System Implementation Strategies + Raft Leader Election

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"Oh, you wanted to *increment a counter*?! Good luck with that!" -- the distributed systems literature

2:55 PM · Mar 9, 2015

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Overview

- Successful System Implementation Strategies
  - Understand the Concepts and Code Structure
  - Iterative Design Process
  - Modular Programming
  - Tips on Debugging
- Raft Leader Election

Understanding Concepts and Code Structure

Understand the Concept and Code Structure

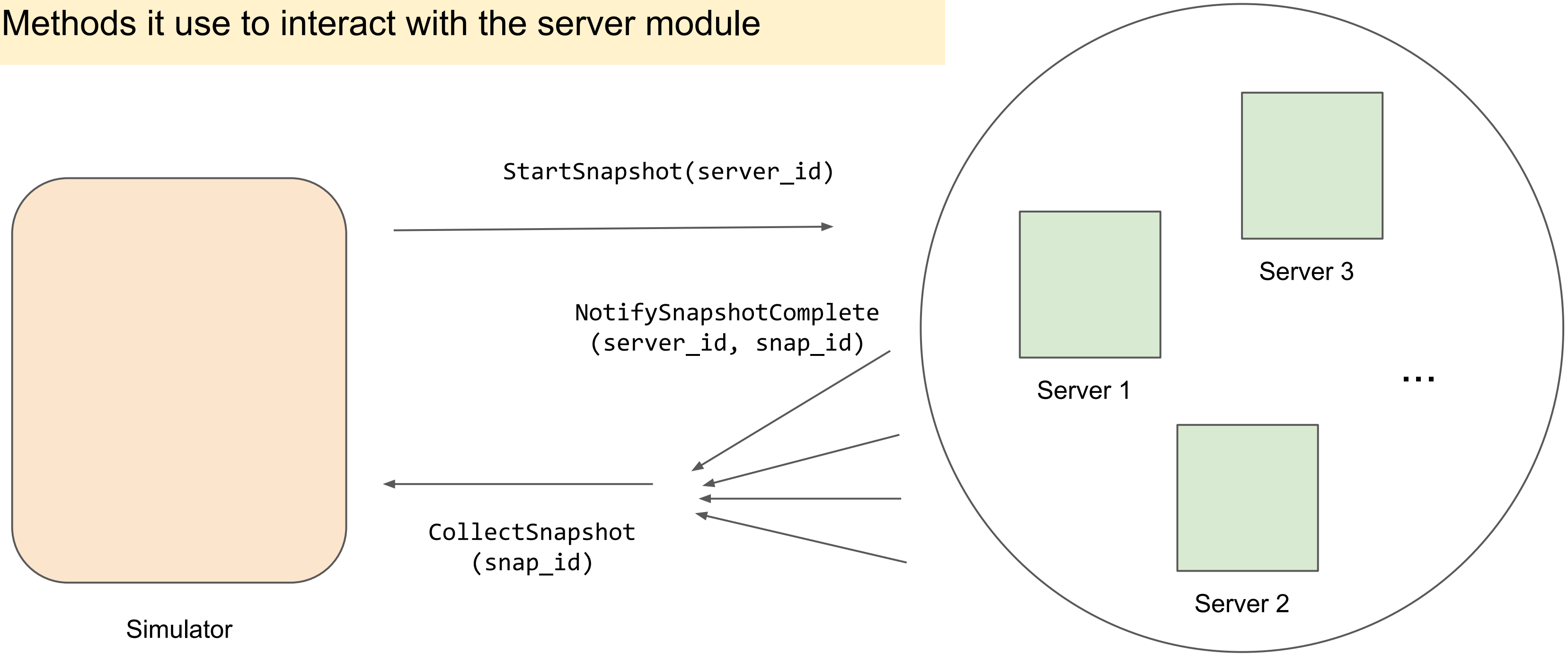
- What is the conceptual system you want to build? **Concept**
  - Understand the concept and verify your knowledge with some examples
  - Rewrite the algorithm to some pseudocode, which can serve as the guide during actual programming
- How is the system physically built? **Build**
  - Read the skeleton code
  - Map the algorithms/concepts to the given code structure
  - Draw flow charts to understand the code flow
- How to use the system? **Usage**
  - Read the testing script to see how an external user will talk to our system and invoke its APIs to accomplish desired tasks

Understand Concept and Code Structure

- Fully comprehend the algorithm
- Spend time to map your understanding of the concept to the starter code
    - For both the system interface and individual modules, understand **what** data is transferred between and **how**
- Charts and pseudocode can help A LOT!

How is the System Physically Built?

