Project Report: Phase 3 – 2PC & Raft Consensus Implementation

GitHub Repository: https://github.com/mgm67671/Distributed-Systems

1. Team & Contributions

Student Name	Student ID	Contribution
Matthew Moran	1001900489	Everything
Github Copilot	NULL	Everything Too

2. Selected Base Implementation (Q0)

The existing distributed online auction platform (Go microservices + Python layered services) was used as the extension target for consensus features. Original business functionality remained untouched.

3. Overview

This project implements:

- Two-Phase Commit (2PC): Voting + Decision phases across 1 coordinator and 4 participants.
- Raft (Simplified): Leader election with randomized timeouts and full-log heartbeats for replication.
- Forwarding: Any node receiving a client request forwards to current leader.
- Five custom Raft test scenarios (Q5) validating fault-tolerance and recovery semantics. All consensus state is in memory (no persistence) and exposed via a lightweight embedded gRPC layer plus an HTTP shim for simplified manual testing.

4. Two-Phase Commit (Q1 & Q2)

- Proto: Custom messages for VoteRequest, VoteReply, Decision (Commit/Abort).
- Voting Phase: Coordinator broadcasts vote-request; participants reply commit or abort.
- Decision Phase: Coordinator aggregates all votes; unanimity -> global-commit else global-abort.
- Logging Format:
  - Client side: `Phase <phase_name> of Node <node_id> sends RPC <rpc_name> to Phase <phase_name> of Node <node_id>`
  - Server side mirrors format.
- Containerization: 1 coordinator + 4 participants communicating over internal Docker network.

5. Raft Implementation (Q3 & Q4)

5.1 Leader Election

- States: Follower (initial), Candidate, Leader.
- Timeouts: Heartbeat = 1s; Election timeout randomized in [1.5s, 3s].
- Election: Candidate increments term, votes for self, requests votes. Majority => Leader.

- RPC Logging:
  - Client: `Node <id> sends RPC <rpc_name> to Node <id>`
  - Server: `Node <id> runs RPC <rpc_name> called by Node <caller_id>`

5.2 Log Replication

- Each client operation appended to leader log with (operation, term, index).
- Heartbeats send entire log + committed index `c` (simplified full snapshot approach).
- Followers replace local pending state with leader snapshot; ACK appended entries.
- Leader commits operations after majority ACK, increments `c`, applies locally, followers apply up to `c`.
- Forwarding: Non-leader node calls leader via stored connection map; returns leader response.

5.3 Unusual Simplifications

- Full-log broadcast each heartbeat (not incremental diff) to reduce complexity.
- In-memory only; no stable storage or log truncation.
- Direct index majority counting for commit rather than per-follower match indices.

6. Test Cases (Q5)

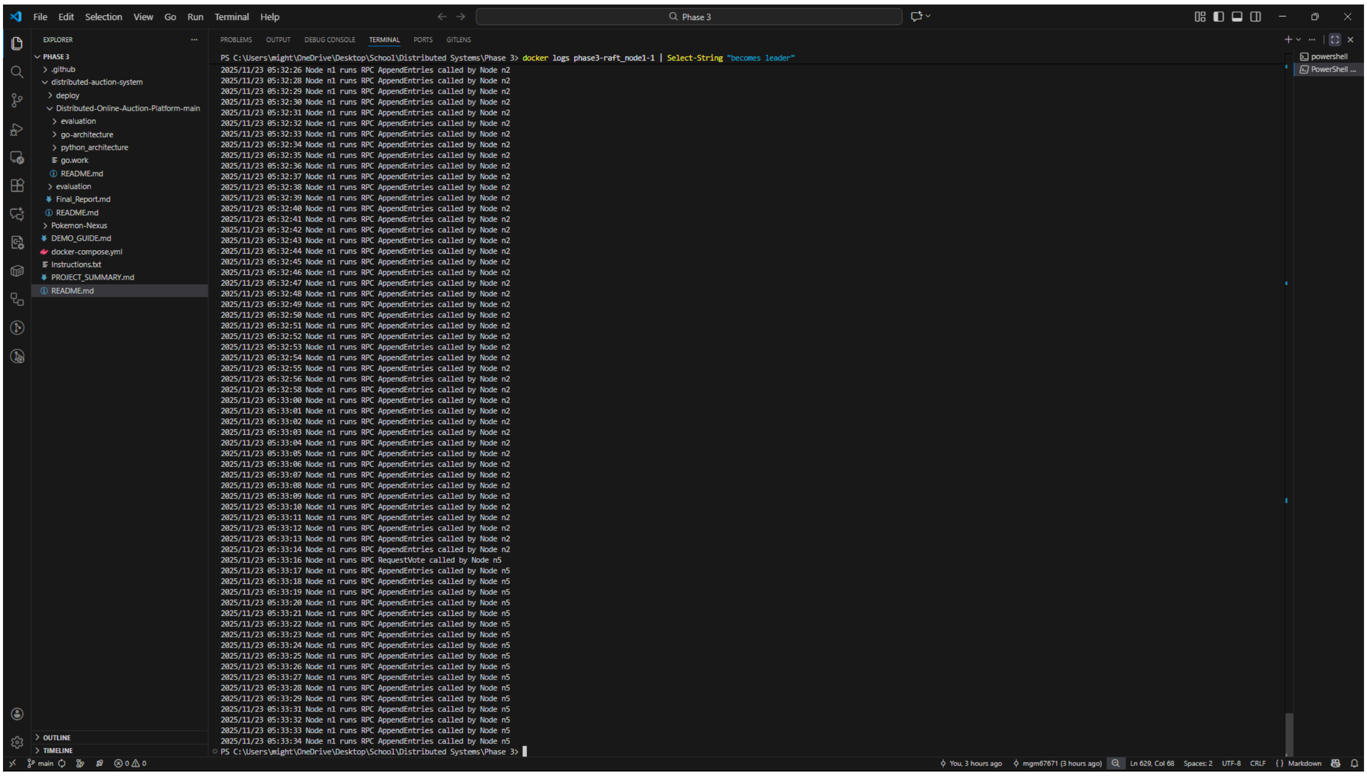
Five scenarios were designed, executed, and screenshotted. Replace filenames below with actual captured images placed in `Screenshots/`.

