

Repo: <https://github.com/jephal/ricart-argawala/>

The system requirements are met with the following specifications:

**R1 – System and Critical Section:** The critical section is emulated by print statements and a 2-second work simulation. The nodes are instantiated to emulate a distributed network where each node can send requests to other nodes in the distributed system. This is ensured by using gRPC for network communication with hardcoded peer discovery (nodes on ports 5001, 5002, 5003).

**R2 – Mutual Exclusion:** Mutual exclusion is ensured by a permission-based entry mechanism where each node only enters the critical section after receiving replies from ALL other nodes. The Ricart-Agrawala rules are enforced in the `RequestAccess` method:

- If a receiver is idle (not requesting and not in CS), it replies immediately
- If a receiver is in the critical section, it defers the request to a deferred queue
- If both sender and receiver are requesting, the receiver compares Lamport timestamps - the lower timestamp (higher priority) wins, with node ID as tiebreaker

There is no possible overlap because everyone respects the same total order and each entrant must collect all permissions before entering.

**R3 – Liveness:** The system guarantees liveness by ensuring that every node requesting access to the critical section will eventually be granted entry. Each request is assigned a Lamport timestamp, and if two requests have the same timestamp, the node ID is used as a tiebreaker. This creates a strict global order among all requests. When a node cannot immediately grant permission (because it is in CS or has higher priority request), it adds the requester to a deferred queue. Once the node exits the critical section, it processes all deferred requests by sending replies, unblocking waiting nodes.

### Algorithm:

The Ricart-Agrawala algorithm implementation demonstrates correct distributed mutual exclusion through a permission-based protocol. The algorithm works in three phases: request, permission gathering, and critical section entry.

**Request Phase:** When a node wants to enter the critical section, it generates a Lamport timestamp and sends REQUEST messages to all peers. Shown in the screenshot below:

```
2025/11/12 19:56:46.690463 Node 1 requesting Critical Section with timestamp 1
2025/11/12 19:56:46.709666 Node 1 waiting for replies from 2 nodes
2025/11/12 19:56:46.711324 Node 1 sent REQUEST to Node 3 with timestamp 1
2025/11/12 19:56:46.711457 Node 1 received REPLY from Node 3
2025/11/12 19:56:46.711488 Node 1 sent REQUEST to Node 2 with timestamp 1
```

**Permission Protocol:** The core algorithm logic is demonstrated when nodes receive competing requests. The logs show correct implementation of the Ricart-Agrawala rules:

Case 1 - Idle node grants immediately:

```
2025/11/12 19:56:46.710715 Node 2 received REQUEST from Node 1 with timestamp 1
2025/11/12 19:56:46.710769 Node 2 sent REPLY to Node 1
```

Case 2 - Node in CS defers requests:

```
2025/11/12 19:56:53.238047 Node 1 received REQUEST from Node 3 with timestamp 11
2025/11/12 19:56:53.238089 Node 1 deferred request from Node 3
2025/11/12 19:56:54.914294 Node 1 EXITED Critical Section
2025/11/12 19:56:54.914349 Node 1 sent deferred REPLY to Node 3
```

Case 3 - Competing requests use timestamp priority:

```
2025/11/12 19:56:57.088985 Node 2 sent REQUEST to Node 3 with timestamp 14
2025/11/12 19:56:57.088998 Node 2 received REPLY from Node 3
2025/11/12 19:56:57.154607 Node 2 received all 2 replies, entering critical section
2025/11/12 19:56:57.154694 Node 2 ENTERED Critical Section
2025/11/12 19:56:58.916907 Node 2 received REQUEST from Node 1 with timestamp 17
2025/11/12 19:56:58.916939 Node 2 deferred request from Node 1
```

```
2025/11/12 19:56:57.054930 Node 1 received REQUEST from Node 2 with timestamp 14
2025/11/12 19:56:57.088496 Node 1 sent REPLY to Node 2
2025/11/12 19:56:58.916191 Node 1 requesting Critical Section with timestamp 17
2025/11/12 19:56:58.916298 Node 1 waiting for replies from 2 nodes
2025/11/12 19:56:58.917083 Node 1 sent REQUEST to Node 3 with timestamp 17
2025/11/12 19:56:58.917286 Node 1 sent REQUEST to Node 2 with timestamp 17
2025/11/12 19:56:58.917464 Node 1 received REPLY from Node 3
2025/11/12 19:56:59.155734 Node 1 received REPLY from Node 2
2025/11/12 19:56:59.218568 Node 1 received all 2 replies, entering critical section
2025/11/12 19:56:59.218620 Node 1 ENTERED Critical Section
2025/11/12 19:57:01.219246 Node 1 EXITED Critical Section
```

