Distributed Algorithms 60009 Coursework - Multi-Paxos

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Architecture

At the top level of the system the Multipaxos module spawns a collection of Servers and Clients and the Monitor which keeps track of the state of the whole system. Each Server has its own Database, Replica, Leader and Acceptor. The initial binding of the modules is done by Multipaxos, each replica gets bound to all leaders and each leader gets bound to all acceptors and replicas, each client gets access to all replicas. I omitted the corresponding `:BIND` messages.

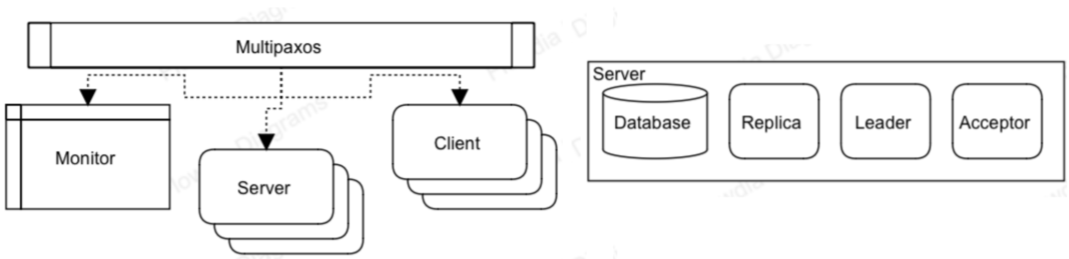


Figure 1: Top-level architecture.

A typical client request flow can be seen in Figure 2 below. The dotted arrows represent spawned child processes, the black solid ones represent directed messages with one recipient, whereas the blue ones represent messages which are broadcast to all modules of a given type. Diagram on the left depicts the phase 1 of the synod protocol, whereas phase 2 can be seen on the right. On the left one of the scouts got preempted and one got adopted. On the right a commander got accepted and broadcast its decision to all replicas which have sent execute requests to the databases.

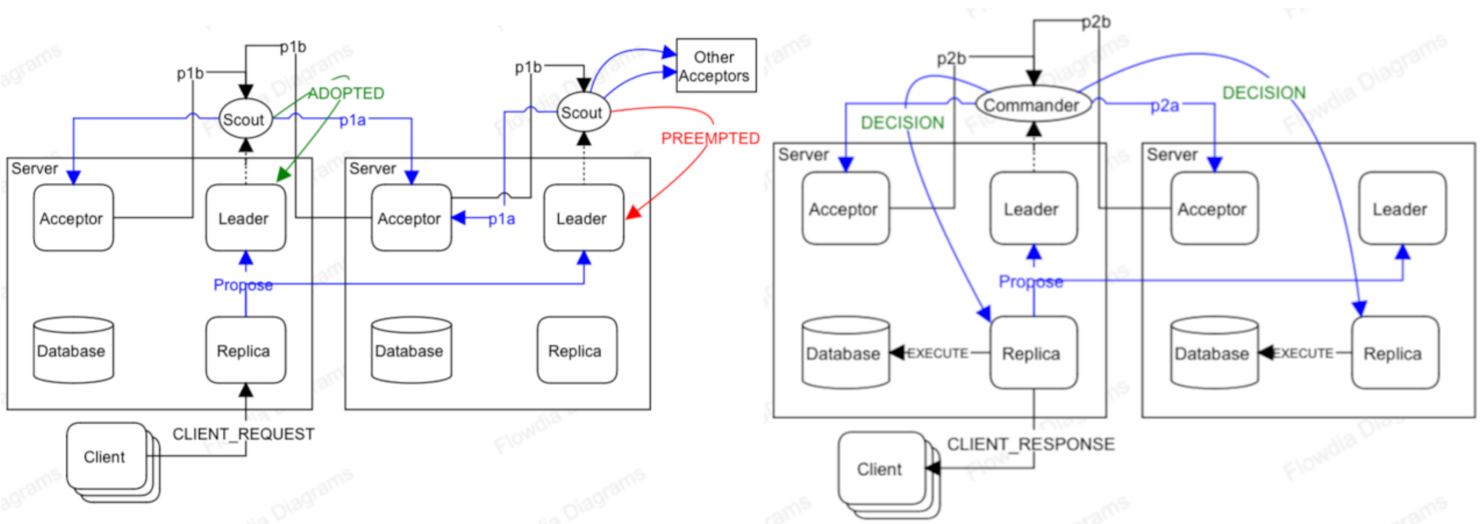


Figure 2: Typical client request flow.