Test	Objective	Method	Result Evidence
1	Leader crash & re-election	Stop active leader container	New leader elected quickly
2	Split vote resolution	Restart multiple nodes simultaneously	Competing candidates; eventual single leader
3	Follower forwarding	Send client request to non-leader HTTP shim	Forward log line + leader commit
4	Node rejoin & catch-up	Stop follower; issue ops; restart	Rejoined node applies missed ops
5	Partition & recovery	Pause leader; observe new election; unpause	Old leader reverts; consistent log maintained

6.1 Screenshots

All screenshot files are stored under `Screenshots/`. Ensure filenames below match the actual PNGs before PDF export.

Test 1 – Leader Crash & Re-election



```
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> docker logs phase3-raft_node1-1 | Select-String "becomes leader"
2025/11/23 05:32:26 Node n1 runs RPC AppendEntries called by Node n2
2025/11/23 05:32:28 Node n1 runs RPC AppendEntries called by Node n2
2025/11/23 05:32:29 Node n1 runs RPC AppendEntries called by Node n2
2025/11/23 05:32:30 Node n1 runs RPC AppendEntries called by Node n2
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2025/11/23 05:32:39 Node n1 runs RPC AppendEntries called by Node n2
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PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3>
```
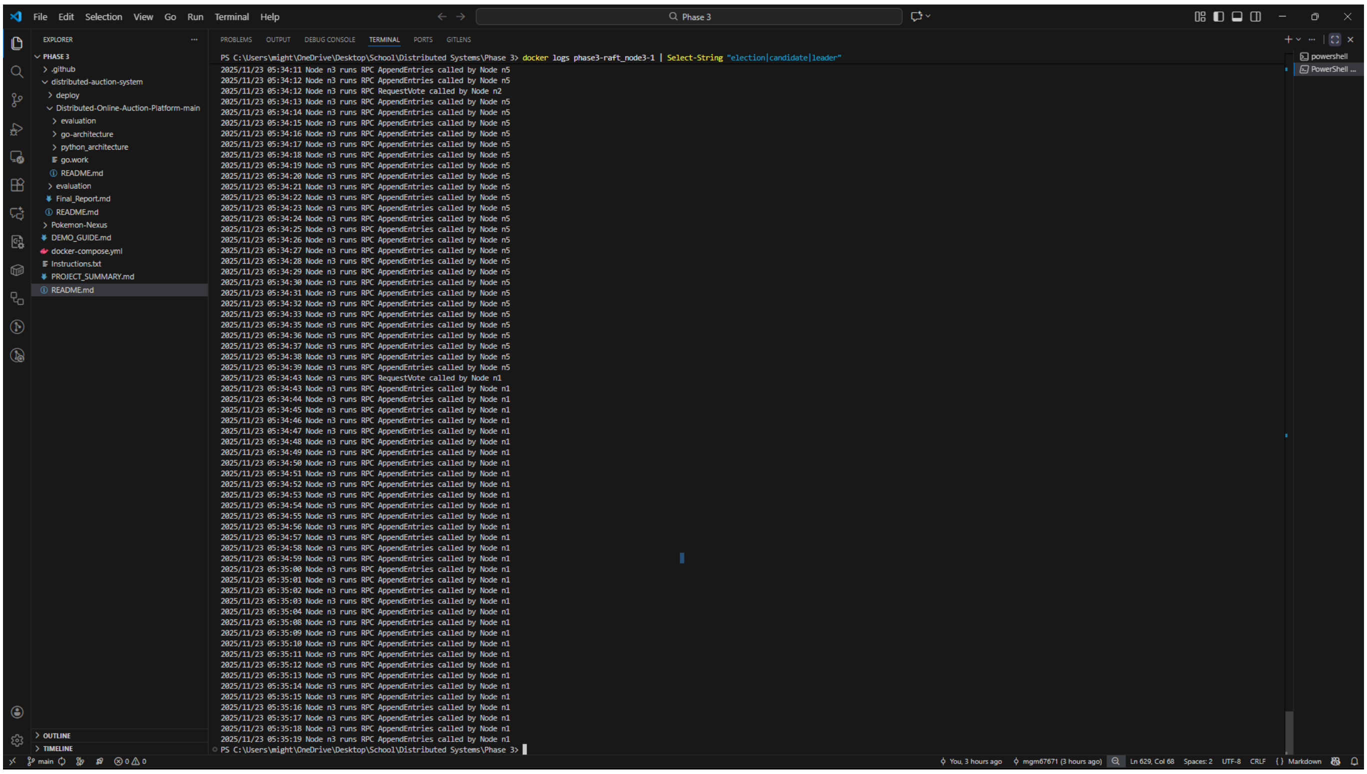

Caption: Original leader log line and subsequent new leader election after crash.