Node 2 requesting Critical Section with timestamp 14

Node 1 requesting Critical Section with timestamp 17

Node 2 received REQUEST from Node 1 with timestamp 17

Node 2 deferred request from Node 1 // Node 2 has priority ( $14 < 17$ )

Node 1 only enter after collecting all permissions:

Node 1 received all 2 replies, entering critical section

Node 1 ENTERED Critical Section

Node 1 EXITED Critical Section

The logs demonstrate that the algorithm maintains strict mutual exclusion - no two nodes ever have overlapping critical section access times, proving correctness of the implementation.

## Appendix

### Node 1 log:

```
2025/11/12 19:56:10.665623 Node 1 gRPC server listening on port 5001
2025/11/12 19:56:40.689637 Node 1 connected to Node 3 at localhost:5003
2025/11/12 19:56:40.689852 Node 1 connected to Node 2 at localhost:5002
2025/11/12 19:56:46.690463 Node 1 requesting Critical Section with timestamp 1
2025/11/12 19:56:46.709666 Node 1 waiting for replies from 2 nodes
```

2025/11/12 19:56:46.711324 Node 1 sent REQUEST to Node 3 with timestamp 1  
2025/11/12 19:56:46.711457 Node 1 received REPLY from Node 3  
2025/11/12 19:56:46.711488 Node 1 sent REQUEST to Node 2 with timestamp 1  
2025/11/12 19:56:46.711468 Node 1 received REPLY from Node 2  
2025/11/12 19:56:46.810195 Node 1 received all 2 replies, entering critical section  
2025/11/12 19:56:46.810248 Node 1 ENTERED Critical Section  
2025/11/12 19:56:48.811342 Node 1 EXITED Critical Section  
2025/11/12 19:56:49.950941 Node 1 received REQUEST from Node 2 with timestamp 4  
2025/11/12 19:56:49.951014 Node 1 sent REPLY to Node 2  
2025/11/12 19:56:52.813251 Node 1 requesting Critical Section with timestamp 8  
2025/11/12 19:56:52.813359 Node 1 waiting for replies from 2 nodes  
2025/11/12 19:56:52.814170 Node 1 sent REQUEST to Node 2 with timestamp 8  
2025/11/12 19:56:52.814217 Node 1 received REPLY from Node 2  
2025/11/12 19:56:52.814234 Node 1 received REPLY from Node 3  
2025/11/12 19:56:52.814324 Node 1 sent REQUEST to Node 3 with timestamp 8  
2025/11/12 19:56:52.913814 Node 1 received all 2 replies, entering critical section  
2025/11/12 19:56:52.913889 Node 1 ENTERED Critical Section  
2025/11/12 19:56:53.238047 Node 1 received REQUEST from Node 3 with timestamp 11  
2025/11/12 19:56:53.238089 Node 1 deferred request from Node 3  
2025/11/12 19:56:54.914294 Node 1 EXITED Critical Section  
2025/11/12 19:56:54.914349 Node 1 sent deferred REPLY to Node 3  
2025/11/12 19:56:57.054930 Node 1 received REQUEST from Node 2 with timestamp 14  
2025/11/12 19:56:57.088496 Node 1 sent REPLY to Node 2  
2025/11/12 19:56:58.916191 Node 1 requesting Critical Section with timestamp 17  
2025/11/12 19:56:58.916298 Node 1 waiting for replies from 2 nodes  
2025/11/12 19:56:58.917083 Node 1 sent REQUEST to Node 3 with timestamp 17  
2025/11/12 19:56:58.917286 Node 1 sent REQUEST to Node 2 with timestamp 17  
2025/11/12 19:56:58.917464 Node 1 received REPLY from Node 3  
2025/11/12 19:56:59.155734 Node 1 received REPLY from Node 2  
2025/11/12 19:56:59.218568 Node 1 received all 2 replies, entering critical section  
2025/11/12 19:56:59.218620 Node 1 ENTERED Critical Section  
2025/11/12 19:57:01.219246 Node 1 EXITED Critical Section  
2025/11/12 19:57:02.947432 Node 1 received REQUEST from Node 3 with timestamp 20  
2025/11/12 19:57:02.947472 Node 1 sent REPLY to Node 3  
2025/11/12 19:57:04.156266 Node 1 received REQUEST from Node 2 with timestamp 23  
2025/11/12 19:57:04.156306 Node 1 sent REPLY to Node 2  
2025/11/12 19:57:05.220253 Node 1 requesting Critical Section with timestamp 26  
2025/11/12 19:57:05.220319 Node 1 waiting for replies from 2 nodes  
2025/11/12 19:57:05.220666 Node 1 sent REQUEST to Node 2 with timestamp 26  
2025/11/12 19:57:05.220764 Node 1 sent REQUEST to Node 3 with timestamp 26  
2025/11/12 19:57:05.220926 Node 1 received REPLY from Node 3  
2025/11/12 19:57:07.061767 Node 1 received REPLY from Node 2  
2025/11/12 19:57:07.125731 Node 1 received all 2 replies, entering critical section  
2025/11/12 19:57:07.125778 Node 1 ENTERED Critical Section  
2025/11/12 19:57:09.126238 Node 1 EXITED Critical Section  
2025/11/12 19:57:11.050310 Node 1 received REQUEST from Node 3 with timestamp 29  
2025/11/12 19:57:11.050398 Node 1 sent REPLY to Node 3  
2025/11/12 19:57:12.063276 Node 1 received REQUEST from Node 2 with timestamp 32

