your Assignment zip should contain your code, Makefile and a README file. You can submit to Marmoset using the `marmoset_submit` command.

Marmoset’s build scripts require that your Makefile be titled *Makefile* and that it is placed in the root directory of your submission zip file. If the Makefile is not located in the right location, you will get a compilation error indicating that the Makefile could not be found --- **be sure when you unzip your code that the Makefile is not in a folder!**

```
$ ls
watdfs_client.c
watdfs_client.h
watdfs_server.c
rpc.h
Makefile
$ zip a2_solution.zip *
  adding: watdfs_client.c (deflated 17%)
...
# Submit a2_solution.zip to Marmoset
```

Section 7.1) More details about Marmoset

If your submitted program does not compile or run successfully on its own, your submission will receive a result of "did not compile" and the detailed test results will contain something similar to the error message you get if you ran your program yourself. In this case, your submission will not be tested with any of the tests.

If your submitted program runs successfully on its own, it will be tested with all of the public tests. If it fails any of the public tests, the detailed test results will display an error message for that public test. In this case, your submission will not be tested with any of the release tests.

If it passes all of the public tests, you will have the option to see information for the release tests. If you do so, you will use up one of your "release tokens" for that Assignment. Normally, for every Assignment, you will be initially given 5 release tokens. If you use up one or more of them, one release token will regenerate once every 24 hours. If the deadline will expire before your token regenerates, you can still submit, though you will not be able to tell how your submission did on the tests.

Marmoset automatically tests each submission with all of the release tests, in some order specified by the course staff. If your submission fails a release test and you use a token to see the results, you will see only that test and one more test in the detailed test results. If your submission passes all the release tests, you will not see any release tests in the detailed test results. If you fail a release test, you will get a very small amount of information about what went wrong. You will not be given details of the test case that you failed. **Please do not attempt to guess what that test case might be; do not ask about it on piazza, and do not speculate about test cases on Piazza. The correct action when failing a release test is to re-examine your own test suite and redesign it to find the error in your code or your assumptions.**

Important Note: `recv()` socket calls used the RPC library will hang if they anticipate receiving more data than the other side sends. If a Marmoset test “times out” it is quite likely that you are either not following the protocol for Assignment 2, or you have incorrectly used the RPC library. Be sure to check that you set the length of arguments correctly on both the client and server side!

Section 8) Evaluation (Assignment 2)

While developing your system, you should be aware that we shall be evaluating your system for the following:

1. Code compiling on linux.student.cs.uwaterloo.ca
2. README file
    a. containing build instructions or any other instructions
    b. name and student ID

3. We will be using a number of tests cases to test the following functionality (though we may add or remove particular tests):
    a. Opening or creating a file
        i. In particular we will only use the following flags: `O_CREAT, O_APPEND, O_EXCL, O_RDONLY, O_WRONLY, and O_RDWR`
    b. Writing to a file
    c. Reading from a file
    d. Getting file attributes, and updating file modification times
    e. Synchronizing a file
    f. Truncating a file
    g. Closing a file
    h. Using appropriate error codes for different error scenarios
4. We will test that Assignment 2 follows the specified protocol for RPC calls.

Section 9) Specific Don'ts

- Do not use any public or web-based source code repository hosting service other than https://git.uwaterloo.ca
- The interface of the WatDFS Client cannot change. We will be using these interfaces to run the FUSE client.
- Do not modify rpc.h, or watdfs_client.h
- Do not assume that the code will compile or run on linux.student.cs without actually compiling and running it on that environment.

It is important that you start this Assignment early!

Section 10) RPC Library Documentation

To ease implementation, an RPC library is provided. The RPC library supports making remote procedure calls from a client to a server. To do so, function handlers and their expected types must be defined and registered before the WatDFS server accepts connections.

Section 10.1) rpcRegister

```
int rpcRegister(char *name, int *argTypes, skeleton f);
//Where skeleton is defined as
typedef int (*skeleton)(int *, void **);
```

Function calls must be registered with the `rpcRegister` call before they can be used by remote clients. This function tells the RPC library what function to call at the server when a client makes an `rpcCall` with a specified named and arguments.