Liveness

My initial implementation of the section 3 followed closely the algorithm described in the paper. Each leader after receiving a `:PREEMPTED` message becomes inactive and starts pinging the leader that has preempted it, instead of picking a higher ballot number and spawning a scout immediately. I implemented that by spawning one failure detector module for each leader. When preempted, a leader notifies its failure detector, which starts pinging the leader associated with the preempting ballot `b`, then the leader deactivates itself and continues.

```
{:PREEMPTED, b} ->
  send(self.failure_detector, {:PING, b})
  self |> deactivate |> next
```

Listing 1: New way of handling `:PREEMPTED` messages.

Each leader associates a timeout with its current ballot number. Every time a leader gets preempted, its next ballot will use a longer timeout (multiplicative increase). However, the timeout of the current ballot decreases linearly with each proposal chosen for that ballot. It is done by sending an appropriate notification from the commander after a `:DECISION` message is sent to the replicas. Whenever an active leader gets pinged by FD of some other leader, it sends its timeout back, and the FD updates it and uses it from now on.

```
{:RESPONSE_REQUESTED, requestor} ->
    cond do
      self.active -> send(requestor, {:STILL_ALIVE, ballot_num, timeout})
      self.preempted_by != nil -> send(requestor, {:STILL_ALIVE, preempted_by, timeout})
```

Listing 2: Leader responding to a ping message.

When tweaking the timeout settings, it was very difficult to pick the appropriate constants. If the timeout decreased too quickly or it didn't grow enough after preemptions, all leaders ended up preempting each other which impacted performance. I noticed that we don't prioritise fairness, it is perfectly fine if one leader is working on its ballot and all of the other ones keep pinging it regularly and only react if they detect a failure. I added a new version of the failure detector which has a static timeout. I realised that it could happen that three leaders λ_1, λ_2, λ_3 behave as follows: λ_2 preempts λ_1 and λ_3 preempts λ_2, in which case λ_2 becomes inactive and stops responding to λ_1's pings, thus λ_1 wakes up and can possibly preempt λ_3. Even though variable timeouts would help to solve this issue and prevent it from live-locking, it introduces an unnecessary congestion. I solved this problem by having each leader record the last preempting ballot number. If a leader was recently preempted and is now inactive and gets pinged by somebody whom he preempted before, it sends the ballot number that preempted it back to the requestor (Listing 2 above). That way the leader who pinged us doesn't wake up immediately but starts pinging the leader who is currently working.

Evaluation

Hardware

The evaluation was conducted on my laptop with the following specification:

OS: Linux 6.1.12-arch1-1, processor: 11th Gen Intel i7-1165G7 4.700GHz, cores: 8, ram: 32GB.

Live-locking Implementation and a Partial Fix

After implementing the multi-paxos without liveness as described in the paper, I found that the system would live-lock even with 5 requests per client (there was 5 clients so it amounts to 25 requests total). To solve the issue for small numbers of requests, I decided to have each leader sleep for a random period of time after it gets preempted. I found that for small numbers of requests (see Figure 3 below) it didn't live-lock, however, when ran with the default config (5 clients, 5 servers and 500 requests per client in a round-robin setting) the partial fix to the liveness problem also live-locked. In the figure below on the right you would normally expect to get to 2500 requests total. The logs corresponding to those two runs can be found in the files with reference numbers from 01 to 04.

