Course Project Report: Simplified Academic Review System (SARS)

1. Project Background and Objectives

Modern academic conferences and journals rely heavily on online review systems, such as OpenReview and EasyChair. This course project aims to implement a "simplified yet comprehensive" review system to facilitate the understanding of core Operating System (OS) concepts, specifically:

- **File System**: Superblock, inode table, data blocks, free bitmap, directory structure, and path resolution.
- **Concurrent Access**: Server-side handling of simultaneous client requests.
- **Caching**: Implementation of a configurable **LRU (Least Recently Used) block cache** with performance statistics (hits, misses, and replacements).
- **Network Communication**: A Client-Server architecture utilizing a custom network protocol for all operations.
- **Authentication and Access Control**: Login mechanisms, session management, and Role-Based Access Control (RBAC).

The system is developed using **C++17** and follows a Client-Server architecture. The client is a **Command Line Interface (CLI)**, while the server maintains a **custom Virtual File System (VFS)** that persists data—such as papers and reviews—into a backend file named `data.fs`.

2. Requirements Analysis — Alignment with Course Guidelines

The following key requirements from the course instructions have been addressed:

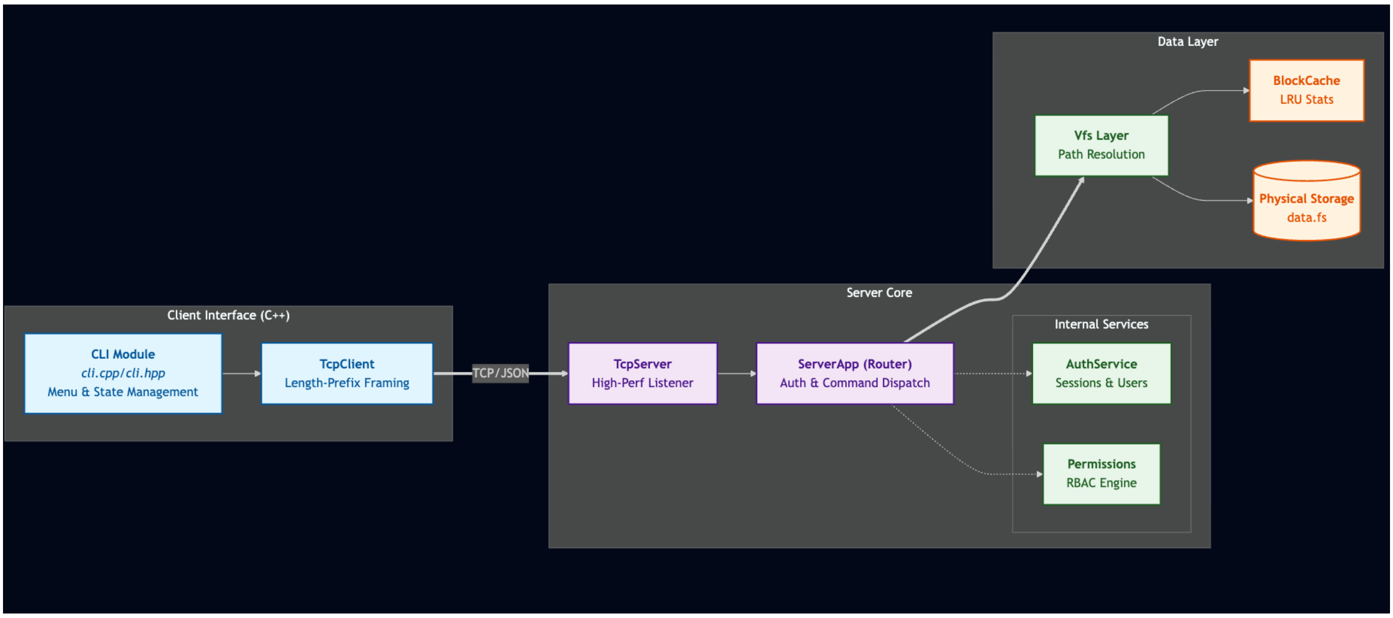
- **C/S Architecture**: All operations are initiated by the client and executed by the server, which accesses the server-side file system. The server must support concurrent client access.
- **Four User Roles**: Author, Reviewer, Editor, and Admin, each with distinct permissions and command sets.
- **File System Implementation**: Must include a superblock, inode table, data blocks, and free bitmap. Support for multi-level directories, file creation, deletion, read/write operations, and path parsing is required.
- **LRU Block Cache**: Configurable capacity with output for hit, miss, and replacement statistics.
- **Backup and Recovery**: Support for creating, listing, and restoring backups, with optional extension to snapshot-based mechanisms.
- **Protocol Design**: A clear, extensible protocol (textual or binary) for structured data exchange.

3. System Architecture Design

3.1 Architecture Overview

The system consists of a CLI Client and a Server Application (`ServerApp`):

- **Client (CLI)**: Parses user input, encapsulates commands into a unified JSON protocol, transmits requests via TCP, and renders the JSON responses. It automatically manages the `sessionId` after a successful login and maintains a "current directory" state for `LIST` operations.
- **Server (ServerApp)**: Listens for messages, parses commands, validates sessions, performs permission checks, and invokes the `Vfs` module for data persistence, returning a unified response structure.



