Project 3 Final Technical Report

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CS 4440: Introduction to Operating Systems

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Table of Contents

Introduction

This project is a culmination of our work in CS 4440: Operating Systems; from the basic principles in network programming to the working, network-accessible filesystem we have today. We completed the five guidelines as outlined:

1. A basic, multi-threaded client-server that reverses strings and is also resistant against denial-of-service attacks (DoS).
2. An extension of the client-server that provides directory/file listing, layering a remote ls service over sockets.
3. An extension of the client-server that upgrades it to a simulated physical disk-storage system (addressed sectorially and cyclically in 128 bytes) by exposing a “block device” over TCP
4. An extension of the client-server that builds a flat filesystem on the “block device”
5. An extension of the client-server that extends the filesystem with a hierarchical directory structure (MKDIR, CD, PWD, and RMDIR)

Note: All components are written in C using POSIX sockets and pthreads.

Part 1: User's Manual

Overall Build - Two Options

Option 1: Using the Makefile provided in zip file

Option 2: Manually compiles files (see below)

Question 1: Basic Client-Server

Function:

- Server listens on TCP port 8080, spawns a thread per connection, reads one string, reverses it, and replies.
- Client connects to server-ip 8080, sends a single argument string, prints the reversed response.

How to Run:

Additional Notes:

- Server prints each connection and uses a mutex for clean console output
- Client usage: ./q1_client <server-ip> <string>; validates args, errors gracefully on bad address/connection

Question 2: Directory Listing Server

Function:

- Server accepts a connection on TCP port 8083, executes ls with flags provided by the client, and then streams the output back.
- Client connects to <server-ip>:8083 and sends the space-joined ls parameters, then prints the response

How to Run:

Additional Notes:

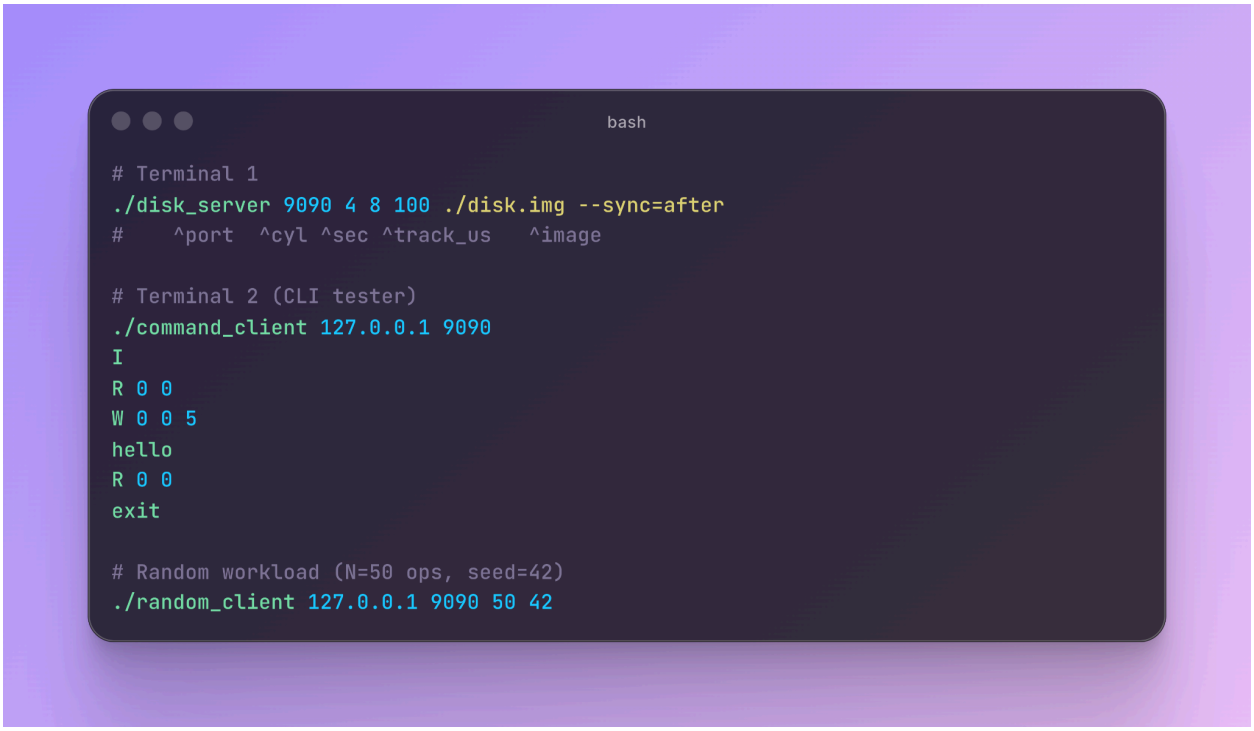
- Ensure the server process has permission to exec ls and read target directories.
- Client usage: ./q2_ls_client <server-ip> [ls options...]. It connects and sends exactly the options/paths you type; output is printed verbatim.