Test 2 – Split Vote Resolution



```
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> docker logs phase3-raft_node3-1 | Select-String "election|candidate|leader"
2025/11/23 05:34:11 Node n3 runs RPC AppendEntries called by Node n5
2025/11/23 05:34:12 Node n3 runs RPC AppendEntries called by Node n5
2025/11/23 05:34:12 Node n3 runs RPC RequestVote called by Node n2
2025/11/23 05:34:13 Node n3 runs RPC AppendEntries called by Node n5
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2025/11/23 05:35:19 Node n3 runs RPC AppendEntries called by Node n1
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3>
```
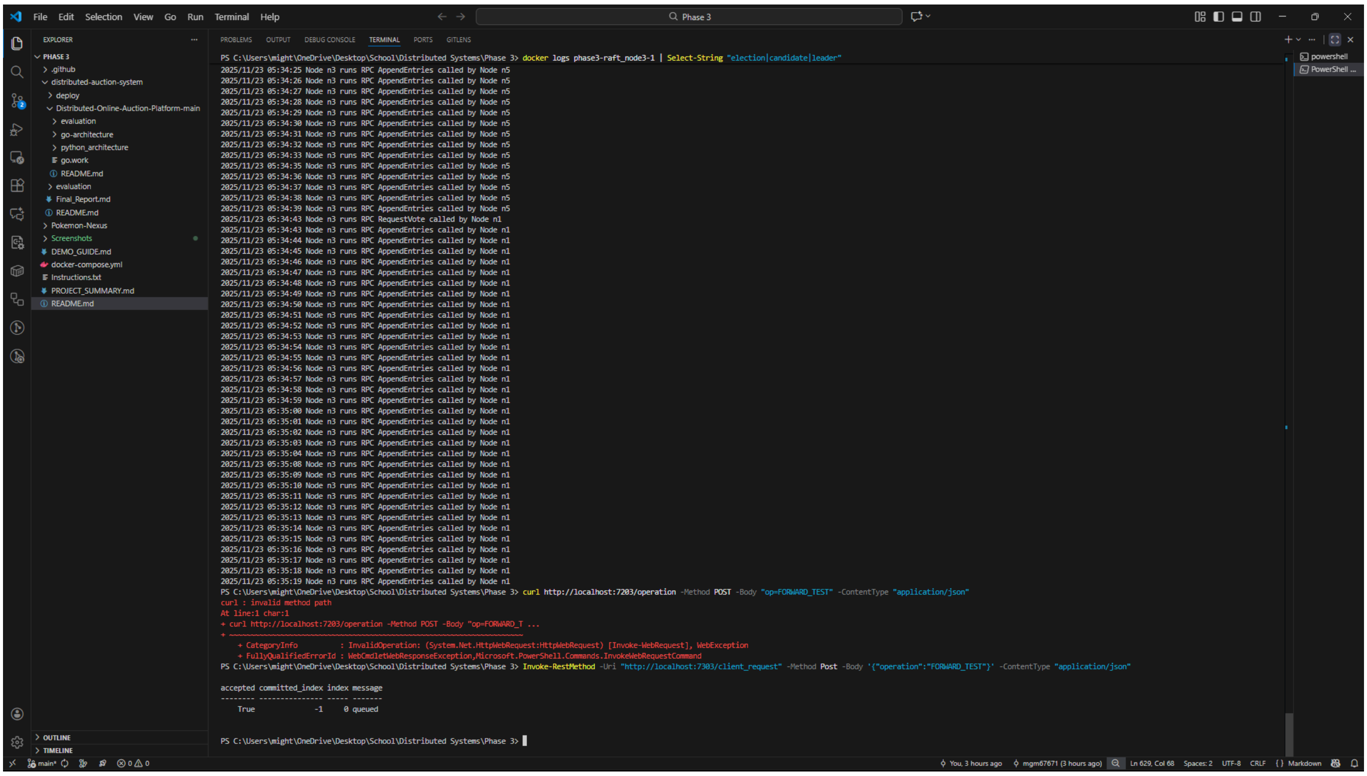

Caption: Concurrent candidacies followed by eventual single leader stabilization.