3.2 Software Module Decomposition

The project is organized into the following modules within the `src/` directory:

- `src/common/`: Shared types and protocol definitions.
  - `types.hpp`: Fundamental types such as `UserId`, `PaperId`, `Role`, and `Credentials`.
  - `protocol.hpp`: Message envelopes, the unified `Command` structure, serialization/deserialization, and response construction.
- `src/domain/`: Domain models, permissions, and authentication.
  - `auth.hpp/.cpp`: In-memory user registry and session management (educational implementation).
  - `permissions.hpp/.cpp`: Permission matrix mapping roles to authorized actions.
  - `paper.hpp` / `review.hpp` / `user.hpp`: Domain object definitions.
- `src/server/`: Server-side implementation.
  - `server_app.hpp/.cpp`: Command routing, authentication, permission validation, and business logic.
  - `filesystem/`: VFS implementation including superblock, inodes, bitmaps, directories, path parsing, and the LRU cache.
  - `net/`: TCP server utilizing length-prefixed JSON framing.

- `src/client/`: Client-side implementation.
  - `cli.hpp/.cpp`: Interactive CLI featuring role-specific menu wizards.
  - `net/`: TCP client responsible for request-response cycles.

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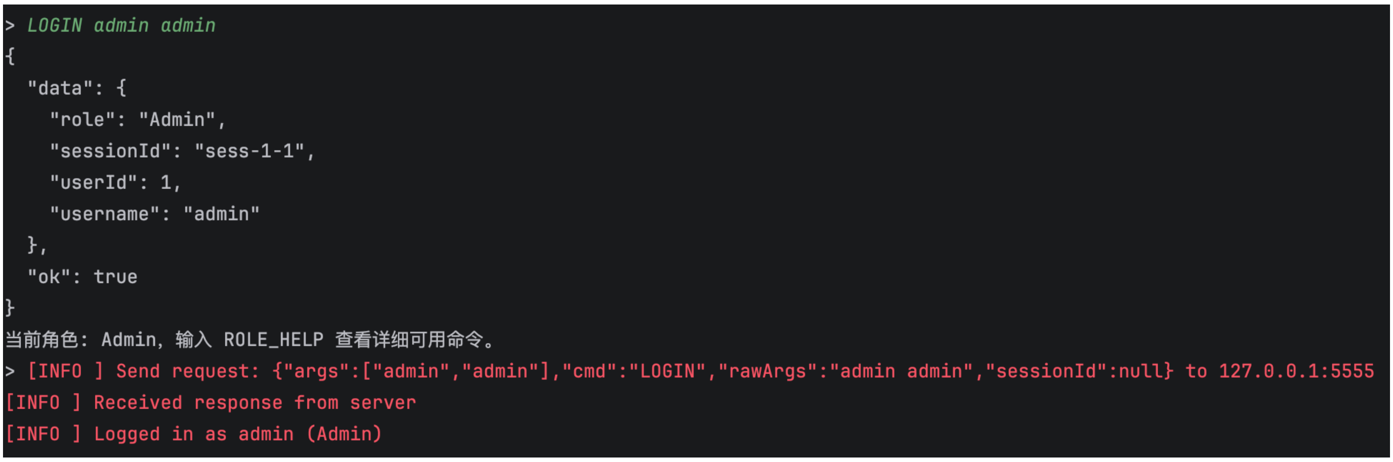
4. Communication Protocol: Extensible JSON Envelope and Command

4.1 Message Envelope

Communication messages consist of a `MessageType` and a JSON `payload`, serialized into a JSON string:

- `type`: `"CommandRequest" | "CommandResponse" | "Error" | ...`
- `payload`: A JSON object containing specific request or response data.

The transport layer employs **4-byte network-order length-prefix framing** followed by **N bytes of JSON data** to prevent packet fragmentation and coalescing issues.



```
> LOGIN admin admin
{
  "data": {
    "role": "Admin",
    "sessionId": "sess-1-1",
    "userId": 1,
    "username": "admin"
  },
  "ok": true
}
当前角色: Admin, 输入 ROLE_HELP 查看详细可用命令。
> [INFO ] Send request: {"args":["admin","admin"],"cmd":"LOGIN","rawArgs":"admin admin","sessionId":null} to 127.0.0.1:5555
[INFO ] Received response from server
[INFO ] Logged in as admin (Admin)
```

4.2 Unified Command Structure

The `payload` utilizes a standardized command structure:

- `cmd`: Command identifier (e.g., `PING`, `LOGIN`, `LIST_PAPERS`).
- `args`: Array of space-delimited parameters.
- `rawArgs`: Original parameter string, used for commands like `WRITE` or `REVIEW` that require preservation of whitespace.
- `sessionId`: Carried after login to facilitate stateless authentication.