Question 3: Basic Disk Storage System

Function:

- I = server replies with <cylinders> <sectors>\n
- R c s = server returns 1<128 bytes> on success, 0 if out of range
- W c s l <data> with $0 \leq l \leq 128$ = returns 1 on a valid write, 0 if otherwise
- Seek time simulated by a track delay (µs). Storage is a regular file (aka image).

How to Run:



Additional Notes:

- Out-of-range cylinders/sectors and invalid lengths (ex: L=129) are rejected.
- Random client prints a compact progress stream (R/W characters).

Question 4: File System Server

Function:

- F = format; initializes superblock, FAT, and directory table in the backing image.
- C f = create; 0 ok, 1 exists, 2 errors.
- D f = delete; 0 ok, 1 not found, 2 errors.
- L b = list names (b=0) or name size (b=1), ends with a blank line.
- R f = read; replies code len <raw-bytes>.
- W f l <bytes> = overwrite file with l bytes.

How to Run:

Additional Notes:

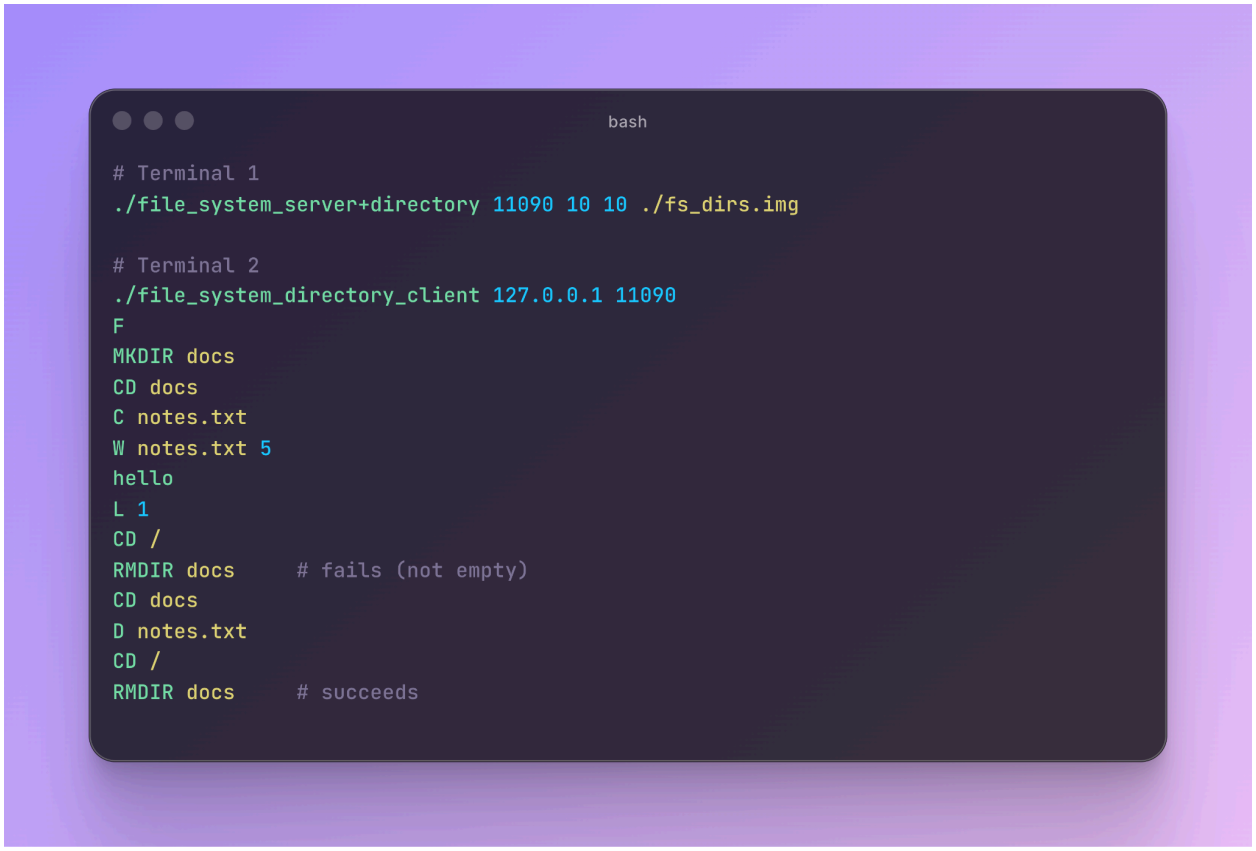
- N/A

Question 5: Directory Structure

Function:

- MKDIR name = 0/1/2 (ok/exist/error)
- CD name|...| / = 0 ok, 1 not found, 2 not a directory
- PWD = absolute path + newline
- RMDIR name = 0 ok, 1 not found, 2 not empty/other