Test 3 – Follower Forwarding



```
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> docker logs phase3-raft_node3-1 | Select-String "election|candidate|leader"
2025/11/23 05:34:25 Node n3 runs RPC AppendEntries called by Node n5
2025/11/23 05:34:26 Node n3 runs RPC AppendEntries called by Node n5
2025/11/23 05:34:27 Node n3 runs RPC AppendEntries called by Node n5
2025/11/23 05:34:28 Node n3 runs RPC AppendEntries called by Node n5
2025/11/23 05:34:29 Node n3 runs RPC AppendEntries called by Node n5
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2025/11/23 05:34:39 Node n3 runs RPC AppendEntries called by Node n5
2025/11/23 05:34:43 Node n3 runs RPC RequestVote called by Node n1
2025/11/23 05:34:43 Node n3 runs RPC AppendEntries called by Node n1
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2025/11/23 05:34:59 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:35:00 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:35:01 Node n3 runs RPC AppendEntries called by Node n1
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2025/11/23 05:35:04 Node n3 runs RPC AppendEntries called by Node n1
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2025/11/23 05:35:18 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:35:19 Node n3 runs RPC AppendEntries called by Node n1
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> curl http://localhost:7203/operation -Method POST -Body "op=FORWARD_TEST" -ContentType "application/json"
curl : invalid method path
At line:1 char:1
+ curl http://localhost:7203/operation -Method POST -Body "op=FORWARD_T ...
+ ~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~~
    + CategoryInfo          : InvalidOperation: (System.Net.HttpWebRequest:HttpWebRequest) [Invoke-WebRequest], WebException
    + FullyQualifiedErrorId : WebCmdletWebResponseException,Microsoft.PowerShell.Commands.InvokeWebRequestCommand