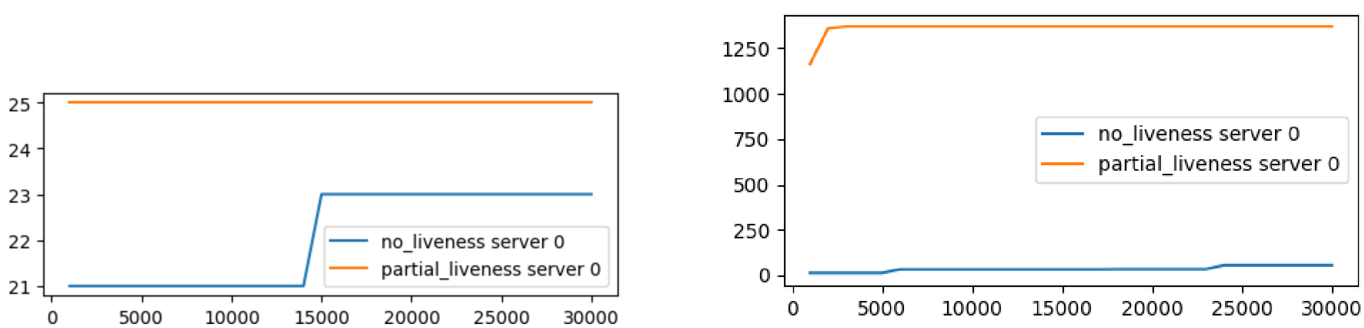


Figure 3: 5 servers and 5 clients with 5 and 500 requests respectively.

Full Liveness and Simple Liveness

The most interesting observation that I made when running different configurations of my implementation for liveness was that the performance of the system was dependent on the configuration settings for the timeouts. If settings are picked incorrectly, the leaders can decrease their timeouts too quickly then get preempted immediately. One big disadvantage of the AIMD-like approach described in the paper was that a leader who is successful in getting its proposals accepted decreases the timeout associated with its ballot, and therefore it will eventually get preempted by one of the leaders who are pinging it. That's not necessarily what we want for performance. I noticed that after preempting a leader it takes a while for the system to make new decisions because all of the leaders who were previously pinging the main leader have now sent scouts and are competing against each other for being the first one who preempts everyone else. It tends to happen that multiple of them get adopted, and the leaders spawn new commanders. Given that each active leader will spawn one commander for each slot, when we have 10000 slots, the system gets congested with messages and it takes a very long time before the acceptors can accept one commander successfully. That can be seen in the figure below, the log files associated with it have reference numbers 08, 09, 10.

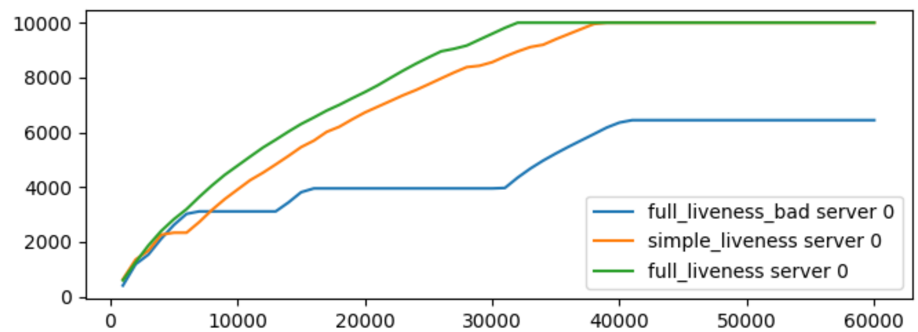


Figure 4: 2000 requests with 5 servers and 5 clients.

