Distributed consensus, replicated state machines and… a Raft!?

K∩W - August 11, 2015

Aaron Ounn

Summary

“Laying the groundwork”: Consensus; CAP theorem; Failures semantics.

Raft: Motivation; Assumptions; Overview; Leadership election; Log safety; Fault-tolerance; (Lots of) Examples

Recent work: Byzantine fault-tolerance; Asymmetric partitions; Linearizability proof (Coq - Verdi) etc...

Distributed consensus?

Getting a set of processes to agree on a single data value.

T. V. I. A.

Example:

- A national election: “Who are we going to elect president?”

- Processes are servers; database replica on each servers (=nodes)

CAP Theorem

In the event of a network partition, which property do you want to keep without sacrificing latency?

<u>Consistency:</u> All clients see the same data even if requested concurrently.

<u>Availability:</u> All client’s requests to non-failing nodes must result in a response.

Consistency?

Many different consistency models:

strict, atomic, causal, eventual, strong, weak etc...

In the case of Raft, we are using “**atomic consistency**” as our CM.

For more details, refer to [Tanen]

Failures semantics

How are nodes (= processes) in our cluster allowed to fail?

Failures semantics

Fail-stop: a process fails by stopping without warning.

Example: power outage, kernel panic etc...

Byzantine: a process fails by deviating from its expected behavior, and/or exhibiting different behavior for different observers.

Example: “traitorous” Byzantine general, defect on telemetric hardware etc...

Raft: In Search of an Understandable distributed consensus algorithm.

Dr Diego Ongaro, and Professor John Ousterhout
Stanford University (2014)

Distributed consensus algorithms

The Part-Time Parliament **-** Leslie Lamport **(Paxos)**

Viewstamped replication - B. Oki, Barbara Liskov **(Influenced Raft)**

Unreliable failure detectors for reliable distributed systems - T. Chandra, S. Toueg **(Chandra-Toueg)**

Motivation

“There are significant gaps between the description of the Paxos algorithm and the needs of a real-world system… the final system will be based on an unproven protocol”

- Chubby authors

“The dirty little secret of the NSDI community is that at most five people really, truly understand every part of Paxos ;-).”

- NSDI reviewer

See [1:RaFT]

Paxos made simple - L. Lamport

Paxos made moderately complex - R. Van Renesse, D. Altinzbuken

Paxos made practical - D. Mazieres

Paxos made transparent - H. Cui et al.

Paxos made live - T. Chandra, R. Griesmert, J. Redstone

Paxos made fun - A. Ounn *(wip)*

Assumptions

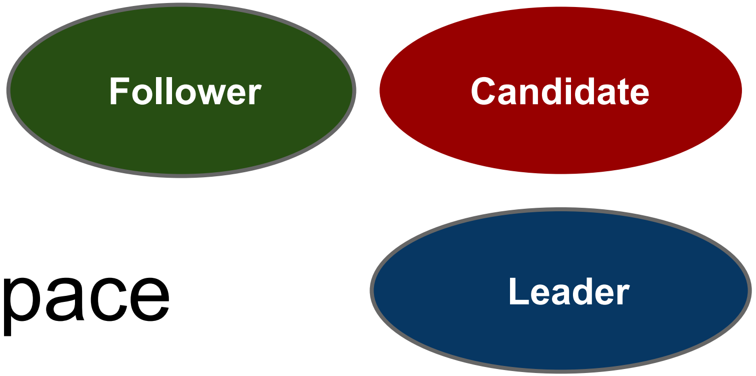
- The cluster works in an asynchronous fashion (no upper bounds for message delays)
- The network is unreliable: partitions, duplication, reordering can happen (will happen).
- Nodes fail by stopping (i.e no Byzantine fault-tolerance).

Assumptions

- It is the client's responsibility to communicate with the leader

- nodes have access to infinite persistent storage; no corruptions; write-ahead logging.