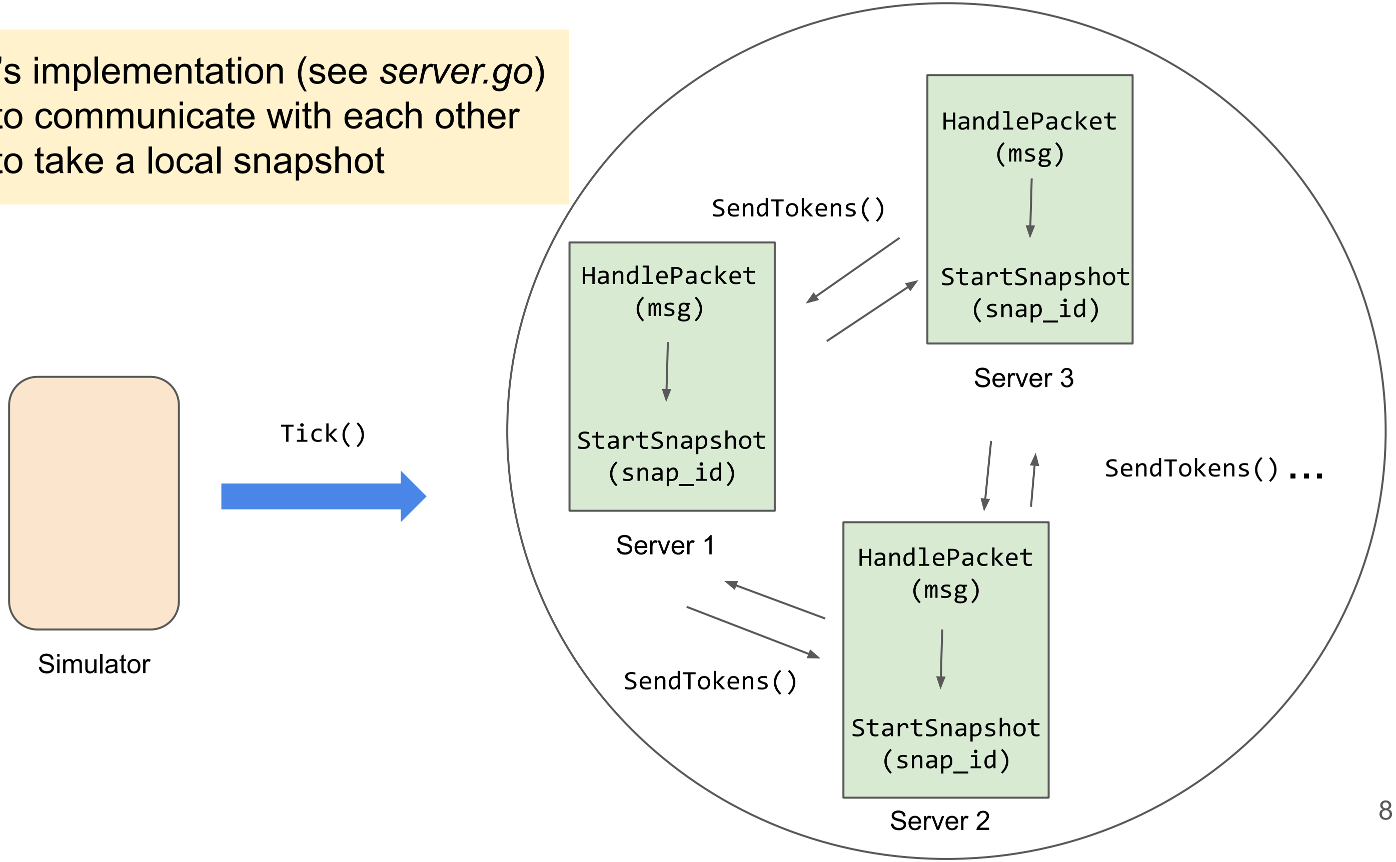
Understand the simulator's implementation (see *simulator.go*)
- The role of the simulator
- Methods it use to interact with the server module



How is the System Physically Built?

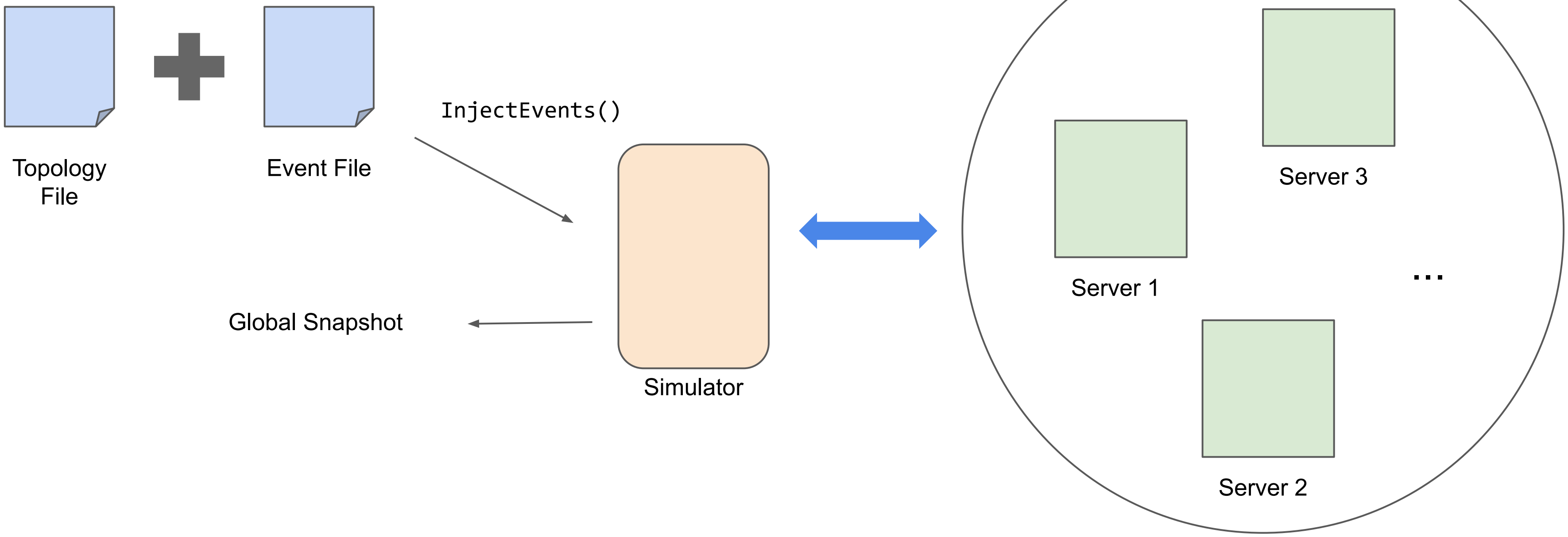
Understand the server's implementation (see *server.go*)

- Methods it uses to communicate with each other
- Methods it uses to take a local snapshot



How to Use the System?

Understand how the external environment talks to our system (see *test_common.go* and *snapshot_test.go*)



Iterative Design Process

Iterative Design Process

Common design methodology in product design, including software design

You will understand a little more about your design when you start implementing it.

