State machine replication

Schneider. Implementing fault-tolerant services using the state machine approach: a tutorial. CSUR 1990
State machine replication

• What is the system model? (What is our world?)
  • *Deterministic* state machine (with replicas): $sm_i$. Same seq of commands $\Rightarrow$ same state.

  • Clients: submit commands to the state machine
    • Why are clients distinct from replicas?
    • Clients may be non-deterministic, less stateful.
    • Clients don’t have to be as powerful as replicas nor as reliable ($ argument: many cheap clients, and a few expensive replicas)

  • Output device. Generality — separate the (passive) consumer/receiver of the state machine output. (Something that needs the notification of command execution). Actuators.

• What types of failures do we care about?
State machine replication

- Challenges with achieving a deterministic state machine. (Depends on what is a state machine)
  - Concurrency (for perf)
  - Correctness (correct implementation)
  - Synchronization of code between replicas: they have to run the same state machine.
State machine replication

• What types of failures do we care about?
  • Fail-stop failures (weaker: non-paranoid). Failure in which a device either works or doesn’t. Observable by other components (disinfect from halting failures, where observability is not provided).
  • Byzantine failures (stronger: paranoid). Some # of processes can have arbitrary behaviour. Dangerous!
    • Includes software bugs, hardware failures, cosmic rays
    • “A horse that is electrocuted and falls onto the power cables, disconnecting the data center”
    • Includes malicious (attacker) behaviour: hacking!
  • In general failures are detected by “failure detectors”, which is a large research area.

• What about the network?
  • Generally FIFO (first in first out): ordering on the wire (fairly unrealistic)
  • In reality, msgs may be dropped, no set route (msgs can take different paths)
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• Why do we want replication? (Another benefit of distributed state?)
  • Fault tolerance
  • Better performance (maybe), e.g., use replica closer to me (in network distance)
SMR+ failure model

• Assume that at most t replicas can fail; design a system to withstand this number of failures.

• Fail-stop: need at least $t + 1$ replicas. Need only one replica to be working (the other t can fail). I trust this last remaining replica to work correctly.

• Byzantine: need at least $2t + 1$ replicas. You don’t know which t are the byz replicas. Use voting to determine the “true” behaviour. This works because $t + 1$ are correct, and $t+1$ is always a majority in a set of $2t + 1$. 
State machine replication

- **Agreement**: All replicas receive all requests (as a set)
  - Why is the paper quiet on how to achieve agreement?
  - Network is FIFO... it’s also reliable.

- **Order**: Replicas execute requests in same relative order (this order is indep. of client order)
  - *If a client issues a, then b; SMR executes a before b.*
  - Many ways to achieve it!

- Assume that we have IDs on requests; **request stability**: a request is stable if once no request from a correct client bearing a lower id can be delivered to the replica.

- Order can be achieved: **if a replica next executes the stable request with the smallest unique identifier**
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- Lamport-clock based ordering/stability algorithm. Order / stability is achieved with logical clocks.

- **The bad**
  - Must wait for all clients to send a message *after* some request (to determine it’s stability)
  - If a client has no request to send... they must send a no-op (communicate timestamp to replica)
  - All-to-all connectivity. High bandwidth. *Every client needs to know every replica.*
  - *If I have many many clients (10^6), this is a terrible approach. Doesn’t scale in number of clients.*

- **The good?**
  - No communication between replicas (they don’t need to know each other)
  - It’s very simple. Replicas are trivial. Clients are more complex.
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- What about physical clocks? Same structure, but instead of Lamport clocks, use assumptions about clock speed.
  - Hard bounds on estimate of propagation delay (latency between nodes)
  - Hard bounds on estimate on the clock synchronization between clients
  - Then formulate stability as a mathematical formula that constraints what timestamp can appear in the future given a timestamp in the past.
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- Replica coordination as another approach to derive order/stability.

- This is the more tradition RSM technique

- **Paxos, Raft**: solve both agreement and ordering simultaneously in an *async network*. (Both suffer from the FLP result, which means that they are not always live & safe).