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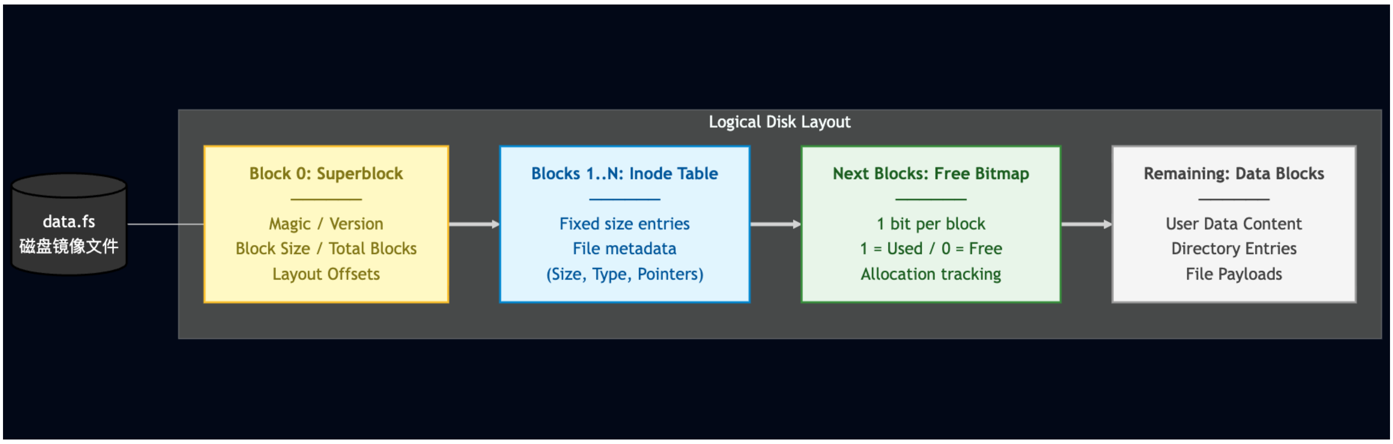
5. Virtual File System (VFS) Design

5.1 Disk Layout: `data.fs`

The server mounts `data.fs` upon startup. If the file is missing or the magic number is invalid, the system undergoes an automatic format. The current implementation uses a fixed layout:

- **Block Size**: 4096 bytes
- **Total Capacity**: 1024 blocks
- **Superblock**: Block 0
- **Inode Table**: Fixed allocation (currently 8 blocks)
- **Free Bitmap**: 1 block for data block management
- **Data Blocks**: Remaining blocks



5.2 Inode and Data Block Management

- **Inode Metadata**: Each inode records an `id`, type (file/directory), size, and a set of **direct blocks**.
- **Allocation**: Data blocks are managed via the **free bitmap** using a "first-fit" scan.
- **I/O**: Block access is performed via `readBlock/writeBlock` at specific offsets within `data.fs`.

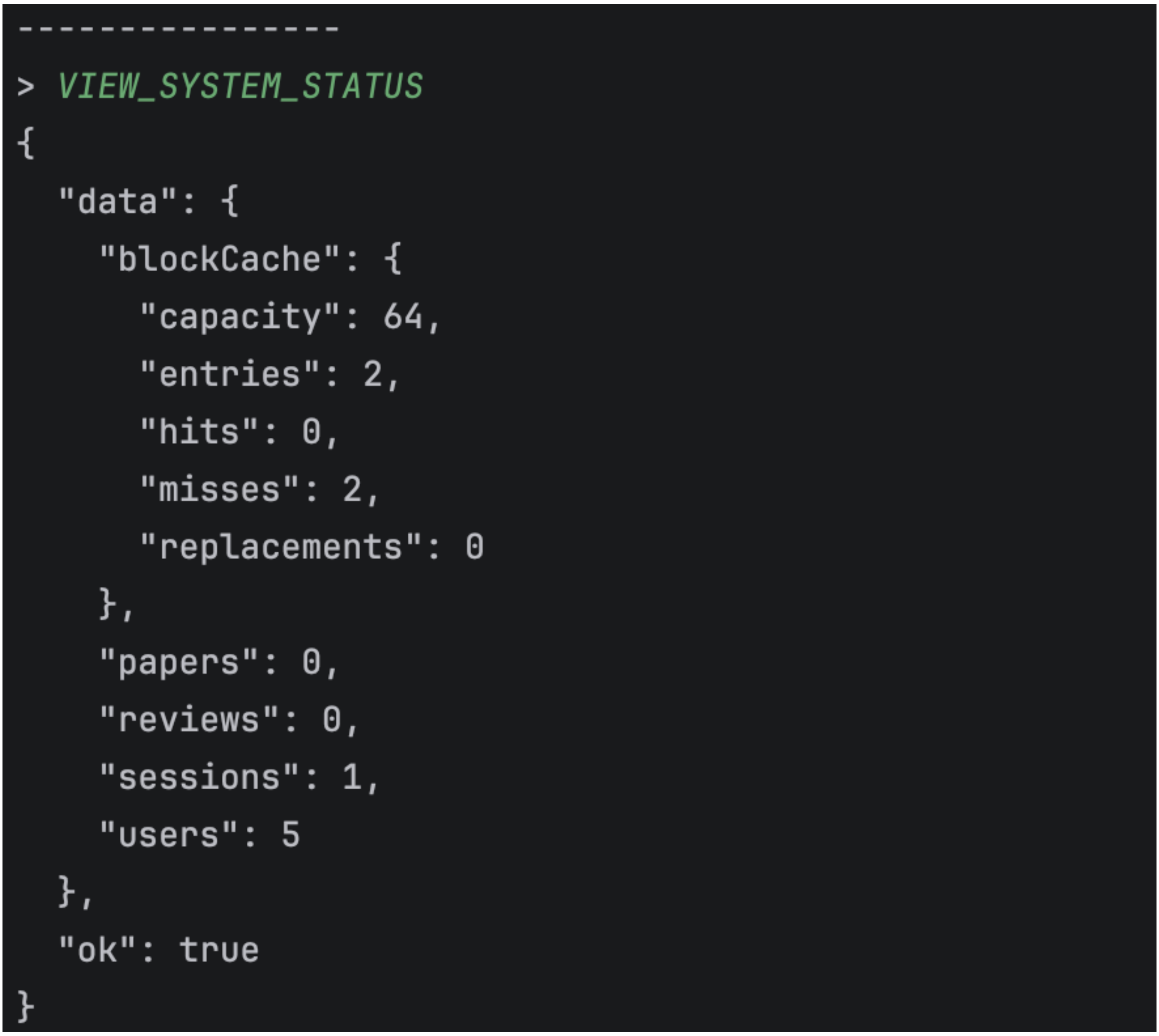
5.3 Directory Structure and Path Resolution