- Start with the base case (aka simplest case)
    - Example: one global snapshot at a time for Assignment 2, distributed MapReduce without any failure for Assignment 1.3
- Test regularly: should pass test case for 2 nodes, then 3 nodes and …
- Add one more complexity at a time

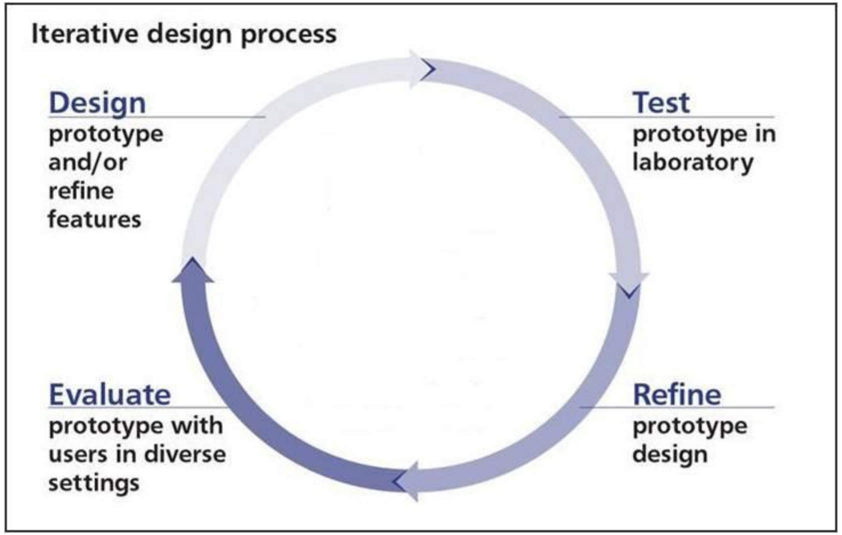
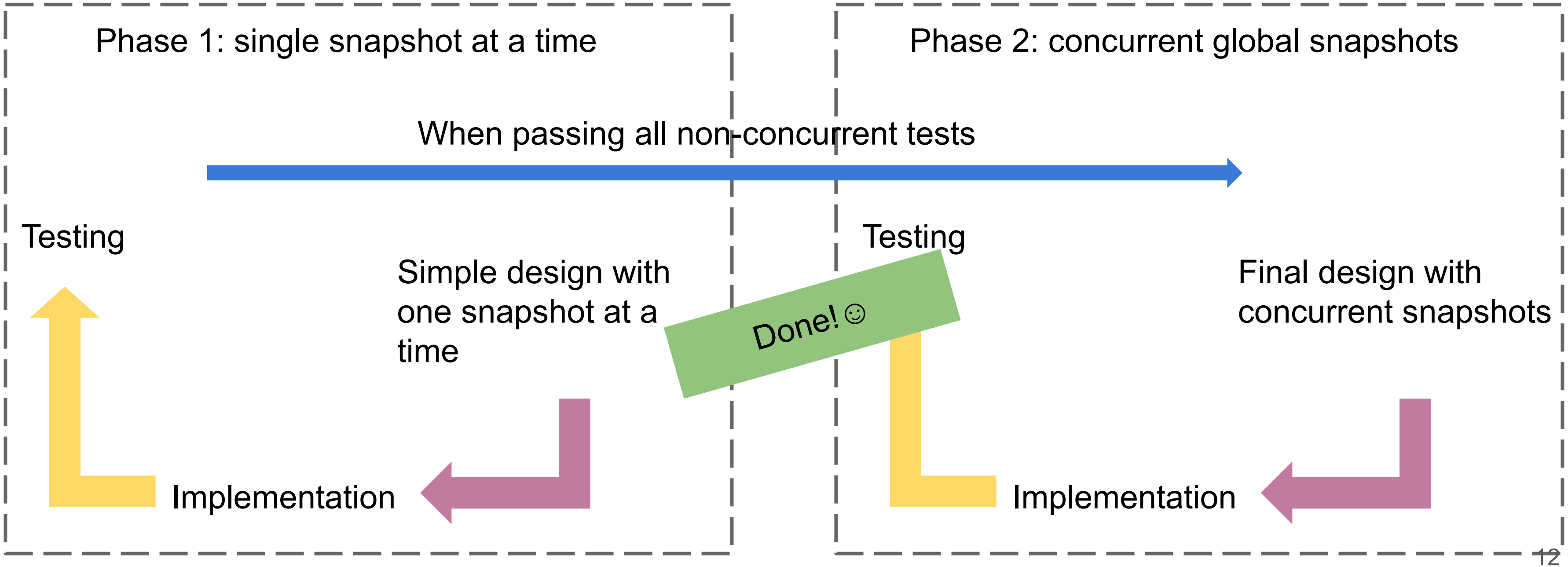


Image Source from the Internet

Iterative Design Process: Distributed Snapshot

Key Idea: Start Simple, then Build Up



Modular Programming

Modular Programming

Iterative design means code change every time when refining the design ☹️

Modular programming

- Decompose the system into several independent modules/pieces
- Use a set of simple yet flexible APIs for intra-module communication

Advantages of modular programming

- Makes it easier to reason about and debug each component of your system
- Requires minimal change in the code