2025/11/12 19:57:12.096340 Node 1 sent REPLY to Node 2  
2025/11/12 19:57:13.127283 Node 1 requesting Critical Section with timestamp 35  
2025/11/12 19:57:13.127340 Node 1 waiting for replies from 2 nodes  
2025/11/12 19:57:13.128059 Node 1 sent REQUEST to Node 2 with timestamp 35  
2025/11/12 19:57:13.128089 Node 1 sent REQUEST to Node 3 with timestamp 35  
2025/11/12 19:57:13.151862 Node 1 received REPLY from Node 3  
2025/11/12 19:57:15.200970 Node 1 received REPLY from Node 2  
2025/11/12 19:57:15.234447 Node 1 received all 2 replies, entering critical section  
2025/11/12 19:57:15.234496 Node 1 ENTERED Critical Section

#### **Node 2 log:**

2025/11/12 19:56:12.944758 Node 2 gRPC server listening on port 5002  
2025/11/12 19:56:42.947543 Node 2 connected to Node 1 at localhost:5001  
2025/11/12 19:56:42.947810 Node 2 connected to Node 3 at localhost:5003  
2025/11/12 19:56:46.710715 Node 2 received REQUEST from Node 1 with timestamp 1  
2025/11/12 19:56:46.710769 Node 2 sent REPLY to Node 1  
2025/11/12 19:56:49.950209 Node 2 requesting Critical Section with timestamp 4  
2025/11/12 19:56:49.950320 Node 2 waiting for replies from 2 nodes  
2025/11/12 19:56:49.951208 Node 2 sent REQUEST to Node 1 with timestamp 4  
2025/11/12 19:56:49.951374 Node 2 received REPLY from Node 3  
2025/11/12 19:56:49.951377 Node 2 received REPLY from Node 1  
2025/11/12 19:56:49.951587 Node 2 sent REQUEST to Node 3 with timestamp 4  
2025/11/12 19:56:50.050958 Node 2 received all 2 replies, entering critical section  
2025/11/12 19:56:50.051112 Node 2 ENTERED Critical Section  
2025/11/12 19:56:52.051604 Node 2 EXITED Critical Section  
2025/11/12 19:56:52.813801 Node 2 received REQUEST from Node 1 with timestamp 8  
2025/11/12 19:56:52.813849 Node 2 sent REPLY to Node 1  
2025/11/12 19:56:53.238022 Node 2 received REQUEST from Node 3 with timestamp 11  
2025/11/12 19:56:53.238065 Node 2 sent REPLY to Node 3  
2025/11/12 19:56:57.054256 Node 2 requesting Critical Section with timestamp 14  
2025/11/12 19:56:57.054338 Node 2 waiting for replies from 2 nodes  
2025/11/12 19:56:57.088831 Node 2 sent REQUEST to Node 1 with timestamp 14  
2025/11/12 19:56:57.088929 Node 2 received REPLY from Node 1  
2025/11/12 19:56:57.088985 Node 2 sent REQUEST to Node 3 with timestamp 14  
2025/11/12 19:56:57.088998 Node 2 received REPLY from Node 3  
2025/11/12 19:56:57.154607 Node 2 received all 2 replies, entering critical section  
2025/11/12 19:56:57.154694 Node 2 ENTERED Critical Section  
2025/11/12 19:56:58.916907 Node 2 received REQUEST from Node 1 with timestamp 17  
2025/11/12 19:56:58.916939 Node 2 deferred request from Node 1  
2025/11/12 19:56:59.154906 Node 2 EXITED Critical Section  
2025/11/12 19:56:59.155039 Node 2 sent deferred REPLY to Node 1  
2025/11/12 19:57:02.947434 Node 2 received REQUEST from Node 3 with timestamp 20  
2025/11/12 19:57:02.947490 Node 2 sent REPLY to Node 3  
2025/11/12 19:57:04.155592 Node 2 requesting Critical Section with timestamp 23  
2025/11/12 19:57:04.155692 Node 2 waiting for replies from 2 nodes  
2025/11/12 19:57:04.156604 Node 2 sent REQUEST to Node 1 with timestamp 23  
2025/11/12 19:57:04.156638 Node 2 sent REQUEST to Node 3 with timestamp 23  
2025/11/12 19:57:04.156659 Node 2 received REPLY from Node 1