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> Invoke-RestMethod -Uri "http://localhost:7303/client_request" -Method Post -Body '{"operation":"FORWARD_TEST"}' -ContentType "application/json"

accepted committed_index index message
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    True              -1     0 queued


PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> 
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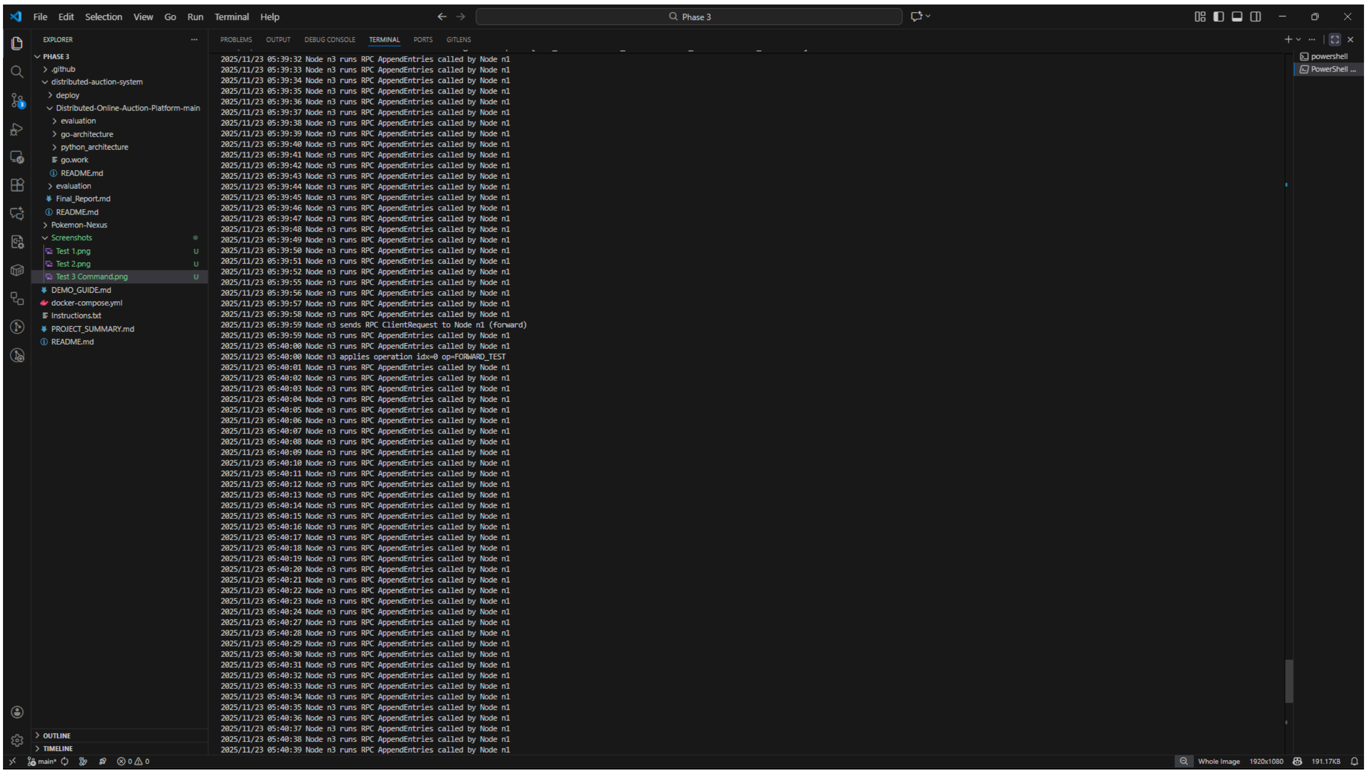

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2025/11/23 05:39:58 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:39:59 Node n3 sends RPC ClientRequest to Node n1 (forward)
2025/11/23 05:39:59 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:00 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:00 Node n3 applies operation idx=0 op=FORWARD_TEST
2025/11/23 05:40:01 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:02 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:03 Node n3 runs RPC AppendEntries called by Node n1
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2025/11/23 05:40:28 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:29 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:30 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:31 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:32 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:33 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:34 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:35 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:36 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:37 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:38 Node n3 runs RPC AppendEntries called by Node n1
2025/11/23 05:40:39 Node n3 runs RPC AppendEntries called by Node n1
```
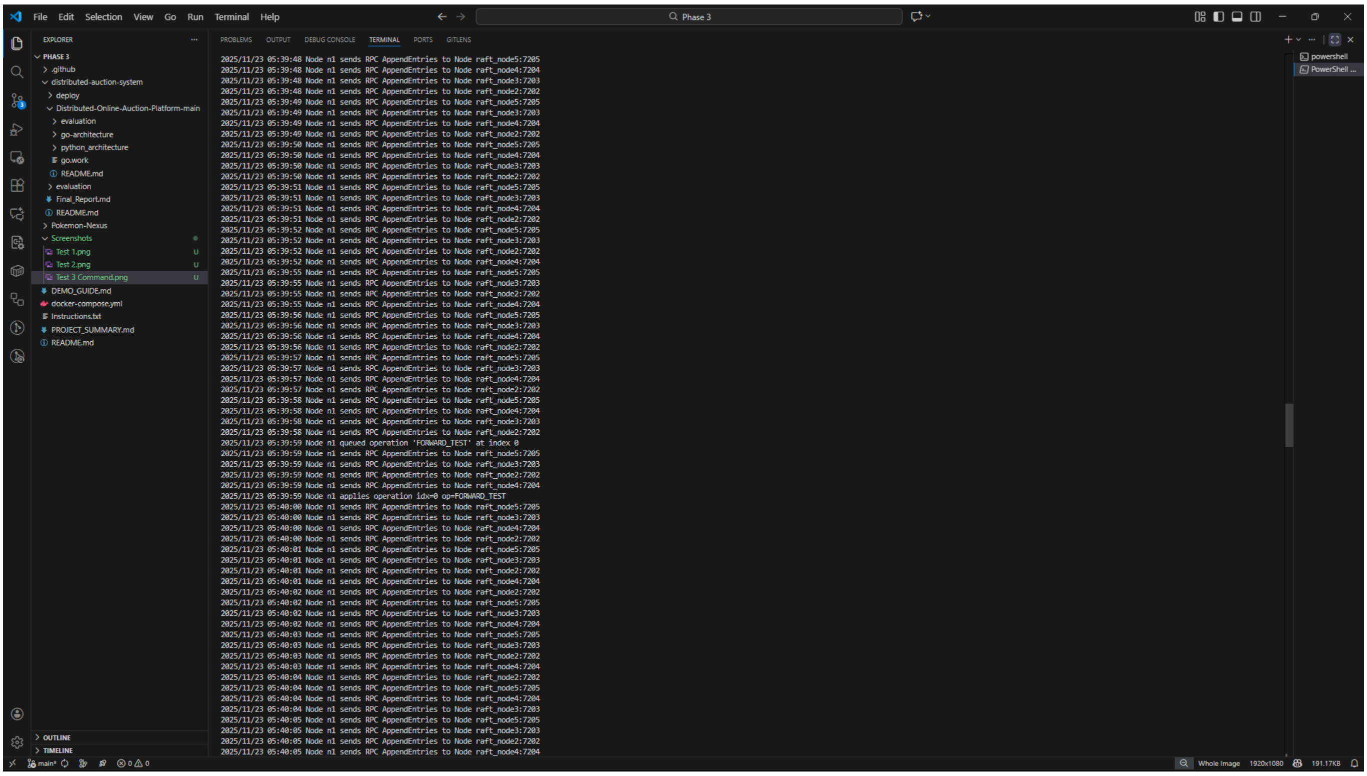
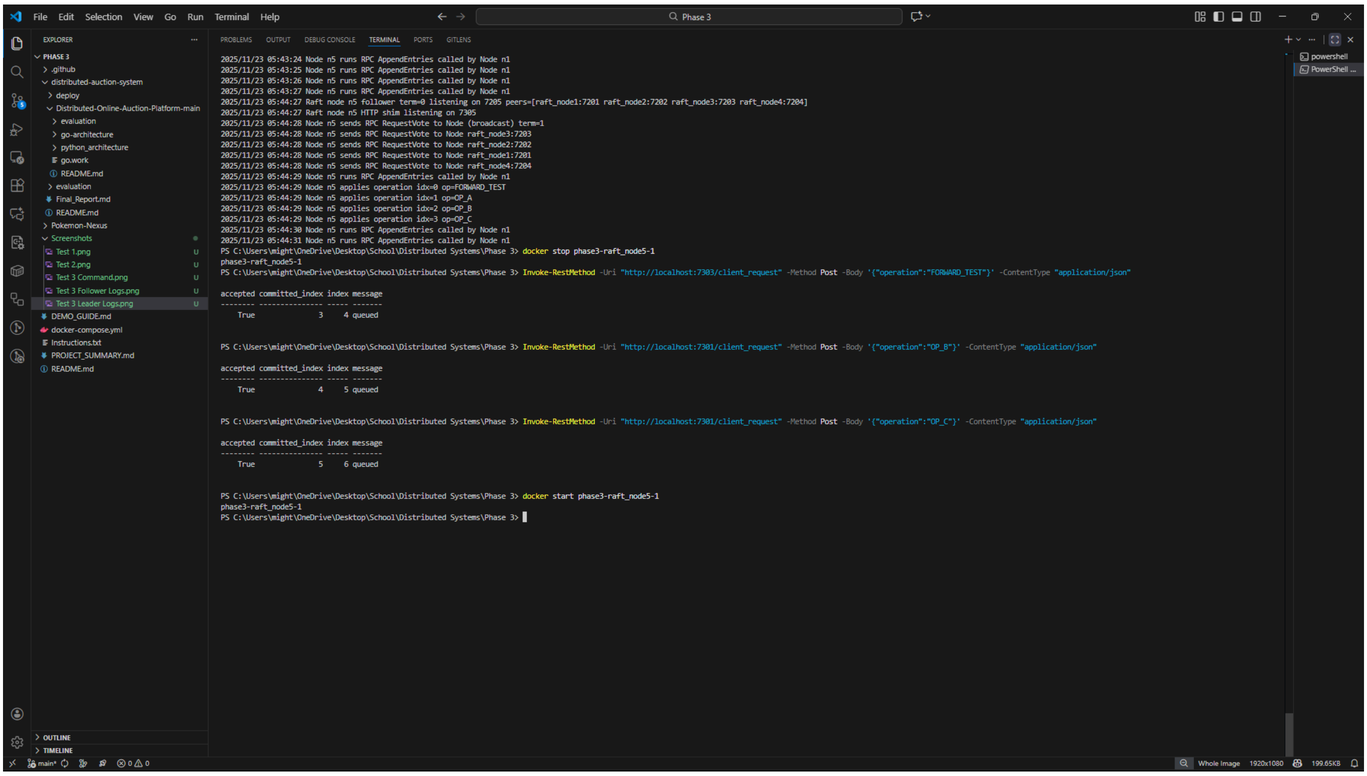