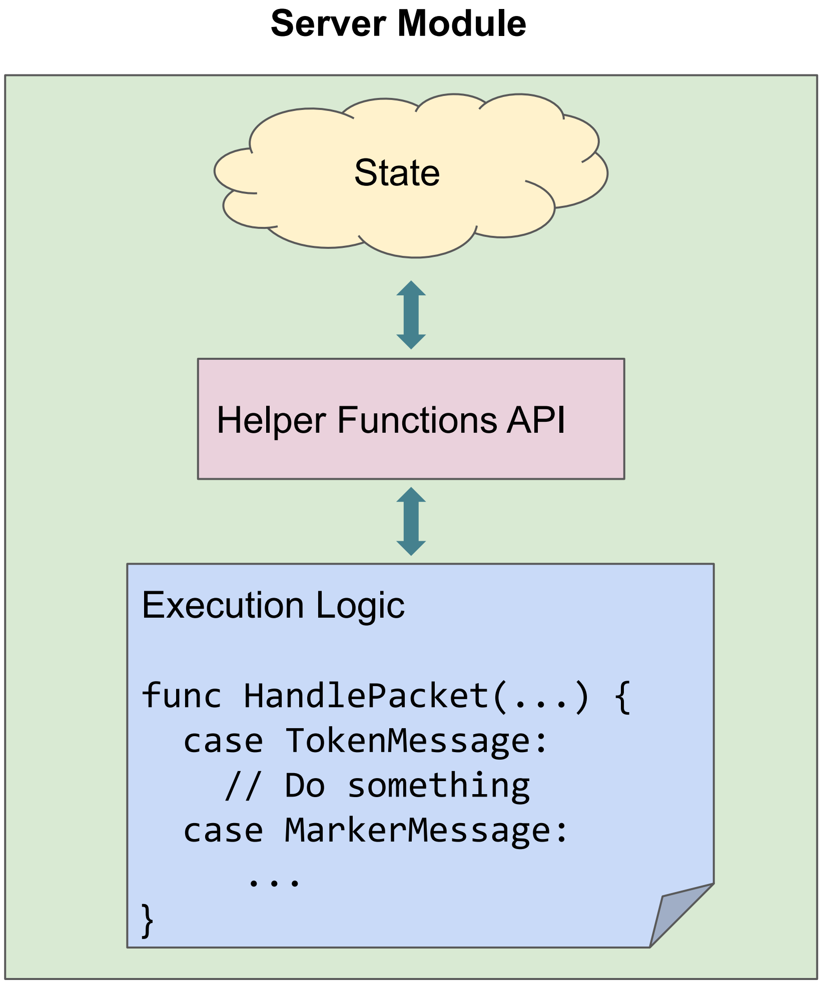
Modular Programming

Phase 1: single snapshot at a time

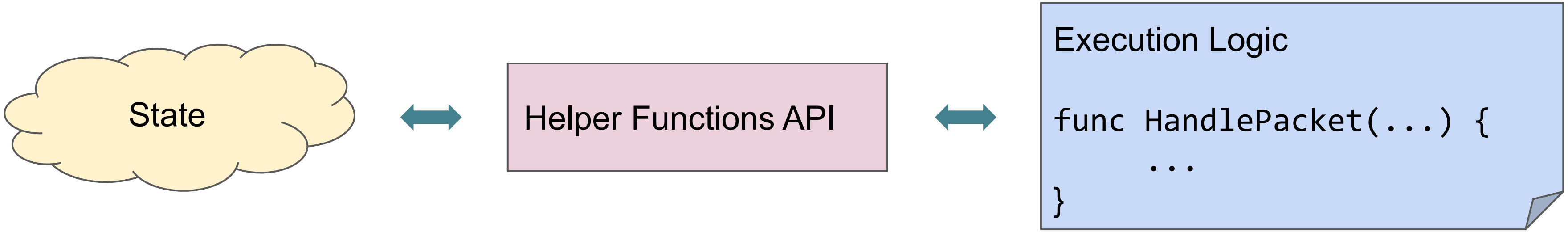
Divide our server module into 3 pieces:

- Server State
- Execution logic
- A layer of helper functions

Goal: write a flexible layer of helper functions



Modular Programming: Single Snapshot




```
// ID of the current snapshot
snapId: int (init to -1)

// State of the current snapshot
snapState: SnapshotState

// Track if each incoming channel has
seen a marker message (default to
false)
receivedMarker:
map(source channel, bool)
```

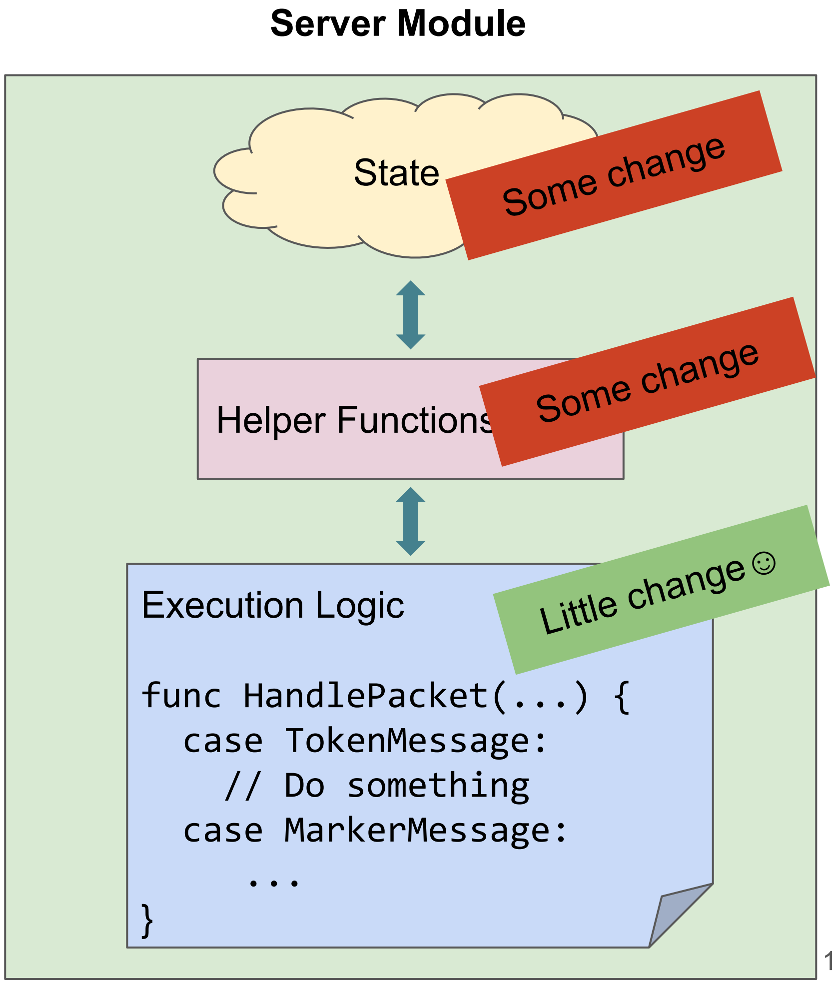
```
func updateSnapshot(src, msg) {
  snapMsg = SnapshotMessage(src, msg)
  snapState.messages.append(snapMsg)
}

func setReceivedMarker(src) {
  receivedMarker[src] = true
}

func firstMarkerMsg(snap_id) {
  return snapId != snap_id
}

Func receiveAllMarkers() {
  return receivedMarker.size == inboundLinks.size
}
```

```
func HandlePacket(src, msg) {
  ...
  case TokenMessage:
    updateSnapshot(src, msg)
    // Also, update server's local state
  case MarkerMessage:
    snap_id = getSnapId(msg)
    if firstMarkerMsg(snap_id) {
      StartSnapshot(snap_id)
    } else {
      setReceivedMarker(src)
      if receiveAllMarkers() {
        // Notify simulator of the completion
      }
}
```

