project3_executive_summary_weiqing_gao

Assignment Overview

From my perspective, this assignment extends the previous RMI-based Key-Value Store project by introducing replication and consistency among multiple server instances. That is to say, I touched the implementation of a real distributed system. The objective is to guarantee the availability and the consistency across 5 distinct server replicas. The most critical learning goal of this assignment is the implementation of Two-Phase Commit (2PC) protocol, which is the most commonly used atomic commit protocol. Another important goal is to ensure that replicas can dynamically discover and connect to each other, even if they are started at different times. This involves understanding distributed system bootstrapping, dynamic connection management, and handling temporary failures in replica communication.

Overall, this assignment helps us explore distributed consistency protocols (2PC), replication strategies, and fault recovery mechanisms, extending beyond basic client-server communication to a more realistic distributed system setting.

Technical Impression

During this assignment, I realized that distributed consistency is a non-trivial problem. Unlike the previous project, where only a single server handled client requests, this project requires coordination and agreement among all replicas before committing any update to the store. To achieve this, I implemented Two-Phase Commit (2PC):

- In Phase 1 (Voting Phase), the server receiving a client request acts as the coordinator, sending a prepare request to all replicas. Each replica replies with an ACK if ready, or a NACK if any issue.
- In Phase 2 (Commit/Abort Phase), based on responses, the coordinator decides whether to commit or abort, and sends the decision to all replicas.
  The first impressive point to me is the differences between distributed consistency and fault tolerance. I found that some types of errors should lead to a transaction abort, while some should not. Because some errors are local, or non-fatal. I realized that incorrectly aborting due to transient, non-fatal errors would introduce excessive coordination overhead and unnecessary transaction failures.
  Another major technical lesson was managing dynamic replica discovery when servers started at different time. At the very beginning, I did not even realize that this could be an issue. Thus, I started five replicas sequentially by `java KeyValueStoreRMIServer 1099 localhost:1100 localhost:1101 localhost:1102 localhost:1103`. Then I found that each server could only connect to replicas that were already running when it started. Thus, only when the client connects to the last running server, the only one knew all other replicas, the distributed system can work properly. To solve this, I implemented a retry mechanism that allows each server to periodically

attempt connections to replicas it previously failed to connect to. At first, I used a Timer to periodically retry connections. However, when all replicas had finally been connected, I wanted to print a success message like `"All replicas found!"`. Unfortunately, this message kept printing repeatedly, because Timer tasks cannot be stopped easily without external control, and my retry loop ran indefinitely even after achieving its goal. To address this, I refactored the retry logic using `ScheduledExecutorService` (Scheduler), through which I can invoke `scheduler.shutdown()` to stop retries, solving the infinite message issue.

Furthermore, I observed that dealing with failures during 2PC is challenging: if one replica is down, should we abort the whole transaction, or wait? Although this project assumes no permanent failures, it would be an import aspect to make improvement in the future.

Screenshots

The client connects to the server with the port 1102.

first server 1099

```
weiqinggao@Weiqings-MBP src % java KeyValueStoreRMIServer 1099 localhost:1100 localhost:1101 lo
calhost:1102 localhost:1103
[Server] RMI Key-Value Store running on port 1099...
Failed connecting to replica: localhost:1100 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
Failed connecting to replica: localhost:1101 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
Failed connecting to replica: localhost:1102 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
Failed connecting to replica: localhost:1103 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
[Server] Ready. Press Ctrl+C to stop.
[Server] Found replica at localhost:1100
Failed connecting to replica: localhost:1101 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
Failed connecting to replica: localhost:1102 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
Failed connecting to replica: localhost:1103 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
[Server] Found replica at localhost:1101
[Server] Found replica at localhost:1102
Failed connecting to replica: localhost:1103 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
[Server] Found replica at localhost:1103
All replicas found!
```

```
Failed connecting to replica: localhost:1103 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
[Server] Found replica at localhost:1103
All replicas found!
[Replica] COMMIT PUT: key_0 => value_0
[Replica] COMMIT PUT: key_1 => value_1
[Replica] COMMIT PUT: key_2 => value_2
[Replica] COMMIT PUT: key_3 => value_3
[Replica] COMMIT PUT: key_4 => value_4
[Replica] COMMIT PUT: lexus => ls460
[Replica] COMMIT PUT: genesis => g90
[Replica] ABORT: 08033136-03d3-4cde-bff7-1271a27d794b
[Replica] COMMIT PUT: lincoln => continental
[Replica] COMMIT PUT: cadillac => ct6
[Replica] COMMIT PUT: bmw => 7 series
[Replica] COMMIT DELETE: bmw
[Replica] COMMIT DELETE: genesis
[Replica] COMMIT DELETE: key_2
[Replica] COMMIT DELETE: lexus
[Replica] COMMIT DELETE: lincoln
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
```