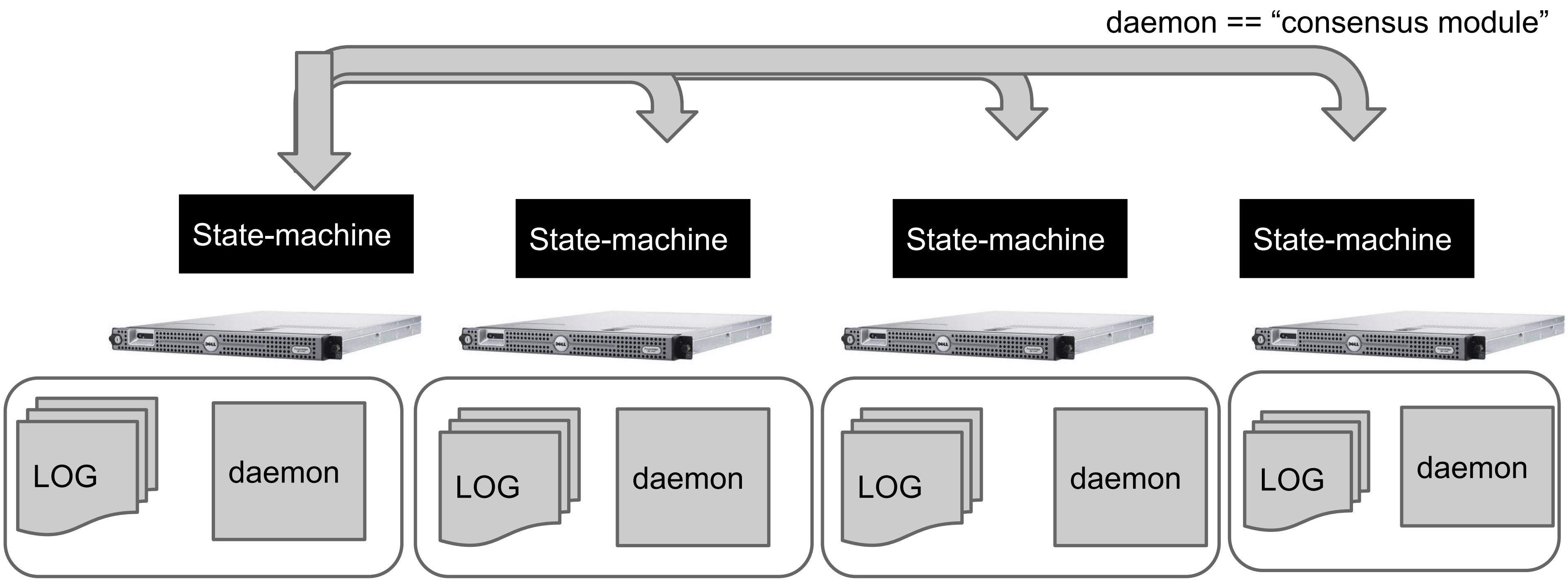
See [3: ARC RaFt]



- Reduction of the state space

- Detailed specifications (RPCs etc..)

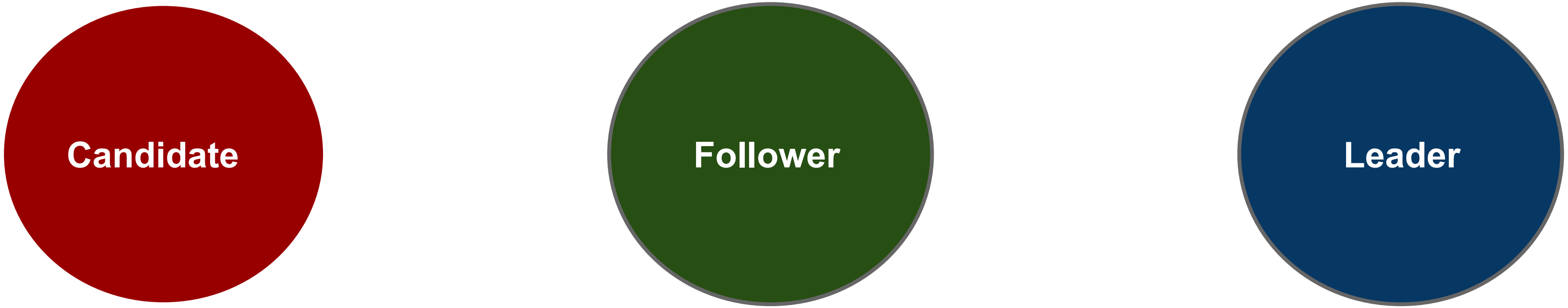
- Lots of existing implementations (check out mine!)