- **Multi-level Path Resolution**: The system decomposes paths (e.g., `/a/b/c`) into components and traverses directory entries to locate target inodes.
- **Directory Entry (DirEntry)**: A fixed-length structure containing `inodeId` and `name[60]`.
- **Operations**: Supports `MKDIR`, `LIST`, file/directory creation and deletion (directory must be empty for removal).

5.4 LRU Block Cache: Configuration and Statistics

The `BlockCache` is an in-memory LRU cache:

- **Capacity**: Configurable via server startup arguments or the `OSP_CACHE_CAPACITY` environment variable.
- **Monitoring**: Tracks `hits`, `misses`, `replacements`, and `entries`.
- **Status Reporting**: The `VIEW_SYSTEM_STATUS` command returns cache statistics for performance evaluation.



```
----------------
> VIEW_SYSTEM_STATUS
{
  "data": {
    "blockCache": {
      "capacity": 64,
      "entries": 2,
      "hits": 0,
      "misses": 2,
      "replacements": 0
    },
    "papers": 0,
    "reviews": 0,
    "sessions": 1,
    "users": 5
  },
  "ok": true
}
```

6. Authentication and Access Control

6.1 Session Management

The `AuthService` maintains:

- `usersByName_`: A mapping of usernames to user information.
- `sessionsById_`: A mapping of session IDs to session data. Sessions follow the format `sess-<uid>-<counter>`.

6.2 Role-Based Access Control (RBAC)

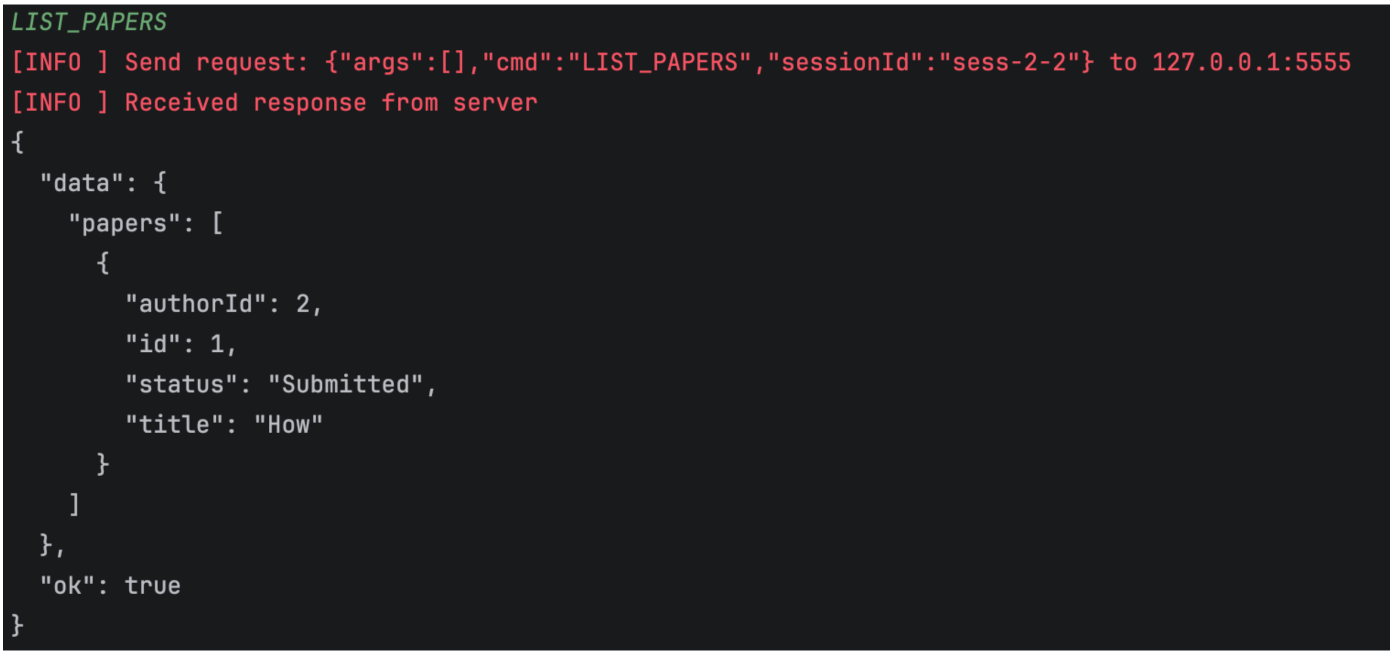
The `Permission` abstraction defines high-level actions (e.g., uploading papers, assigning reviewers). A role-based matrix determines whether a user can execute a specific command. Permission checks are centralized in the server’s command router.