- L now lists current directory (types shown when b=1: d for dirs, - for files)

How to Run:



Additional Notes:

- N/A

Part B: Technical Manual

Disk Design

Geometry + Block Size

- The disk is a rectangular grid: cylinders × sectorsPerCylinder. Each sector is 128 bytes.
- The server persists to an image file and simulates track-to-track latency via a sleep parameter (μs).

Protocol

- I = ASCII: <cyl> <sec>\n.
- R c s = returns '1' followed by 128 raw bytes on success; '0' if out of range.
- W c s l data = $l \in [0,128]$. Returns '1' for valid c,s,l (data stored, and any unwritten tail bytes of the 128-byte sector may be left as-is or zero-filled), '0' otherwise.

I/O Model

- Sector offset = (c * sectors + s) * 128. Pread/pwrite (or seek+read/write) to the image file.
- Optional mmap is acceptable in our disk; correctness is independent of the API.

Concurrency

- Thread per client
- Each request is atomic at sector granularity; the server serializes conflicting writes

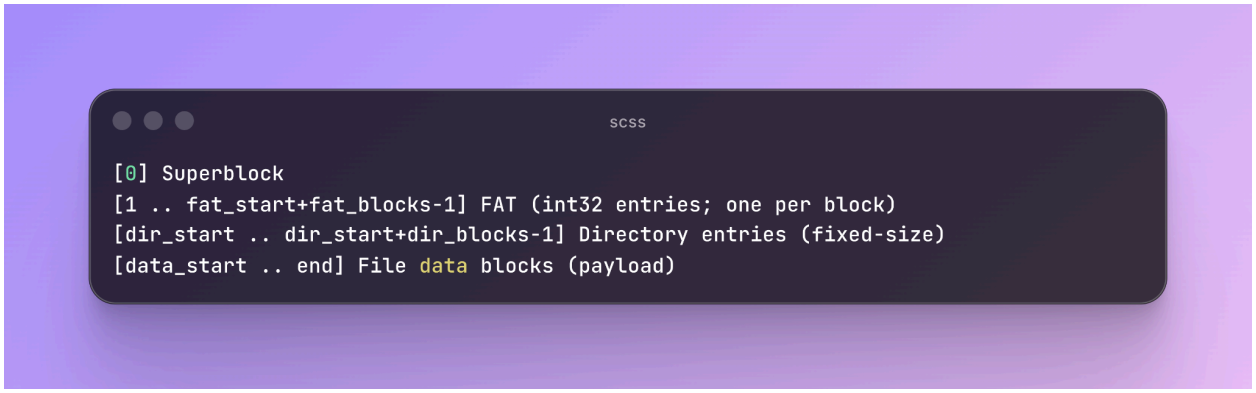
Error Handling

- Parameter validation: $0 \leq c <$ cylinders, $0 \leq s <$ sectors, $0 \leq l \leq 128$.
- Connection errors close that session without affecting others.