We want to have a high-degree of replication

We do not want to return obsolete/stale data

This is a **coordination problem** - how to manage Rs/Ws and guarantee atomic consistency?


Candidate
Follower
Leader

Raft: Overview

Leader election

Log replication

Safety

Leader Election

Randomized timers

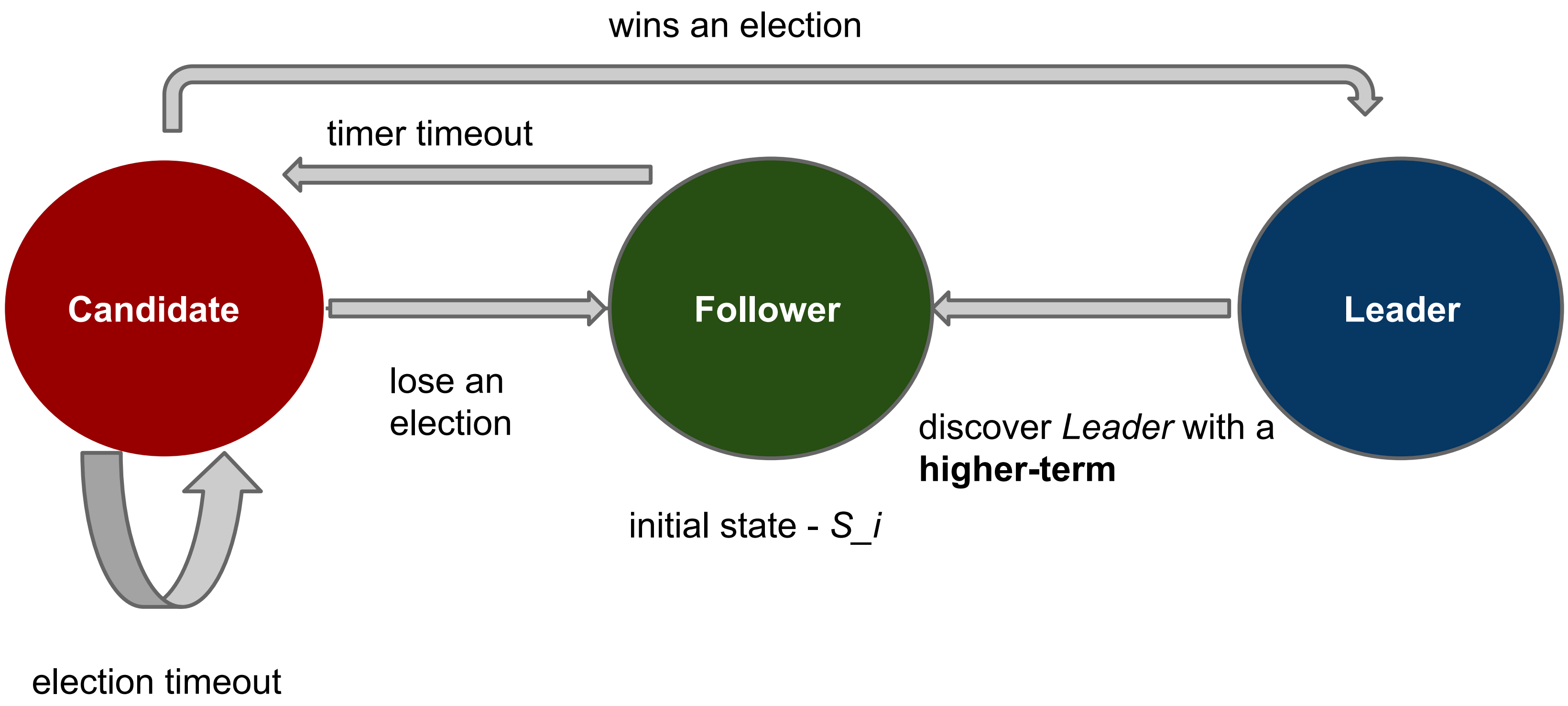
Heartbeats to detect crashes/reset timers