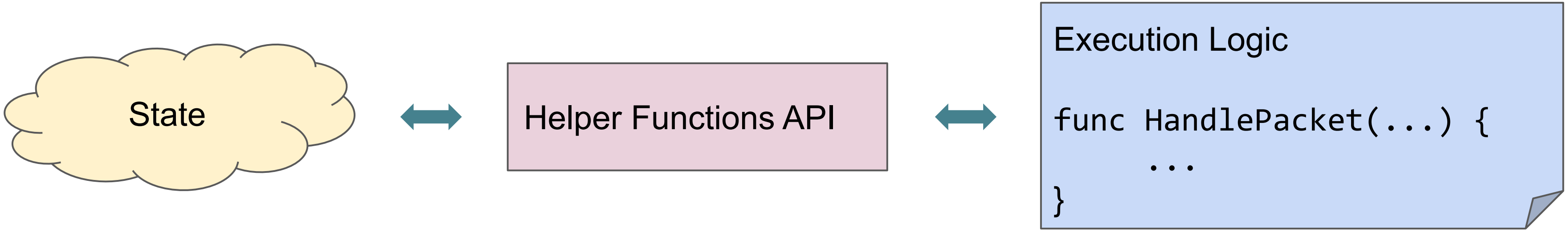
Modular Programming

Phase 2: concurrent snapshots

- Update the state variables and helper functions' implementation
- Keep the API and execution logic unmodified (almost)



Modular Programming: Concurrent Snapshots




```
// States of concurrent snapshots
// map snapshot ID to its state
snapStates: map(int, SnapshotState)

// For each snapshot, track if each
incoming channel has seen a marker
message (default to false)
receivedMarker:
map(int, map(source channel, bool))
```

1. Update state variables

```
func updateSnapshot(snap_id, src, msg) {
  snapMsg = SnapshotMessage(src, msg)
  snapStates[snap_id].messages.append(snapMsg)
}

func setReceivedMark(snap_id, src) {
  receivedMarker[snap_id][src] = true
}

func firstMarkerMsg(snap_id) {
  return (snap_id in snapStates.keys())
}

Func receiveAllMarkers(snap_id) {
  return receivedMarker[snap_id].size ==
inboundLinks.size
}
```

2. Update helper functions while keeping most of its API intact

```
func HandlePacket(src, msg) {
  ...
  case TokenMessage:
    for snap_id in snapStates.keys() {
      updateSnapshot(snap_id, src, msg)
    }
    // Also, update server's local state
  case MarkerMessage:
    snap_id = getSnapId(msg)
    if firstMarkerMsg(snap_id) {
      StartSnapshot(snap_id)
    } else {
      setReceivedMarker(snap_id, src)
      if receiveAllMarkers(snap_id) {
        // Notify simulator of the completion
      }
}
```

3. Minimal change on execution logic

Tips for Debugging

Tips on Debugging

- **Start Early! (This is imperative for Assignment #4)**
- Commit your code to Git often and early, and every time when you pass a new test (enable comparative debugging later if necessary)
- Have proper naming for variables and add comments in your code
    - Easier for both you and others to read and debug your code
- Take advantage of Go Playground if you are not familiar with any Go specifics
- Print statements are your friend!
- Read this ASAP

Prints Are Your Friend ☺

- Always verify the behavior of your program! Sometimes, it may not align with your expectation because of some hidden bugs.
- Track execution using printing statements to understand the code flow
    - Especially helpful in the early development of your design when the code complexity is not too high
- Help catch errors in the early stage
- Example
    - In Assignment 2, we can print out the server state before and after `HandlePacket()` and `StartSnapshot()` that you implement after each tick of the simulator

Raft Leader Election

Raft

- System for enforcing strong consistency (linearizability)
- Similar to Paxos and Viewstamped Replication, but much **simpler**
- Clear boundary between *leader election* and *consensus*
- Leader log is ground truth; log entries only flow in one direction (from leader to followers)

Leader election

Everyone sets a randomized timer that expires in [T, 2T] (e.g. T = 150ms)