2025/11/12 19:57:05.048707 Node 2 received REPLY from Node 3  
2025/11/12 19:57:05.060052 Node 2 received all 2 replies, entering critical section  
2025/11/12 19:57:05.060101 Node 2 ENTERED Critical Section  
2025/11/12 19:57:05.220567 Node 2 received REQUEST from Node 1 with timestamp 26  
2025/11/12 19:57:05.220588 Node 2 deferred request from Node 1  
2025/11/12 19:57:07.061293 Node 2 EXITED Critical Section  
2025/11/12 19:57:07.061351 Node 2 sent deferred REPLY to Node 1  
2025/11/12 19:57:11.050225 Node 2 received REQUEST from Node 3 with timestamp 29  
2025/11/12 19:57:11.050257 Node 2 sent REPLY to Node 3  
2025/11/12 19:57:12.062292 Node 2 requesting Critical Section with timestamp 32  
2025/11/12 19:57:12.062382 Node 2 waiting for replies from 2 nodes  
2025/11/12 19:57:12.096739 Node 2 sent REQUEST to Node 1 with timestamp 32  
2025/11/12 19:57:12.096899 Node 2 sent REQUEST to Node 3 with timestamp 32  
2025/11/12 19:57:12.096966 Node 2 received REPLY from Node 1  
2025/11/12 19:57:13.127786 Node 2 received REQUEST from Node 1 with timestamp 35  
2025/11/12 19:57:13.127848 Node 2 deferred request from Node 1  
2025/11/12 19:57:13.151921 Node 2 received REPLY from Node 3  
2025/11/12 19:57:13.199352 Node 2 received all 2 replies, entering critical section  
2025/11/12 19:57:13.199398 Node 2 ENTERED Critical Section  
2025/11/12 19:57:15.200530 Node 2 EXITED Critical Section  
2025/11/12 19:57:15.200583 Node 2 sent deferred REPLY to Node 1