7. Business Logic and Persistence: Academic Review Flow

7.1 VFS Data Structure Conventions

All review-related data is persisted within the VFS:

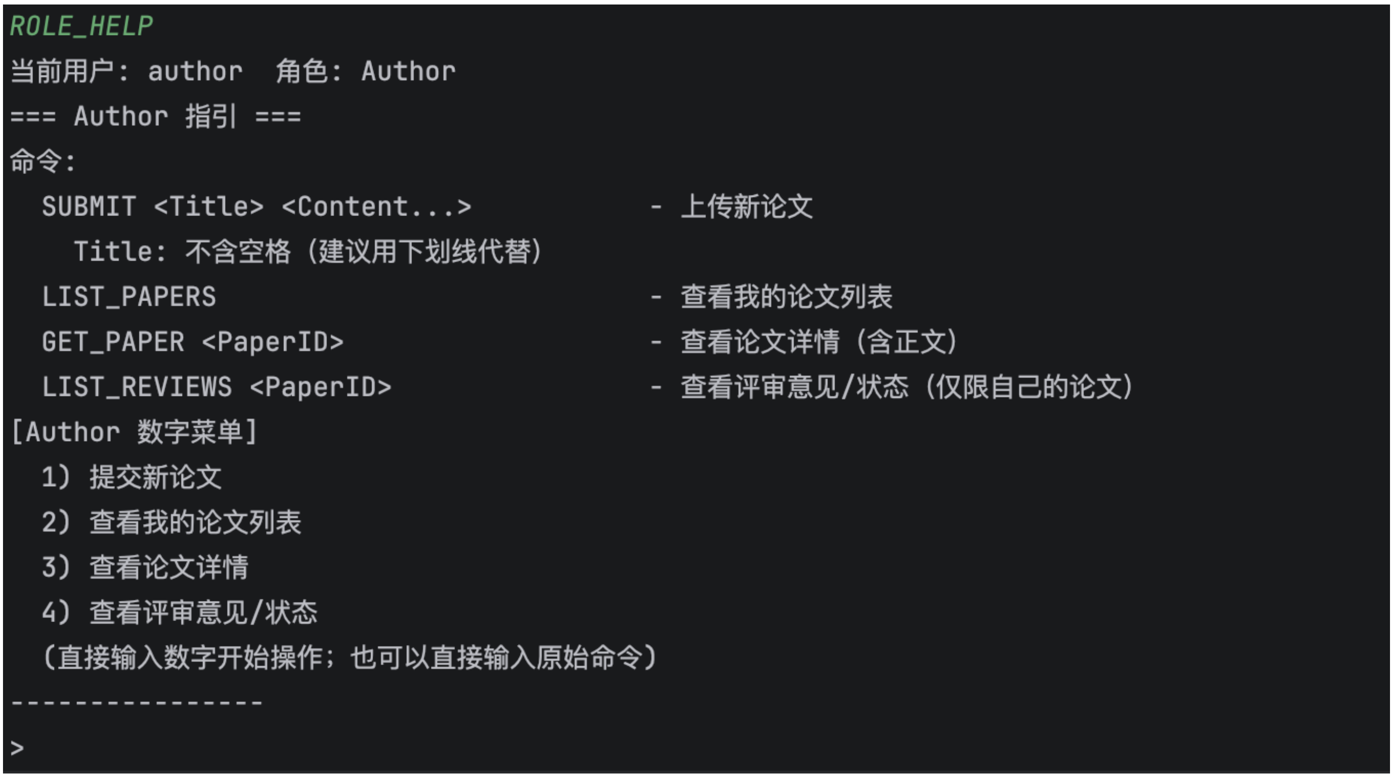
- `/papers/<id>/meta.txt`: Metadata (Author ID, status, title).
- `/papers/<id>/content.txt`: Paper body.
- `/papers/<id>/reviewers.txt`: List of assigned reviewer IDs.
- `/papers/<id>/reviews/<reviewerId>.txt`: Review content (decision and comments).



```
LIST_PAPERS
[INFO ] Send request: {"args":[],"cmd":"LIST_PAPERS","sessionId":"sess-2-2"} to 127.0.0.1:5555
[INFO ] Received response from server
{
  "data": {
    "papers": [
      {
        "authorId": 2,
        "id": 1,
        "status": "Submitted",
        "title": "How"
      }
    ]
  },
  "ok": true
}
```

7.2 Key Role-Based Commands

- **Author**: `SUBMIT`, `LIST_PAPERS` (personal), `GET_PAPER`, `LIST_REVIEWS`.
- **Reviewer**: `LIST_PAPERS` (assigned only), `REVIEW` (submit decision).
- **Editor**: `ASSIGN_REVIEWER`, `MAKE_FINAL_DECISION` (updates status in `meta.txt`).
- **Admin**: `MANAGE_USERS`, `VIEW_SYSTEM_STATUS` (cache and system metrics), `BACKUP/RESTORE`.



```
ROLE_HELP
当前用户: author  角色: Author
=== Author 指引 ===
命令:
  SUBMIT <Title> <Content...>           - 上传新论文
    Title: 不含空格（建议用下划线代替）
  LIST_PAPERS                           - 查看我的论文列表
  GET_PAPER <PaperID>                   - 查看论文详情（含正文）
  LIST_REVIEWS <PaperID>                - 查看评审意见/状态（仅限自己的论文）
[Author 数字菜单]
  1）提交新论文
  2）查看我的论文列表
  3）查看论文详情
  4）查看评审意见/状态
  （直接输入数字开始操作；也可以直接输入原始命令）
----------------
>
```

8. Current Progress Summary

8.1 Implemented Features

- **Core Communication**: TCP with length-prefix framing and JSON serialization.
- **Protocol**: Unified `CommandRequest/Response` framework.
- **Authentication**: Session-based login and validation.
- **Access Control**: RBAC matrix enforcement at the server level.
- **VFS Core**: Superblock, inode table, bitmap, and block-level I/O.
- **Path Logic**: Multi-level path resolution and directory CRUD operations.
- **LRU Cache**: Configurable capacity and performance monitoring.
- **Business Flow**: End-to-end review process (Submission → Assignment → Review → Decision).