The `skeleton f` is the address of the server function, which corresponds with the server function being registered. Skeletons return an integer error code indicating success with a zero, or failure with a negative error code. **Values that you wish to return should be provided as an argument to the skeleton and indicated as outputs via the `argTypes` array.** `rpcRegister` will return an integer indicating success (`0`) or failure (a negative number).

The `argTypes` array specifies the types of the argument, and whether the argument is an input, output, or both an input and output argument for the function call. Each argument has an integer to encode the type information (described in the following paragraphs), which will collectively form the `argTypes` array. Thus `argTypes[0]` specifies the type information for `args[0]`. Since it is not known how many arguments there are, the last value in the `argTypes` array must be 0. Consequently, the size of `argTypes` is 1 greater than the size of `args`. The args array is an array of pointers to the different arguments, which will be discussed later. For array arguments, they are specified by pointers in C++, and can be used directly, instead of the addresses of the pointers.
The number of output arguments is arbitrary and they can be positioned anywhere within the args vector.

The argument type integer (of size 4 bytes) will be broken down as follows:
(a) The first byte will specify the input/output nature of the argument. Specifically, if the first bit is set then the argument is input to the server. If the second bit is set the argument is output from the server. The third bit indicates whether the argument is an array type. The remaining 5 bits of this byte are currently undefined and must be set to 0.

(b) The second byte contains argument type information.

```
#define ARG_CHAR    1
#define ARG_SHORT   2
#define ARG_INT     3
#define ARG_LONG    4
#define ARG_DOUBLE  5
#define ARG_FLOAT   6
```

(c) The last two bytes of the argument type integer specify the length of the array. Arrays are limited to a length of 2^16 - 1 (defined as `MAX_ARRAY_LEN`). If the argument is not an array, then these last two bytes must be 0. **It is expected that the client programmer will have reserved sufficient space for any output arrays.**
Important Note: When the function is registered with `rpcRegister`, the server may not know the length of the array; it is therefore acceptable to specify the length of the array as `1` in the call to `rpcRegister`.

For convenience, the following definitions are provided:

```
#define ARG_INPUT      31
#define ARG_OUTPUT     30
#define ARG_ARRAY      29
```

For example, “`(1 << ARG_INPUT) | (1 << ARG_ARRAY) | (ARG_INT << 16) | 20`” represents an array of 20 integers being sent to the server.

We show an example of registering the `sum` function used in the example below.

```
     int sumFunction(int *argTypes, void** args) {
          // Expected args are output int and input array of ints
          // get lowest 2 bytes (array len)
          int len = argTypes[1] & ((1 << 16) - 1);
          int total = 0;
          int* to_sum = (int*) args[1];
          for (int pos = 0; pos < len; pos++) {
               total += to_sum[pos];
          }
          *((int *)(args[0])) = total;
          return 0;
     }

     // result = sum(vector);
     #define PARAMETER_COUNT 2       // Number of RPC arguments
     #define LENGTH 1                // it is an array


     int argTypes[PARAMETER_COUNT+1];

     argTypes[0] = (1 << ARG_OUTPUT) | (ARG_INT << 16);// result
     // input vector to sum
     argTypes[1] = (1 << ARG_INPUT)  | (1 << ARG_ARRAY) |
                   (ARG_INT << 16) | LENGTH;

     argTypes[2] = 0;                 // Terminator


     rpcRegister("sum", argTypes, sumFunction);
```

Important note: The RPC server may call your registered function from any thread that it has available so you should not keep any thread-local state, as it will not be available on subsequent (future) function executions!

Section 10.2) rpcCall

```
int rpcCall(char *name, int *argTypes, void **args);
```

The client executes an RPC by calling the `rpcCall` function. The integer returned is the result of executing the `rpcCall`, **not the result of the procedure that the `rpcCall` was executing.** That is, if the `rpcCall` failed, that would be indicated by a negative number and success is indicated by a 0. It is expected that you check the return value for errors. If your function is expected to return a value, it should be specified as an output argument in the same way as defined in `rpcRegister`.