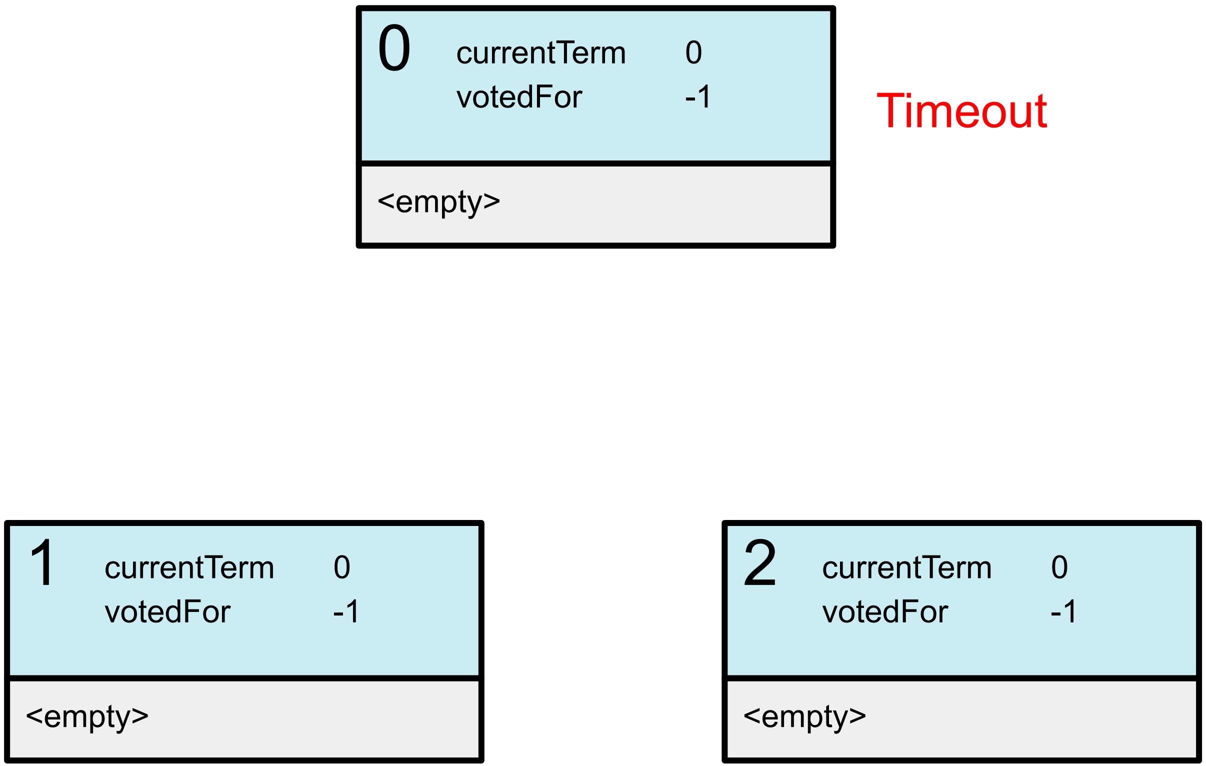
When timer expires, increment term and send a `RequestVote` to everyone

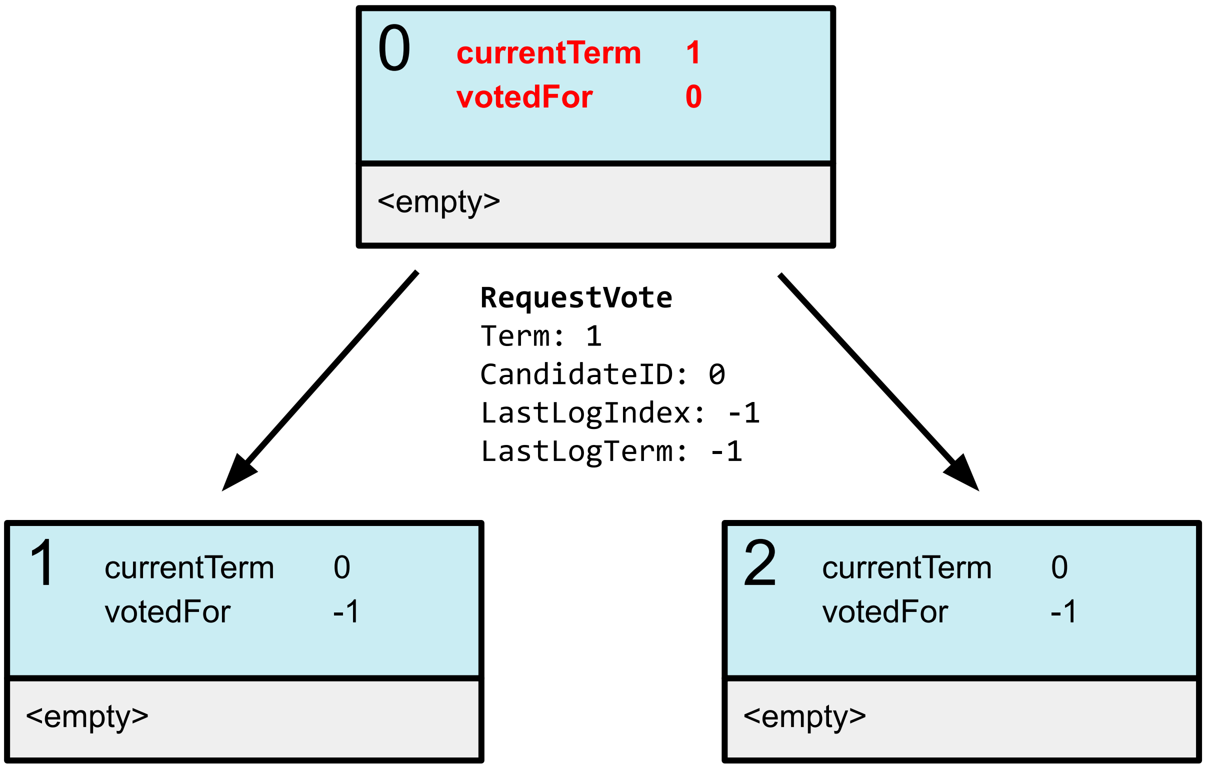
Retry this until either:

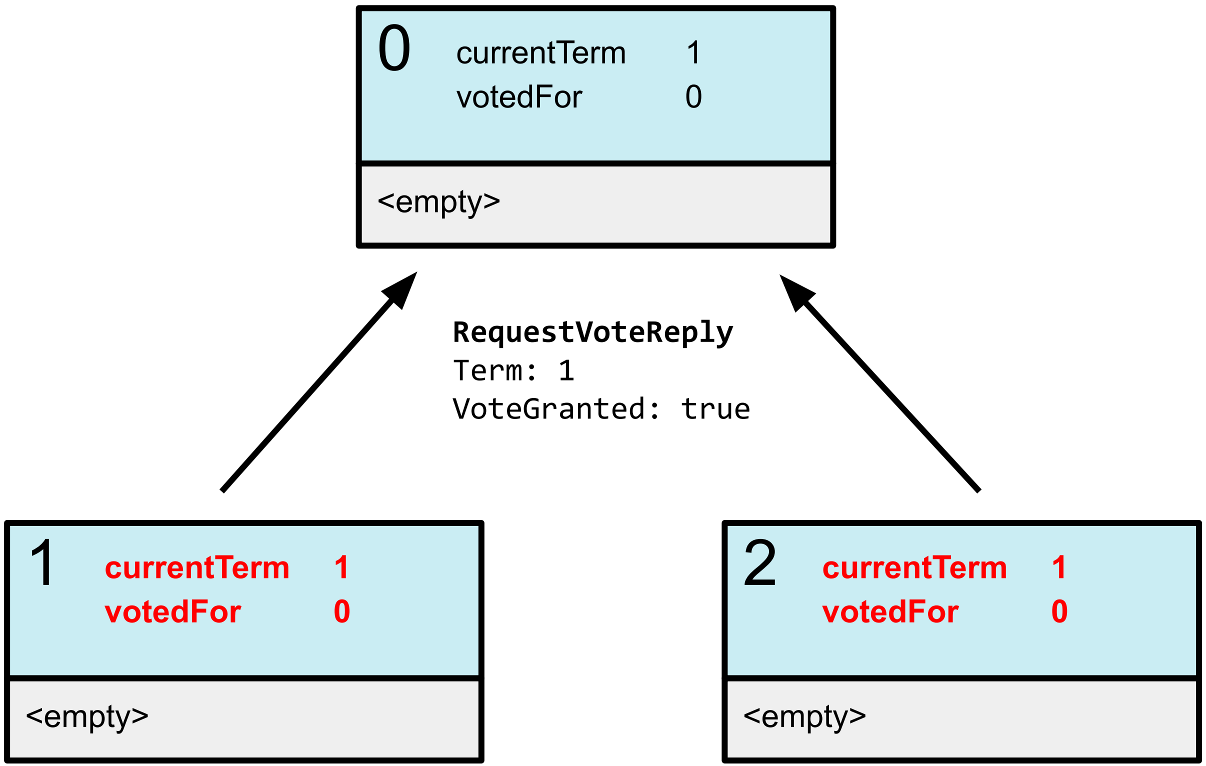
1. You get majority of votes (including yourself): become leader
2. You receive an RPC from a valid leader: become follower again

Conditions for granting vote

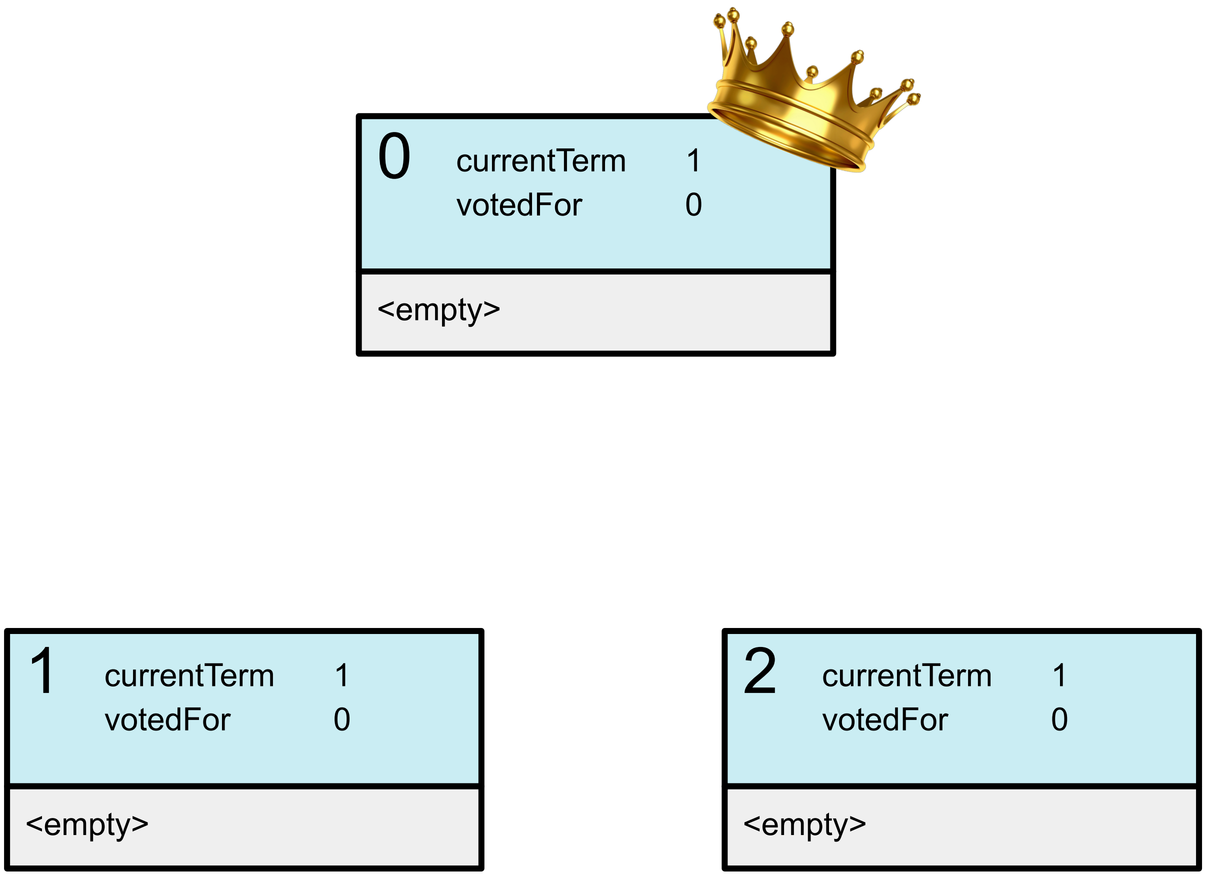
1. (A3) We did not vote for anyone else in this term
2. (A3) Candidate term must be >= ours
3. (A4) Candidate log is at least as *up-to-date* as ours
    a. The log with higher term in the last entry is more up-to-date
    b. If the last entry terms are the same, then the longer log is more up-to-date