File System Design

Block Size + Addressing

- Uses the same 128-byte block size. Blocks are addressed by absolute block index.
- Layout (Note: The indices are block indices):



Superblock

- magic ('FSL1'), cylinders, sectors, block_size, total_blocks
- fat_start, fat_blocks, dir_start, dir_blocks, data_start
- max_files (derived from directory region size)
- All fields are 32-bit except the padding since the server initializes and validates these.

FAT

- Values: FREE = -1, EOC = -2, otherwise next block index in the chain.
- First-fit allocation by scanning for free entries; chains are singly linked.

Directory Entries

- used (1B), padding
- first_block (int32 head of FAT chain, or -1 if empty)
- size_bytes (uint32)
- name[48] (NUL-terminated, truncated if needed)
- Two entries fit in one 128-byte block; the directory region has a fixed capacity.

Main Algorithms

- Format: compute FAT/dir region sizes; mark metadata blocks as reserved (EOC), clear FAT and dir.
- Create: ensure unique name; claim a free directory slot; first_block = -1, size = 0.
- Delete: walk the FAT chain (if any at all) and mark all blocks FREE; clear the directory entry.
- Write W f l data:
    1. Compute required blocks ceil (l/128)
    2. Grow/shrink FAT chain via ensure_capacity (extend or free tail)
    3. Copy bytes block-by-block; zero any partial tail
- Append A f l data: grow chain to fit oldSize + l; write starting at tail offset (handle partial first block, then whole blocks).
- Read R f: iterate chain, copying up to size_bytes.
- List L b: iterate directory table; skip used = = 0.
- Thread Safety: one global FS mutex guarding metadata and data accesses.

Limits + Complexity

- File count limited by dir_blocks * (128 / 64). With 8 dir blocks: 16 entries.
- Allocation and deallocation are O(totalBlocks) worst-case scans of the FAT; average case is small.

Directory Support

Extended Directory Entry

Add two fields to the previous entry to support a tree and per-connection CWD:

- is_dir (bool/byte)
- parent (int32, index of parent directory entry; root has parent = -1)

Your hierarchical build also bumps the on-disk magic to distinguish formats.

Root and CWD

- Root directory is entry 0, name '/', is_dir = 1, parent = -1.
- Each connection tracks its own CWD index (defaults to root). All file operations are interpreted relative to that CWD.

New commands

- MKDIR name = create a child directory of CWD; reject names containing / ; return 1 if exists.
- CD name|..| / = update CWD to child, parent, or root; reject non-directory targets.
- PWD = compute absolute path by walking parent pointers to root and joining names.
- RMDIR name = only succeeds for empty directories (no entries with parent = = thatDir).

Main Algorithms

- Lookup in CWD: linear scan of directory table for used && parent = = cwd && name = = input…
- Emptiness Check: scan for any used && parent = = target.

- Path build (PWD): collect component names following parent pointers to root, then print in reverse.
- Listing (L): filter by parent = = cwd; with b = 1, prefix each line with type (d or -) and include size for files.

Error Handling

- Return codes mirror Question 4 (0/1/2), with 1 meaning “not found” or “name conflict,” and 2 for “not directory,” “not empty,” or no space.
- Names are sanitized to forbid / so that path resolution is unambiguous within this flat table implementation.