8.2 Partial Implementation

- **Directory Limits**: Single-block directory limit (entries constrained by block size).
- **File Limits**: Direct blocks only; no support for indirect blocks or large file indexing.

8.3 Pending Features

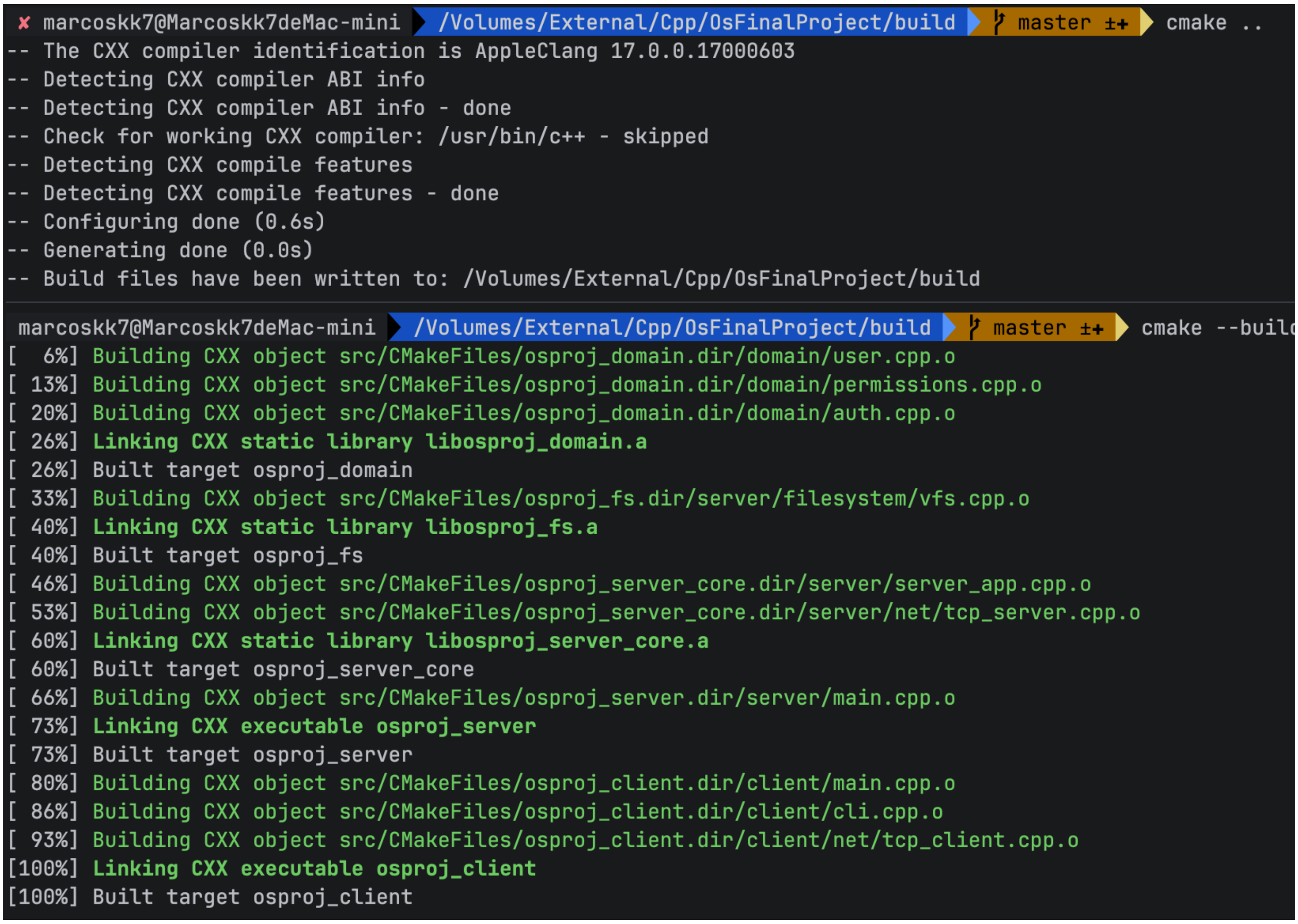
- **Concurrency**: The current TCP server utilizes a synchronous model; multi-threaded/concurrent request handling is pending.
- **Backup Persistence**: While the interface and permissions are ready, the logic for file snapshots and restoration needs to be finalized.