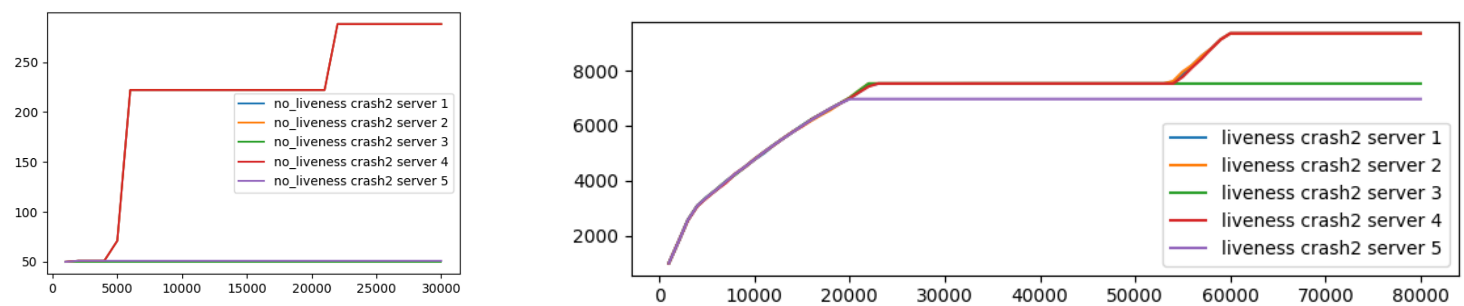
The figure above illustrates the performance of three different configurations. The one in green is the liveness implementation described in the paper with some sane bounds imposed on the range of timeouts that can be associated with each ballot. The one in orange is the simple implementation with a static timeout that I described in the Liveness section. The one in blue is the liveness implementation where the timeout changing settings were tuned incorrectly. As you can see it has periods where it is making progress, however it also has three sections where the system looks like it is stuck. Before each of those sections what happens is that the current main leader gets preempted and the others compete against each other to get accepted. Because their timeouts are adjusted incorrectly, it takes a long time before one of them finally manages to secure a ballot. This occurs because as the main leader gets preempted, the others start spawning scouts and it can happen that multiple of them receive an adopted message and cause the leaders to spawn new commanders, which exerts a high stress on acceptors and the whole system slows down.

Another interesting observation was that the system seems to get slower over time, If you examine the Figure 4 above, you can see that the green line representing the correctly-configured liveness implementation is not straight, its gradient decreases which means that as the number of accepted requests grows, the system is able to make less progress in a given time period. A possible cause of this behaviour is that the acceptors maintain a MapSet of all accepted pvalues, therefore as the number of accepted proposals approaches 10000, they keep sending those MapSets around and each leader when updating its pvalues needs to iterate over the big object.

Having conducted these experiments, I have concluded that the most desirable situation is where one leader gets to preempt everyone else at the beginning, and then within a single ballot processes all requests while the others are patiently pinging it to check if it hasn't crashed. If they detect a failure they should act accordingly and "elect" (by fighting who gets accepted first) and then continue processing the remaining requests.

Crash Failure Experiments

To examine failures I have checked if two servers crashing impact the liveness of the system. In the figure below on the left you can see a run where two servers crash right at the start of it. The configuration used during that run was 5 clients, 5 servers and 500 requests per client. I found that, when compared to Figure 3, two servers crashing allowed the system to perform more requests, although it still live-locked in the end. That run has reference number 06.



(a) Crash Failure and Liveness

(b) Main Leader Crash Failure.

Figure 5: Crash Failure Testing

As I explained before the most desirable situation is when a single leader gets to decide on all proposals. However, the immediate issue that question that comes up is: Does the system continue to work if that main leader crashes? The configuration used was the same as in Figure 4, and the server 5 and 3 crashed after 20 and 22 seconds respectively. The logs can be found in the output file with reference number 11. I needed to re-run the experiment several times to make sure that that main leader crashes. In the figure above you can see that at the start there was a single leader responsible for deciding on all proposals (because there are no pauses). After leader 3 has crashed, the system didn't accept any new requests for about 30 seconds. It could look like a live lock, however after looking at the logs below one can see that the leader who eventually started processing new commands only needed to spawn two sets of commanders (roughly 2 times 7000). A live-lock normally causes the system to be flooded with scouts and many more commanders than we have in this case. This indicates that the system is able to recover from crash failures.

```
time = 22000  db requests done = [{1, 7454}, {2, 7530}, {3, 7529}, {4, 7422}, {5, 6967}]
time = 22000  commanders up = [{1, 1064}, {2, 0}, {3, 7530}, {4, 0}, {5, 1063}]
time = 22000  commanders down = [{1, 1064}, {2, 0}, {3, 7530}, {4, 0}, {5, 1063}]
...
time = 55000  db requests done = [{1, 7853}, {2, 7965}, {3, 7529}, {4, 7771}, {5, 6967}]
time = 55000  commanders up = [{1, 1064}, {2, 15081}, {3, 7530}, {4, 15514}, {5, 1063}]
time = 55000  commanders down = [{1, 1064}, {2, 15081}, {3, 7530}, {4, 15513}, {5, 1063}]
```

Listing 3: Commanders spawned before starting to make progress.