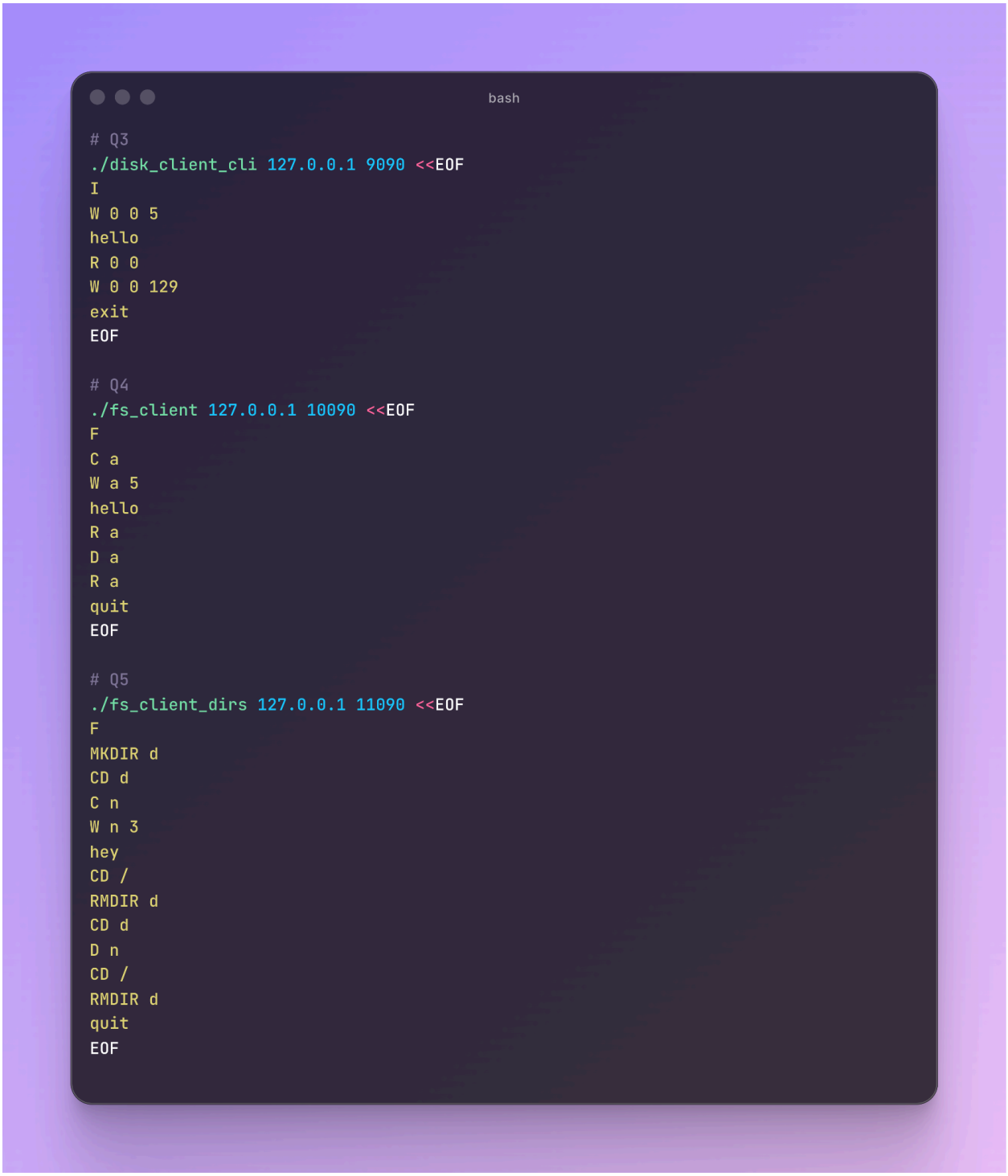
Concurrency + Networking

- All servers use TCP, accept() loop, and spawn a thread per request/connection; Question 1's multi-threading is explicit in server.c.
- Each client is a simple single-connection program for test/interaction.

  Question 1's client shows straightforward connect/send/recv.
- For Q3–Q5, a single global mutex around FS/disk state is sufficient for correctness.

Testing Tips

Quick Routine Checks:



References

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