9. Build and Execution

9.1 Build Process

The project uses CMake. Binaries are generated in the `build/` directory:

- `osproj_server`
- `osproj_client`

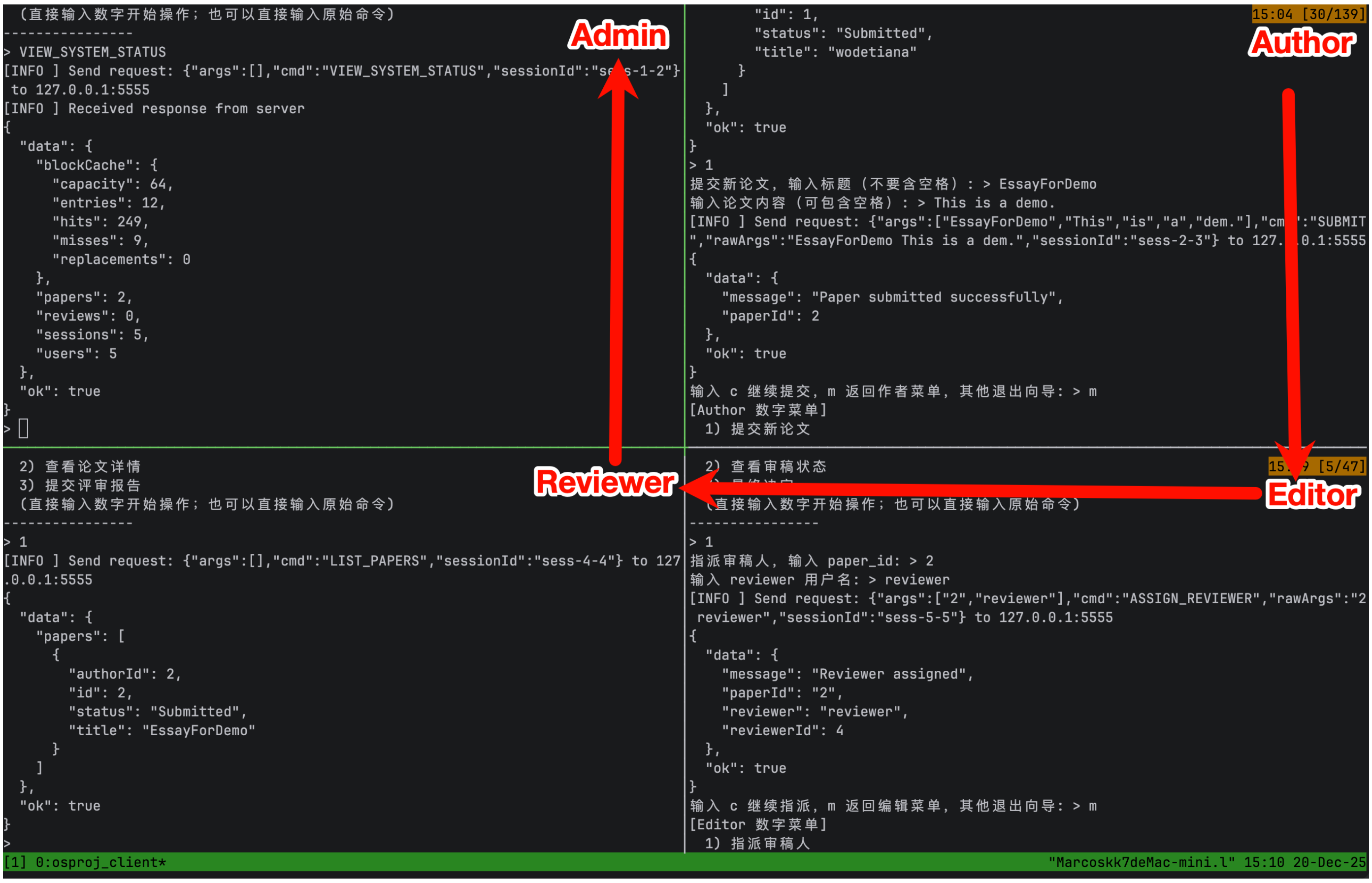


```
✘ marcoskk7@Marcoskk7deMac-mini  /Volumes/External/Cpp/OsFinalProject/build  master ±+  cmake ..
-- The CXX compiler identification is AppleClang 17.0.0.17000603
-- Detecting CXX compiler ABI info
-- Detecting CXX compiler ABI info - done
-- Check for working CXX compiler: /usr/bin/c++ - skipped
-- Detecting CXX compile features
-- Detecting CXX compile features - done
-- Configuring done (0.6s)
-- Generating done (0.0s)
-- Build files have been written to: /Volumes/External/Cpp/OsFinalProject/build

 marcoskk7@Marcoskk7deMac-mini  /Volumes/External/Cpp/OsFinalProject/build  master ±+  cmake --buil
[  6%] Building CXX object src/CMakeFiles/osproj_domain.dir/domain/user.cpp.o
[ 13%] Building CXX object src/CMakeFiles/osproj_domain.dir/domain/permissions.cpp.o
[ 20%] Building CXX object src/CMakeFiles/osproj_domain.dir/domain/auth.cpp.o
[ 26%] Linking CXX static library libosproj_domain.a
[ 26%] Built target osproj_domain
[ 33%] Building CXX object src/CMakeFiles/osproj_fs.dir/server/filesystem/vfs.cpp.o
[ 40%] Linking CXX static library libosproj_fs.a
[ 40%] Built target osproj_fs
[ 46%] Building CXX object src/CMakeFiles/osproj_server_core.dir/server/server_app.cpp.o
[ 53%] Building CXX object src/CMakeFiles/osproj_server_core.dir/server/net/tcp_server.cpp.o
[ 60%] Linking CXX static library libosproj_server_core.a
[ 60%] Built target osproj_server_core
[ 66%] Building CXX object src/CMakeFiles/osproj_server.dir/server/main.cpp.o
[ 73%] Linking CXX executable osproj_server
[ 73%] Built target osproj_server
[ 80%] Building CXX object src/CMakeFiles/osproj_client.dir/client/main.cpp.o
[ 86%] Building CXX object src/CMakeFiles/osproj_client.dir/client/cli.cpp.o
[ 93%] Building CXX object src/CMakeFiles/osproj_client.dir/client/net/tcp_client.cpp.o
[100%] Linking CXX executable osproj_client
[100%] Built target osproj_client
```