second server 1100

```
                                                                    weiqinggao@
Weiqings-MBP src % java KeyValueStoreRMIServer 1100 localhost:1099 localhost:1101 localhost:110
2 localhost:1103

[Server] RMI Key-Value Store running on port 1100...
[Server] Found replica at localhost:1099
Failed connecting to replica: localhost:1101 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
Failed connecting to replica: localhost:1102 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
Failed connecting to replica: localhost:1103 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
[Server] Ready. Press Ctrl+C to stop.
[Server] Found replica at localhost:1101
[Server] Found replica at localhost:1102
Failed connecting to replica: localhost:1103 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
[Server] Found replica at localhost:1103
All replicas found!
[Replica] COMMIT PUT: key_0 => value_0
[Replica] COMMIT PUT: key_1 => value_1
[Replica] COMMIT PUT: key_2 => value_2
[Replica] COMMIT PUT: key_3 => value_3
[Replica] COMMIT PUT: key_4 => value_4
[Replica] COMMIT PUT: lexus => ls460
[Replica] COMMIT PUT: genesis => g90
[Replica] ABORT: 08033136-03d3-4cde-bff7-1271a27d794b
[Replica] COMMIT PUT: lincoln => continental
[Replica] COMMIT PUT: cadillac => ct6
[Replica] COMMIT PUT: bmw => 7 series
[Replica] COMMIT DELETE: bmw
[Replica] COMMIT DELETE: genesis
[Replica] COMMIT DELETE: key_2
[Replica] COMMIT DELETE: lexus
[Replica] COMMIT DELETE: lincoln
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
^C%
```

third server 1101

```
Weiqings-MBP src % java KeyValueStoreRMIServer 1101 localhost:1099 localhost:1100 localhost:110
2 localhost:1103
[Server] RMI Key-Value Store running on port 1101...
[Server] Found replica at localhost:1099
[Server] Found replica at localhost:1100
Failed connecting to replica: localhost:1102 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
Failed connecting to replica: localhost:1103 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
[Server] Ready. Press Ctrl+C to stop.
[Server] Found replica at localhost:1102
[Server] Found replica at localhost:1103
All replicas found!
[Replica] COMMIT PUT: key_0 => value_0
[Replica] COMMIT PUT: key_1 => value_1
[Replica] COMMIT PUT: key_2 => value_2
[Replica] COMMIT PUT: key_3 => value_3
[Replica] COMMIT PUT: key_4 => value_4
[Replica] COMMIT PUT: lexus => ls460
[Replica] COMMIT PUT: genesis => g90
[Replica] ABORT: 08033136-03d3-4cde-bff7-1271a27d794b
[Replica] COMMIT PUT: lincoln => continental
[Replica] COMMIT PUT: cadillac => ct6
[Replica] COMMIT PUT: bmw => 7 series
[Replica] COMMIT DELETE: bmw
[Replica] COMMIT DELETE: genesis
[Replica] COMMIT DELETE: key_2
[Replica] COMMIT DELETE: lexus
[Replica] COMMIT DELETE: lincoln
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
^C%
```

forth server 1102

```
Weiqings-MBP src % java KeyValueStoreRMIServer 1102 localhost:1099 localhost:1100 localhost:110
1 localhost:1103
[Server] RMI Key-Value Store running on port 1102...
[Server] Found replica at localhost:1099
[Server] Found replica at localhost:1100
[Server] Found replica at localhost:1101
Failed connecting to replica: localhost:1103 -> Connection refused to host: localhost; nested e
xception is:
        java.net.ConnectException: Connection refused
[Server] Ready. Press Ctrl+C to stop.
[Server] Found replica at localhost:1103
All replicas found!
[Replica] COMMIT PUT: key_0 => value_0
[Coordinator] 2PC success for PUT key_0=value_0
[Replica] COMMIT PUT: key_1 => value_1
[Coordinator] 2PC success for PUT key_1=value_1
[Replica] COMMIT PUT: key_2 => value_2
[Coordinator] 2PC success for PUT key_2=value_2
[Replica] COMMIT PUT: key_3 => value_3
[Coordinator] 2PC success for PUT key_3=value_3
[Replica] COMMIT PUT: key_4 => value_4
[Coordinator] 2PC success for PUT key_4=value_4
[Replica] COMMIT PUT: lexus => ls460
[Coordinator] 2PC success for PUT lexus=ls460
[Replica] COMMIT PUT: genesis => g90
[Coordinator] 2PC success for PUT genesis=g90
[Replica] ABORT: 08033136-03d3-4cde-bff7-1271a27d794b
[Replica] COMMIT PUT: lincoln => continental
[Coordinator] 2PC success for PUT lincoln=continental
[Replica] COMMIT PUT: cadillac => ct6
[Coordinator] 2PC success for PUT cadillac=ct6
[Replica] COMMIT PUT: bmw => 7 series
[Coordinator] 2PC success for PUT bmw=7 series
[Server] GET: key_0 => value_0
[Server] GET: bmw => 7 series
[Server] GET: lexus => ls460
[Server] GET: key_2 => value_2
[Server] GET: genesis => g90
[Server] GET: key_99 => NOT_FOUND
[Replica] COMMIT DELETE: bmw
[Coordinator] 2PC success for DELETE bmw
[Server] GET: bmw => NOT_FOUND
[Replica] COMMIT DELETE: genesis
[Coordinator] 2PC success for DELETE genesis
[Replica] COMMIT DELETE: key_2
[Coordinator] 2PC success for DELETE key_2
[Replica] COMMIT DELETE: lexus
```

```
[Replica] COMMIT DELETE: lexus
[Coordinator] 2PC success for DELETE lexus
[Replica] COMMIT DELETE: lincoln
[Coordinator] 2PC success for DELETE lincoln
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
^C%
```