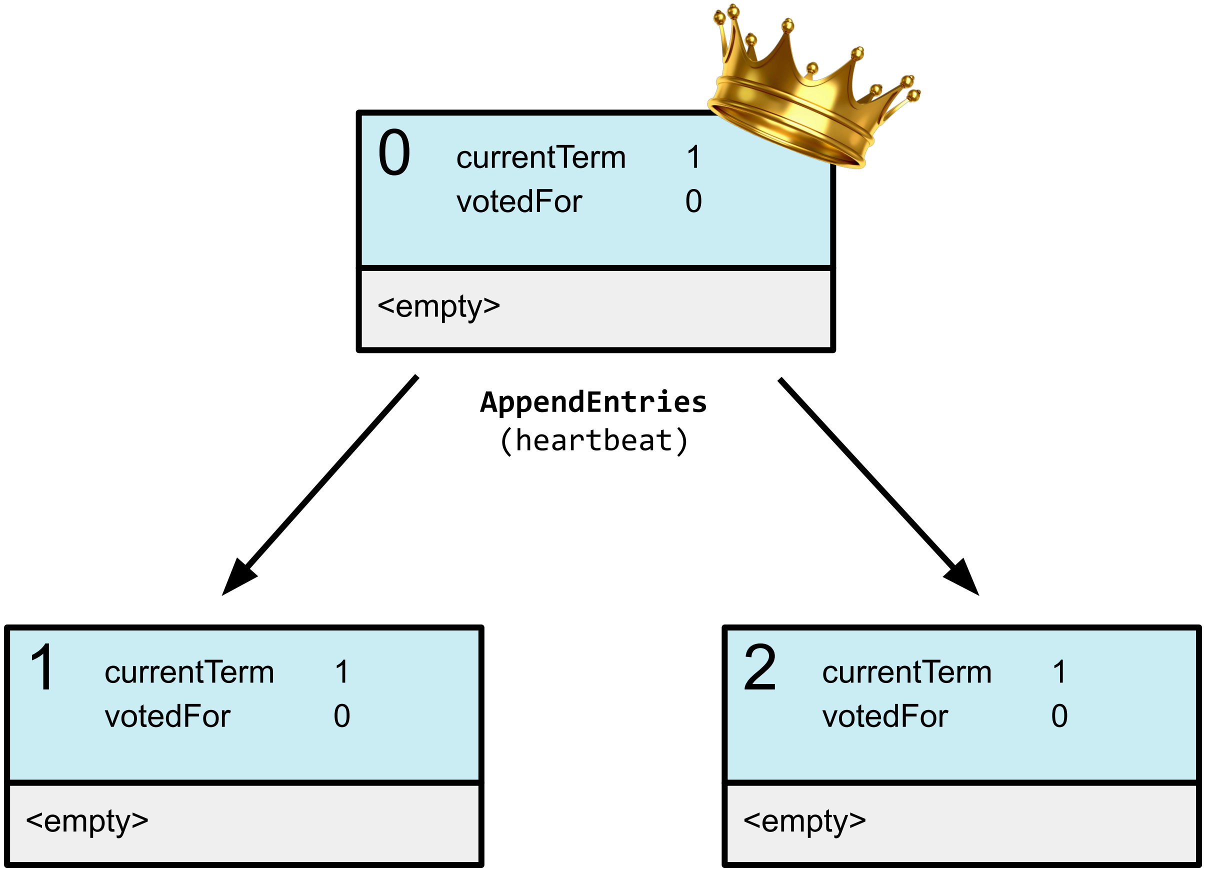

0
currentTerm 0
votedFor -1
<empty>
Timeout
1
currentTerm 0
votedFor -1
<empty>
2
currentTerm 0
votedFor -1
<empty>


0
currentTerm 1
votedFor 0
<empty>
RequestVote
Term: 1
CandidateID: 0
LastLogIndex: -1
LastLogTerm: -1
1
currentTerm 0
votedFor -1
<empty>
2
currentTerm 0
votedFor -1
<empty>



0
currentTerm 1
votedFor 0
<empty>
RequestVoteReply
Term: 1
VoteGranted: true
1
currentTerm 1
votedFor 0
<empty>
2
currentTerm 1
votedFor 0
<empty>


0
currentTerm 1
votedFor 0
<empty>
1
currentTerm 1
votedFor 0
<empty>
2
currentTerm 1
votedFor 0
<empty>


0
currentTerm 1
votedFor 0
<empty>
AppendEntries
(heartbeat)
1
currentTerm 1
votedFor 0
<empty>
2
currentTerm 1
votedFor 0
<empty>

Assignments 3 and 4

You will implement the *leader election* portion of Raft in Assignment 3
You will implement the *log replication* portion of Raft in Assignment 4

Use `time.Timer` and `select` statements to implement timeout

- Need to time out on heartbeats (AppendEntries) → Start election
- Need to time out on waiting for majority of votes

When voting for yourself, you can skip the RPC

Importance of readability

A luxury for small projects, but a necessity for large and complex projects

A4 will build on top of your solution for A3
A3 only accounts for about 20% of the work

Some tips:

- Duplicate code is *really* bad; avoid at all costs
- If a function is more than 30 lines, it is too long → split!
- Avoid nested if-else's; use `returns` and `continues` where possible

Good luck 😅