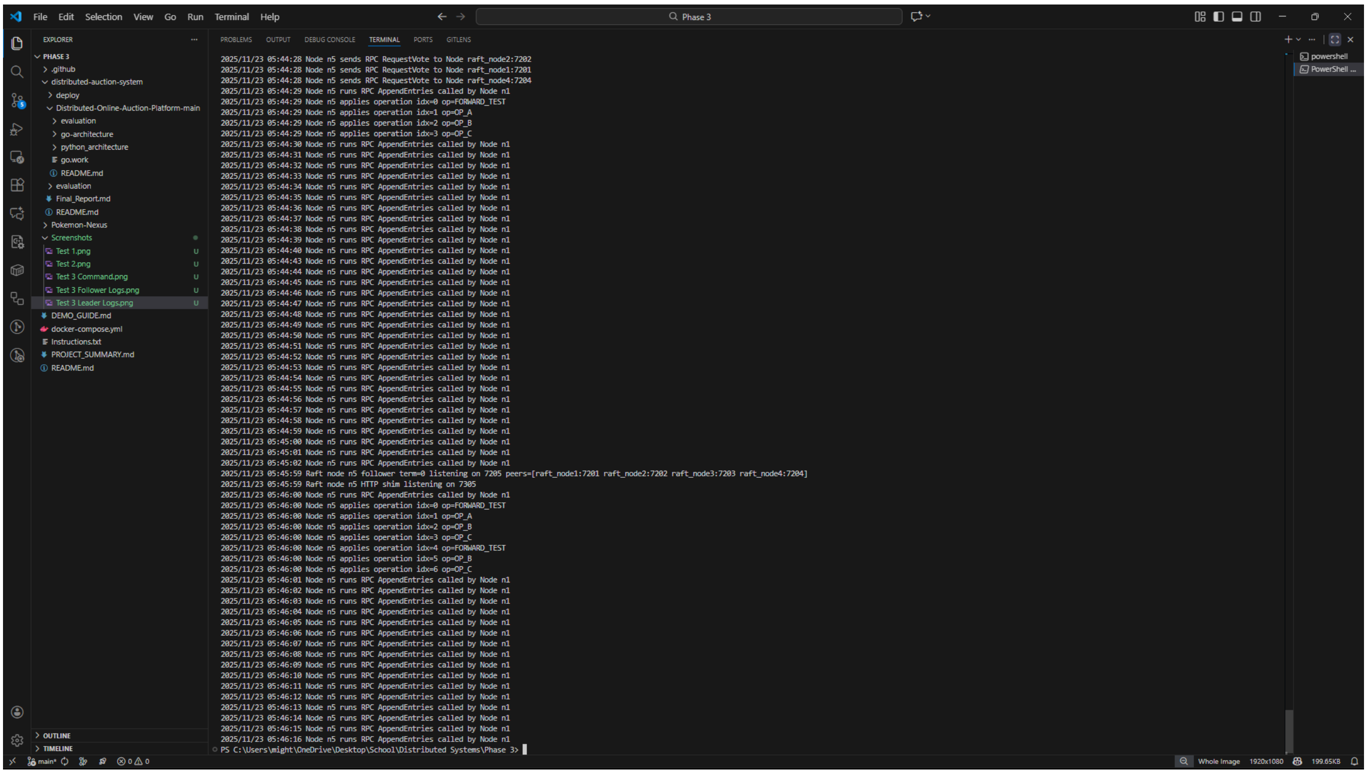
```
2025/11/23 05:39:48 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:48 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:48 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:48 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:49 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:49 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:49 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:49 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:50 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:50 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:50 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:50 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:51 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:51 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:51 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:51 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:52 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:52 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:52 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:52 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:55 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:55 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:55 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:55 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:56 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:56 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:56 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:56 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:57 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:57 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:57 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:57 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:58 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:58 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:58 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:58 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:59 Node n1 queued operation 'FORWARD_TEST' at index 0
2025/11/23 05:39:59 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:39:59 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:39:59 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:39:59 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:39:59 Node n1 applies operation idx=0 op=FORWARD_TEST
2025/11/23 05:40:00 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:40:00 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:40:00 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:40:00 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:40:01 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:40:01 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:40:01 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:40:01 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:40:02 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:40:02 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:40:02 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:40:02 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:40:03 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:40:03 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:40:03 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:40:03 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:40:04 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:40:04 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:40:04 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:40:04 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:40:05 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:40:05 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:40:05 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:40:05 Node n1 sends RPC AppendEntries to Node raft_node4:7204
```