fifth server 1103

```
                                                              weiqinggao@
Weiqings-MBP src % java KeyValueStoreRMIServer 1103 localhost:1099 localhost:1100 localhost:110
1 localhost:1102
[Server] RMI Key-Value Store running on port 1103...
[Server] Found replica at localhost:1099
[Server] Found replica at localhost:1100
[Server] Found replica at localhost:1101
[Server] Found replica at localhost:1102
All replicas found!
[Server] Ready. Press Ctrl+C to stop.
[Replica] COMMIT PUT: key_0 => value_0
[Replica] COMMIT PUT: key_1 => value_1
[Replica] COMMIT PUT: key_2 => value_2
[Replica] COMMIT PUT: key_3 => value_3
[Replica] COMMIT PUT: key_4 => value_4
[Replica] COMMIT PUT: lexus => ls460
[Replica] COMMIT PUT: genesis => g90
[Replica] ABORT: 08033136-03d3-4cde-bff7-1271a27d794b
[Replica] COMMIT PUT: lincoln => continental
[Replica] COMMIT PUT: cadillac => ct6
[Replica] COMMIT PUT: bmw => 7 series
[Replica] COMMIT DELETE: bmw
[Replica] COMMIT DELETE: genesis
[Replica] COMMIT DELETE: key_2
[Replica] COMMIT DELETE: lexus
[Replica] COMMIT DELETE: lincoln
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
[Replica] ABORT: 005de0c6-e41e-4102-9cec-4984be51c978
^C%
```

client

```
weiqinggao@Weiqings-MBP src % java KeyValueStoreRMIClient localhost 1102
Connected to RMI Key-Value Store on localhost:1102
[Client] Pre-populated: key_0: value_0
[Client] Pre-populated: key_1: value_1
[Client] Pre-populated: key_2: value_2
[Client] Pre-populated: key_3: value_3
[Client] Pre-populated: key_4: value_4
Enter command (PUT/GET/DELETE) or 'exit': PUT
Enter key: lexus
Enter value: ls460
PUT succeeded.
Enter command (PUT/GET/DELETE) or 'exit': put
Enter key: genesis
Enter value: g90
PUT succeeded.
Enter command (PUT/GET/DELETE) or 'exit': Put
Enter key: lexus
Enter value: ls430
Operation failed: Prepare failed on some replica: Replica returned NACK or invalid ack: NACK
Enter command (PUT/GET/DELETE) or 'exit': put
Enter key: lincoln
Enter value: continental
PUT succeeded.
Enter command (PUT/GET/DELETE) or 'exit': cadillac
Invalid command. Use PUT, GET, or DELETE.
Enter command (PUT/GET/DELETE) or 'exit': put
Enter key: cadillac
Enter value: ct6
PUT succeeded.
Enter command (PUT/GET/DELETE) or 'exit': put
Enter key: bmw
Enter value: 7 series
PUT succeeded.
Enter command (PUT/GET/DELETE) or 'exit': get
Enter key: key_0
GET result: value_0
Enter command (PUT/GET/DELETE) or 'exit': GET
Enter key: bmw
GET result: 7 series
Enter command (PUT/GET/DELETE) or 'exit': get
Enter key: lexus
GET result: ls460
Enter command (PUT/GET/DELETE) or 'exit': get
Enter key: key_2
GET result: value_2
Enter command (PUT/GET/DELETE) or 'exit': get
Enter key: genesis
GET result: g90
```

GET result: g98
Enter command (PUT/GET/DELETE) or 'exit': get
Enter key: key_99
GET result: NOT_FOUND

Enter command (PUT/GET/DELETE) or 'exit': get
Enter key: key_99
GET result: NOT_FOUND
Enter command (PUT/GET/DELETE) or 'exit': DELETE
Enter key: bmw
DELETE succeeded.
Enter command (PUT/GET/DELETE) or 'exit': GET
Enter key: bmw
GET result: NOT_FOUND
Enter command (PUT/GET/DELETE) or 'exit': delete
Enter key: genesis
DELETE succeeded.
Enter command (PUT/GET/DELETE) or 'exit': delete
Enter key: key_2
DELETE succeeded.
Enter command (PUT/GET/DELETE) or 'exit': delete
Enter key: lexus
DELETE succeeded.
Enter command (PUT/GET/DELETE) or 'exit': delete
Enter key: lincoln
DELETE succeeded.
Enter command (PUT/GET/DELETE) or 'exit': delete
Enter key: key_99
Operation failed: Prepare failed in delete: Replica returned NACK or invalid ack: NACK
Enter command (PUT/GET/DELETE) or 'exit': exit
Exiting client...
weiqinggao@Weiqings-MBP src %