Majority of nodes

The Leader Election happens using the *RequestVote* RPC.

To become a *Leader*, a node has to receive a **majority** of votes: $\lceil N/2 + 1 \rceil$ where N is the number of nodes in our cluster.

Split votes are handled through nodes’ timers.
If an election timeout, it restarts.


wins an election
timer timeout
Candidate
Follower
Leader
lose an election
discover *Leader* with a **higher-term**
initial state - *S_i*
election timeout

Log replication

The cluster receives a “command” from a client. Somehow (Assumption) the query reaches the Leader who:

- appends the “command” to its log
- replicates the appended entry to the rest of the cluster

Log replication: fixing inconsistencies

Using RaftScope

Safety

Using RaftScope

Safety

1: ``“**State Machine Safety:** if a server has applied a log entry at a given index to its state machine, no other server will ever apply a different log entry for the same index” ``

2: ``broadcastTime ≪ electionTimeout ≪ MTBF``

Recap:

1. Elects a leader
2. Handle client queries
3. Commit log entry when the Leader has committed
4. Return response to the client
5. Rince, and repeat!

More!

Need for Byzantine fault-tolerance?
[Tangaroa] Tangaroa: a Byzantine Fault-tolerant-*ish* Raft consensus algorithm - C.Copeland, H. Zhong

Asymmetric partitions? Geographically distributed datacenters?
[Unanimous] Unanimous: In Pursuit of Consensus at the Internet Edge - H. Howard
[Raft-Dev] - Discussion about asymmetric partitions

Proof of Raft's Linearizability in Coq (using Verdi):
[Verdi] + [VerdiRaft] - https://github.com/uwplse/verdi/pull/16 J. Wilcox - D. Woos

Misc:
[FLP] - Impossibility of Distributed consensus with One faulty process - M. Fischer, N. Lynch, M. Paterson

References

[1:RaFT] - “In Search of an Understandable consensus algorithm” - D.Ongaro, J.Ousterhout (Stanford University)

[2:ARCRaFT] - [“ARC: Analysis of Raft Consensus”]() - H.Howard (Cambridge University)

[3:ARCRaFT] - [2:ARCRaFT] page 15,16

[3:CAP] - “Brewer’s Conjecture and the Feasibility of Consistent, Available, Partition-Tolerant Web Services” - S.Gilbert, N. Lynch (MIT CSAIL)

[4:Consensus] - Distributed Algorithms - N. Lynch (1993 - MIT Press) p.397

[5:CouchDB] - CouchDB Guide 1.0.1 (slide 37)

[6:RaFTTalk] - Raft case study - Professor J. Ousterhout

[Tanen] - “Distributed systems: Principles and Paradigms” A. Tanenbaum

[Tangaroa] - BFTRaft - C.Copeland, H.Zhong

[Unanimous] - In Pursuit of Consensus at the Internet Edge - H. Howard

[Raft-DEV] - Discussion about asymmetric partitions

[Verdi] - "Verdi: A Framework for Implementing and Formally Verifying Distributed Systems"

[FLP] - https://groups.csail.mit.edu/tds/papers/Lynch/jacm85.pdf