The `name` argument is the name of the remote procedure to be executed, a procedure that matches the `name` with the same `argTypes` must have been registered at the server. If no such procedure exists, an error code will be returned indicating so.
Thus, if the client wished to execute `result = sum(int vect[LENGTH])`, the code would be:

```
     // result = sum(vector);
     #define PARAMETER_COUNT 2       // Number of RPC arguments
     #define LENGTH 23               // Vector length


     int argTypes[PARAMETER_COUNT+1];
     void **args = (void **)malloc(PARAMETER_COUNT  * sizeof(void *));


     argTypes[0] = (1 << ARG_OUTPUT) | (ARG_INT << 16);      // result
     // vector
     argTypes[1] = (1 << ARG_INPUT) | (1 << ARG_ARRAY) |
                   (ARG_INT << 16) | LENGTH;

     argTypes[2] = 0;                 // Terminator

     int result;
     int vector[LENGTH]; // suppose this is filled in with values
     args[0] = (void *)&result;
     args[1] = (void *)vector;

    int ret = rpcCall("sum", argTypes, args);
     // if ret < 0, there is an rpcCall error
     // do something with result
```

```
    free(args); // clean up args
```

Section 10.3) Other RPC library calls

There are 4 other calls that must be made to the RPC library. All these calls return `0` on success, and a negative number for failure.

rpcServerInit

Before registering any functions the server must first call `rpcServerInit`, this will initialize any server state that the RPC library must maintain.

rpcExecute

When the server is ready to serve calls, it should call `rpcExecute`. This will transfer control to the RPC library, and when an RPC call is received the registered functions should be called. `rpcServerInit` must be called before `rpcExecute` is called. When `rpcExecute` is called the server will print the address and port that the server is listening on, which must be set by the client, as described in `rpcClientInit`.

```
export SERVER_ADDRESS=address
export SERVER_PORT=port
```

rpcClientInit

The client should call `rpcClientInit` to initialize a connection with the server. `rpcClientInit` should be called before any calls to `rpcCall` are made. To connect with the server the environment variables `SERVER_ADDRESS` and `SERVER_PORT` must be set before the client binary is executed. For example:

```
$ export SERVER_ADDRESS=ubuntu1604-006
$ export SERVER_PORT=12345
$ ./client <args>
```

rpcClientDestroy

The client should call `rpcClientDestroy` when they are finished interacting with the server. This will terminate connections with the server.

RPC Library Tips

The RPC library logs each call, the argument types, and the return value in rpc_client.log and rpc_server.log respectively. Consult these logs if your RPC calls do not succeed.

Section 11) Other Resources

Section 11.1) Resources for working with FUSE

The FUSE headers are available online:
https://github.com/libfuse/libfuse/blob/master/include/fuse.h

A general tutorial for the FUSE functions are available online at:
https://www.cs.nmsu.edu/~pfeiffer/fuse-tutorial/html/index.html

Some pointers on the purpose of each FUSE call:
https://www.cs.hmc.edu/~geoff/classes/hmc.cs135.201109/homework/fuse/fuse_doc.html

Section 11.2) Resources for system calls

You will have to make many system calls. To understand their function, you should read the man pages. Some system calls you might need are listed below

System Calls	Description	Links
open, creat	Opening a file	http://man7.org/linux/man-pages/man2/open.2.html
close	Closing a file	http://man7.org/linux/man-pages/man2/close.2.html
mknod	Creating a file	http://man7.org/linux/man-pages/man2/mknod.2.html
read/write	Reading and writing to a file	http://man7.org/linux/man-pages/man2/read.2.html
pread, pwrite	Reading and writing a file to offsets	http://man7.org/linux/man-pages/man2/pread.2.html
stat, lstat, fstat	Getting file attributes	http://man7.org/linux/man-pages/man2/fstat.2.html
truncate ftruncate	Truncating a file to a length	http://man7.org/linux/man-pages/man2/truncate.2.html
fsync	Sync a file to storage	http://man7.org/linux/man-pages/man2/fsync.2.html
futimens, utimensat	Change file modified/access times	http://man7.org/linux/man-pages/man2/utimensat.2.html