### **Node 3 log:**

2025/11/12 19:56:15.235296 Node 3 gRPC server listening on port 5003  
2025/11/12 19:56:45.236751 Node 3 connected to Node 1 at localhost:5001  
2025/11/12 19:56:45.236900 Node 3 connected to Node 2 at localhost:5002  
2025/11/12 19:56:46.710730 Node 3 received REQUEST from Node 1 with timestamp 1  
2025/11/12 19:56:46.710769 Node 3 sent REPLY to Node 1  
2025/11/12 19:56:49.950942 Node 3 received REQUEST from Node 2 with timestamp 4  
2025/11/12 19:56:49.951004 Node 3 sent REPLY to Node 2  
2025/11/12 19:56:52.813857 Node 3 received REQUEST from Node 1 with timestamp 8  
2025/11/12 19:56:52.813904 Node 3 sent REPLY to Node 1  
2025/11/12 19:56:53.237339 Node 3 requesting Critical Section with timestamp 11  
2025/11/12 19:56:53.237472 Node 3 waiting for replies from 2 nodes  
2025/11/12 19:56:53.238353 Node 3 sent REQUEST to Node 2 with timestamp 11  
2025/11/12 19:56:53.238456 Node 3 sent REQUEST to Node 1 with timestamp 11  
2025/11/12 19:56:53.238548 Node 3 received REPLY from Node 2  
2025/11/12 19:56:54.914773 Node 3 received REPLY from Node 1  
2025/11/12 19:56:54.942475 Node 3 received all 2 replies, entering critical section  
2025/11/12 19:56:54.942593 Node 3 ENTERED Critical Section  
2025/11/12 19:56:56.943372 Node 3 EXITED Critical Section  
2025/11/12 19:56:57.054727 Node 3 received REQUEST from Node 2 with timestamp 14  
2025/11/12 19:56:57.088722 Node 3 sent REPLY to Node 2  
2025/11/12 19:56:58.916818 Node 3 received REQUEST from Node 1 with timestamp 17  
2025/11/12 19:56:58.916876 Node 3 sent REPLY to Node 1  
2025/11/12 19:57:02.946929 Node 3 requesting Critical Section with timestamp 20  
2025/11/12 19:57:02.947036 Node 3 waiting for replies from 2 nodes  
2025/11/12 19:57:02.947601 Node 3 sent REQUEST to Node 1 with timestamp 20

2025/11/12 19:57:02.947789 Node 3 received REPLY from Node 2  
2025/11/12 19:57:02.947848 Node 3 sent REQUEST to Node 2 with timestamp 20  
2025/11/12 19:57:02.947857 Node 3 received REPLY from Node 1  
2025/11/12 19:57:03.047299 Node 3 received all 2 replies, entering critical section  
2025/11/12 19:57:03.047353 Node 3 ENTERED Critical Section  
2025/11/12 19:57:04.156224 Node 3 received REQUEST from Node 2 with timestamp 23  
2025/11/12 19:57:04.156265 Node 3 deferred request from Node 2  
2025/11/12 19:57:05.048320 Node 3 EXITED Critical Section  
2025/11/12 19:57:05.048365 Node 3 sent deferred REPLY to Node 2  
2025/11/12 19:57:05.220637 Node 3 received REQUEST from Node 1 with timestamp 26  
2025/11/12 19:57:05.220671 Node 3 sent REPLY to Node 1  
2025/11/12 19:57:11.049574 Node 3 requesting Critical Section with timestamp 29  
2025/11/12 19:57:11.049771 Node 3 waiting for replies from 2 nodes  
2025/11/12 19:57:11.050545 Node 3 sent REQUEST to Node 1 with timestamp 29  
2025/11/12 19:57:11.050546 Node 3 sent REQUEST to Node 2 with timestamp 29  
2025/11/12 19:57:11.050742 Node 3 received REPLY from Node 1  
2025/11/12 19:57:11.050769 Node 3 received REPLY from Node 2  
2025/11/12 19:57:11.150360 Node 3 received all 2 replies, entering critical section  
2025/11/12 19:57:11.150415 Node 3 ENTERED Critical Section  
2025/11/12 19:57:12.063409 Node 3 received REQUEST from Node 2 with timestamp 32  
2025/11/12 19:57:12.096521 Node 3 deferred request from Node 2  
2025/11/12 19:57:13.127786 Node 3 received REQUEST from Node 1 with timestamp 35  
2025/11/12 19:57:13.127883 Node 3 deferred request from Node 1  
2025/11/12 19:57:13.151436 Node 3 EXITED Critical Section  
2025/11/12 19:57:13.151478 Node 3 sent deferred REPLY to Node 2  
2025/11/12 19:57:13.151487 Node 3 sent deferred REPLY to Node 1  
2025/11/12 19:57:19.152970 Node 3 requesting Critical Section with timestamp 39  
2025/11/12 19:57:19.153080 Node 3 waiting for replies from 2 nodes  
2025/11/12 19:57:19.154048 Node 3 failed to send REQUEST to Node 1: rpc error: code = Unavailable desc = connection error: desc = "transport: Error while dialing: dial tcp 127.0.0.1:5001: connect: connection refused"  
2025/11/12 19:57:19.154053 Node 3 failed to send REQUEST to Node 2: rpc error: code = Unavailable desc = connection error: desc = "transport: Error while dialing: dial tcp 127.0.0.1:5002: connect: connection refused"