9.2 Execution

- **Server**: `./build/src/osproj_server [port] [cacheCapacity]`
- **Client**: `./build/src/osproj_client` (Connects to 127.0.0.1:5555 by default).



```
  (直接输入数字开始操作; 也可以直接输入原始命令)
----------------
> VIEW_SYSTEM_STATUS
[INFO ] Send request: {"args":[],"cmd":"VIEW_SYSTEM_STATUS","sessionId":"sess-1-2"}
 to 127.0.0.1:5555
[INFO ] Received response from server
{
  "data": {
    "blockCache": {
      "capacity": 64,
      "entries": 12,
      "hits": 249,
      "misses": 9,
      "replacements": 0
    },
    "papers": 2,
    "reviews": 0,
    "sessions": 5,
    "users": 5
  },
  "ok": true
}
> 
```

```
        "id": 1,
        "status": "Submitted",
        "title": "wodetiana"
      }
    ]
  },
  "ok": true
}
> 1
提交新论文, 输入标题 (不要含空格) : > EssayForDemo
输入论文内容 (可包含空格) : > This is a demo.
[INFO ] Send request: {"args":["EssayForDemo","This","is","a","dem."],"cmd":"SUBMIT
","rawArgs":"EssayForDemo This is a dem.","sessionId":"sess-2-3"} to 127.0.0.1:5555
{
  "data": {
    "message": "Paper submitted successfully",
    "paperId": 2
  },
  "ok": true
}
输入 c 继续提交, m 返回作者菜单, 其他退出向导: > m
[Author 数字菜单]
  1) 提交新论文
```

```
15:04 [30/139]
```

```
  2) 查看论文详情
  3) 提交评审报告
  (直接输入数字开始操作; 也可以直接输入原始命令)
----------------
> 1
[INFO ] Send request: {"args":[],"cmd":"LIST_PAPERS","sessionId":"sess-4-4"} to 127
.0.0.1:5555
{
  "data": {
    "papers": [
      {
        "authorId": 2,
        "id": 2,
        "status": "Submitted",
        "title": "EssayForDemo"
      }
    ]
  },
  "ok": true
}
>
```

```
  2) 查看审稿状态
  3) 最终决定
  (直接输入数字开始操作; 也可以直接输入原始命令)
----------------
> 1
指派审稿人, 输入 paper_id: > 2
输入 reviewer 用户名: > reviewer
[INFO ] Send request: {"args":["2","reviewer"],"cmd":"ASSIGN_REVIEWER","rawArgs":"2
 reviewer","sessionId":"sess-5-5"} to 127.0.0.1:5555
{
  "data": {
    "message": "Reviewer assigned",
    "paperId": "2",
    "reviewer": "reviewer",
    "reviewerId": 4
  },
  "ok": true
}
输入 c 继续指派, m 返回编辑菜单, 其他退出向导: > m
[Editor 数字菜单]
  1) 指派审稿人
```

```
15:09 [5/47]
```

```
[1] 0:osproj_client*                                "Marcoskk7deMac-mini.l" 15:10 20-Dec-25
```

10. Future Work

1. **Concurrency Refactoring**: Transition the `TcpServer` to a multi-threaded architecture (e.g., thread-per-connection or thread pool) with mutex protection for VFS and Auth resources.
2. **Backup Logic**: Implement full-file copy snapshots for `data.fs`.
3. **VFS Enhancements**: Support for multi-block directories, indirect blocks for larger files, and persistence for the user table.

11. Testing and Verification

- **Protocol Integrity**: Verified via malformed JSON and missing field tests.
- **Permission Boundaries**: Confirmed that Authors cannot access Admin panels and Reviewers cannot access unassigned papers.
- **Cache Statistics**: Validated that repeated reads increase the hit rate in `VIEW_SYSTEM_STATUS`.

12. Team Division

- **Wang Ziheng**: Overall architecture, protocol design, server command routing, and VFS implementation (superblock, inode, bitmap, directory, and cache).
- **Song Xi**: Front-end system architecture and visual interaction implementation, including UI design, dynamic file tree rendering, and communication encapsulation.

- **Zhang Yehan & Li Yutong**: CLI implementation, business logic for four roles, permission matrix, and backup/restore framework.

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13. Appendix: Command Quick Reference

- **Basic**: `PING`, `LOGIN`, `ROLE_HELP`
- **File System**: `LIST`, `MKDIR`, `WRITE`, `READ`, `RM`, `RMDIR`, `CD`
- **Review Flow**: `SUBMIT`, `LIST_PAPERS`, `GET_PAPER`, `ASSIGN_REVIEWER`, `REVIEW`, `VIEW_REVIEW_STATUS`, `MAKE_FINAL_DECISION`
- **Management**: `MANAGE_USERS`, `BACKUP`, `RESTORE`, `VIEW_SYSTEM_STATUS`