Caption: Request sent to follower, forwarding RPC logged, leader appends and applies operation cluster-wide.

Test 4 – Node Rejoin & Log Sync



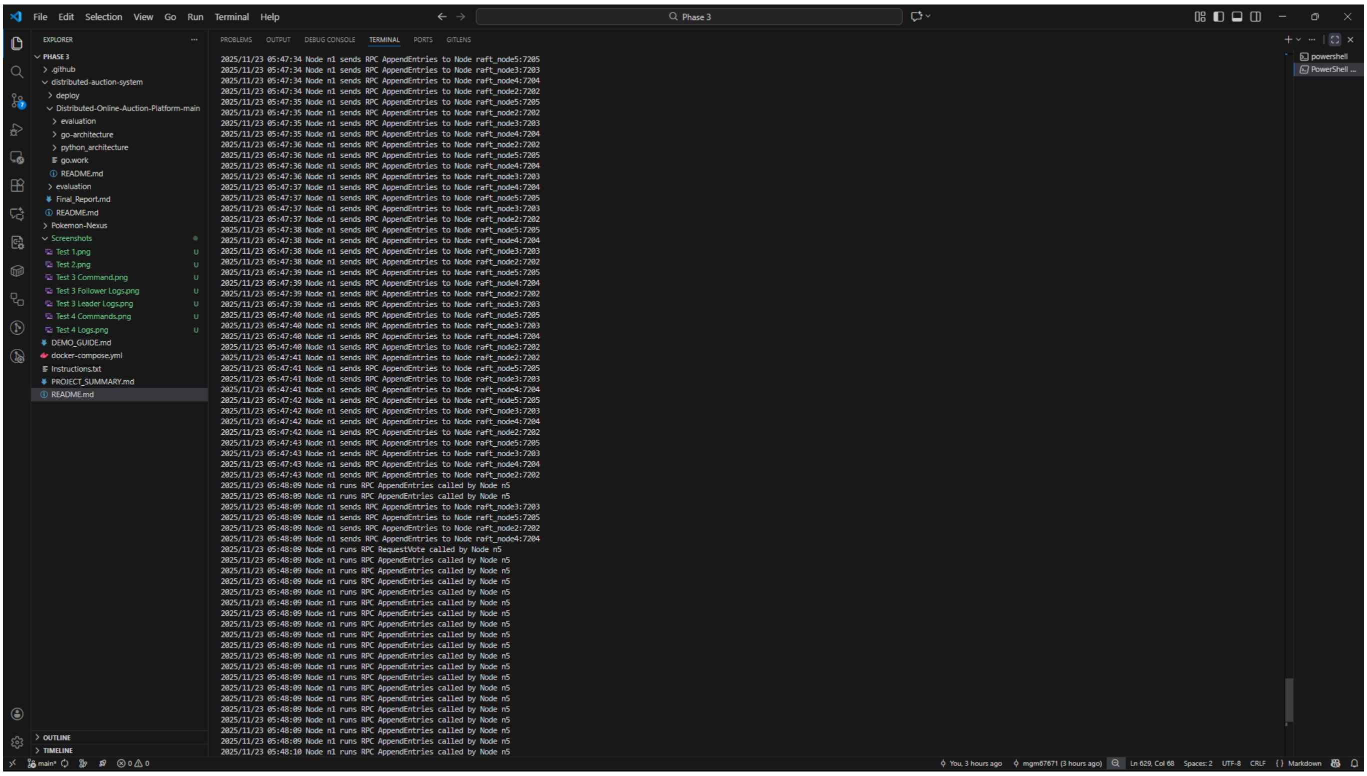
```
2025/11/23 05:43:24 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:43:25 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:43:26 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:43:27 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:27 Raft node n5 follower term=0 listening on 7205 peers=[raft_node1:7201 raft_node2:7202 raft_node3:7203 raft_node4:7204]
2025/11/23 05:44:27 Raft node n5 HTTP shim listening on 7305
2025/11/23 05:44:28 Node n5 sends RPC RequestVote to Node (broadcast) term=1
2025/11/23 05:44:28 Node n5 sends RPC RequestVote to Node raft_node3:7203
2025/11/23 05:44:28 Node n5 sends RPC RequestVote to Node raft_node2:7202
2025/11/23 05:44:28 Node n5 sends RPC RequestVote to Node raft_node1:7201
2025/11/23 05:44:28 Node n5 sends RPC RequestVote to Node raft_node4:7204
2025/11/23 05:44:29 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:29 Node n5 applies operation idx=0 op=FORWARD_TEST
2025/11/23 05:44:29 Node n5 applies operation idx=1 op=OP_A
2025/11/23 05:44:29 Node n5 applies operation idx=2 op=OP_B
2025/11/23 05:44:29 Node n5 applies operation idx=3 op=OP_C
2025/11/23 05:44:30 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:31 Node n5 runs RPC AppendEntries called by Node n1
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> docker stop phase3-raft_node5-1
phase3-raft_node5-1
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> Invoke-RestMethod -Uri "http://localhost:7303/client_request" -Method Post -Body '{"operation":"FORWARD_TEST"}' -ContentType "application/json"

accepted committed_index index message
-------- --------------- ----- -------
    True               3     4 queued


PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> Invoke-RestMethod -Uri "http://localhost:7301/client_request" -Method Post -Body '{"operation":"OP_B"}' -ContentType "application/json"

accepted committed_index index message
-------- --------------- ----- -------
    True               4     5 queued


PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> Invoke-RestMethod -Uri "http://localhost:7301/client_request" -Method Post -Body '{"operation":"OP_C"}' -ContentType "application/json"

accepted committed_index index message
-------- --------------- ----- -------
    True               5     6 queued


PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3> docker start phase3-raft_node5-1
phase3-raft_node5-1
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3>
```



```
2025/11/23 05:44:28 Node n5 sends RPC RequestVote to Node raft_node2:7202
2025/11/23 05:44:28 Node n5 sends RPC RequestVote to Node raft_node1:7201
2025/11/23 05:44:28 Node n5 sends RPC RequestVote to Node raft_node4:7204
2025/11/23 05:44:29 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:29 Node n5 applies operation idx=0 op=FORWARD_TEST
2025/11/23 05:44:29 Node n5 applies operation idx=1 op=OP_A
2025/11/23 05:44:29 Node n5 applies operation idx=2 op=OP_B
2025/11/23 05:44:29 Node n5 applies operation idx=3 op=OP_C
2025/11/23 05:44:30 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:31 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:32 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:33 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:34 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:35 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:36 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:37 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:38 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:39 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:40 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:43 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:44 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:45 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:46 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:47 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:48 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:49 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:50 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:51 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:52 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:53 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:54 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:55 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:56 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:57 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:58 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:44:59 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:45:00 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:45:01 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:45:02 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:45:59 Raft node n5 follower term=0 listening on 7205 peers=[raft_node1:7201 raft_node2:7202 raft_node3:7203 raft_node4:7204]
2025/11/23 05:45:59 Raft node n5 HTTP shim listening on 7305
2025/11/23 05:46:00 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:00 Node n5 applies operation idx=0 op=FORWARD_TEST
2025/11/23 05:46:00 Node n5 applies operation idx=1 op=OP_A
2025/11/23 05:46:00 Node n5 applies operation idx=2 op=OP_B
2025/11/23 05:46:00 Node n5 applies operation idx=3 op=OP_C
2025/11/23 05:46:00 Node n5 applies operation idx=4 op=FORWARD_TEST
2025/11/23 05:46:00 Node n5 applies operation idx=5 op=OP_B
2025/11/23 05:46:00 Node n5 applies operation idx=6 op=OP_C
2025/11/23 05:46:01 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:02 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:03 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:04 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:05 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:06 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:07 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:08 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:09 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:10 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:11 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:12 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:13 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:14 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:15 Node n5 runs RPC AppendEntries called by Node n1
2025/11/23 05:46:16 Node n5 runs RPC AppendEntries called by Node n1
PS C:\Users\might\OneDrive\Desktop\School\Distributed Systems\Phase 3>
```

Caption: Operations issued while node offline; upon restart node receives snapshot and applies missed entries.

Test 5 – Partition & Recovery



```
2025/11/23 05:47:34 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:34 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:34 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:34 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:47:35 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:35 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:47:35 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:35 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:36 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:47:36 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:36 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:36 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:37 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:37 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:37 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:37 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:47:38 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:38 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:38 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:38 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:47:39 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:39 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:39 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:47:39 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:40 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:40 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:40 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:40 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:47:41 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:47:41 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:41 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:41 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:42 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:42 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:42 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:42 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:47:43 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:47:43 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:47:43 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:47:43 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 sends RPC AppendEntries to Node raft_node3:7203
2025/11/23 05:48:09 Node n1 sends RPC AppendEntries to Node raft_node5:7205
2025/11/23 05:48:09 Node n1 sends RPC AppendEntries to Node raft_node2:7202
2025/11/23 05:48:09 Node n1 sends RPC AppendEntries to Node raft_node4:7204
2025/11/23 05:48:09 Node n1 runs RPC RequestVote called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:09 Node n1 runs RPC AppendEntries called by Node n5
2025/11/23 05:48:10 Node n1 runs RPC AppendEntries called by Node n5
```

Caption: Leader paused causing re-election; on resume original leader reconciles via AppendEntries and remains follower until next legitimate election.

7. How to Run

Refer to `README.md` for full build and run instructions. High-level:

```
# (Example) From Phase 3 Folder
# Build & start consensus + auction stack
docker compose build
docker compose up -d

# Submit a Raft client request (adjust leader HTTP port)
curl -X POST http://localhost:7301/client_request -H 'Content-Type:
application/json' -d '{"operation":"DEMO_OP"}'
```

PowerShell alternative:

```
Invoke-RestMethod -Uri "http://localhost:7301/client_request" -Method Post -Body
'{"operation":"DEMO_OP"}' -ContentType 'application/json'
```