Towards fast and deterministic system tests

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Overview

- Explain the problem with current approaches to system tests;
- Give a high-level overview of test library we've started to develop that addresses said problems;
- Demo;
- More detailed explanation of how the test library works, in particular:
  - Elle checker;
  - Lineage-driven fault injection.
- Next steps and future work;
- Summary.

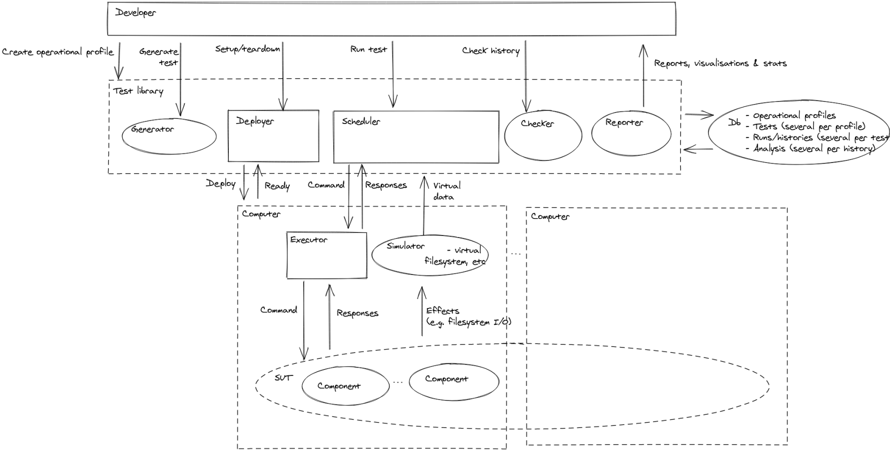
The problem

System tests, in general, are:

- Non-deterministic and slow
  - Running the same test twice can yield different outcomes, esp. around fault-injection;
- Ill-specified or provide weak guarantees
  - What exactly have we shown if the tests pass?
- Ephemeral
  - Hard to test performance over time, i.e. test one month worth of traffic, check if everything is fine, then test another month's worth of traffic the day after;
  - Hard to test upgrades, or backup and restore from crashes, etc;
- Language specific
  - Test libraries/frameworks/tools are programming language specific, while the components of systems under test are written in different languages.

Parts of the solution

- Generator: generates random test cases;
- Scheduler: deterministically controls the network traffic during the test;
- Executor: receives messages from the scheduler and executes them against the system under test (SUT);
- Ldfi: figures out which faults to inject;
- Checker: analyses the output of a test case execution and determines if it was a success or not.



Developer
Create operational profile
Generate test
Setup/teardown
Run test
Check history
Reports, visualisations & stats
Test library
Generator
Deployer
Scheduler
Checker
Reporter
Db
- Operational profiles
- Tests (several per profile)
- Runs/histories (several per test
- Analysis (several per history)
Deploy
Ready
Command
Responses
Virtual data
Computer
Executor
Simulator
- virtual filesystem, etc
Computer
Command
Responses
Effects (e.g. filesystem I/O)
SUT
Component
Component

Solution for non-determinism and speed

- SUT is assumed to be written on reactor form, i.e. given an incoming message and some internal state, update the state and produce a set of outgoing messages (Armstrong 2003, p 87);
- All messages get set via the Scheduler which randomly, but deterministically using a seed, determines the arrival order of the messages;
- Timeouts and retries are handled by explicit tick messages, that are also deterministically sent by the Scheduler, which means we can speed up time and not have to wait for actual timeouts to happen.

Language agnostic solution

- In between the SUT and the Scheduler sits the Executor, whose job is to receive messages from the Scheduler via an http interface and pass them on to the SUT;
- The Executor is written in the same language as the SUT, so once it got the message via http it decodes the message from JSON into a datastructure in the native language and does a simple function call to the the SUT;
- Porting an Executor to a new programming language is simple, which means it's easy to test systems written using many languages.

Solution to ill-specified guarantees

- The Checker component uses Jepsen's state-of-the-art Elle checker, which provides precise models and guarantees;
- Lineage-driven fault injection is used to give guarantees in the presence faults;
- Operational profiles/usage models will later be used to drive test case generation, and guarantee system test coverage and reliability.

Solution to long-lived testing

- Every interaction that the developer can do, e.g. generation, execution, checking, can be done in isolation because the input and output comes and goes via a database;
- The above in combination with determinism means that we can replay an old test and bring the system to the state it was in at the end of a test, we can then extend the test can carry on from there.

Demo: the SUT

- The example SUT is a integer-valued shared/distributed register;
- Any number of clients can write or read an integer from the register;
- The register is replicated to try to achieve fault tolerance.

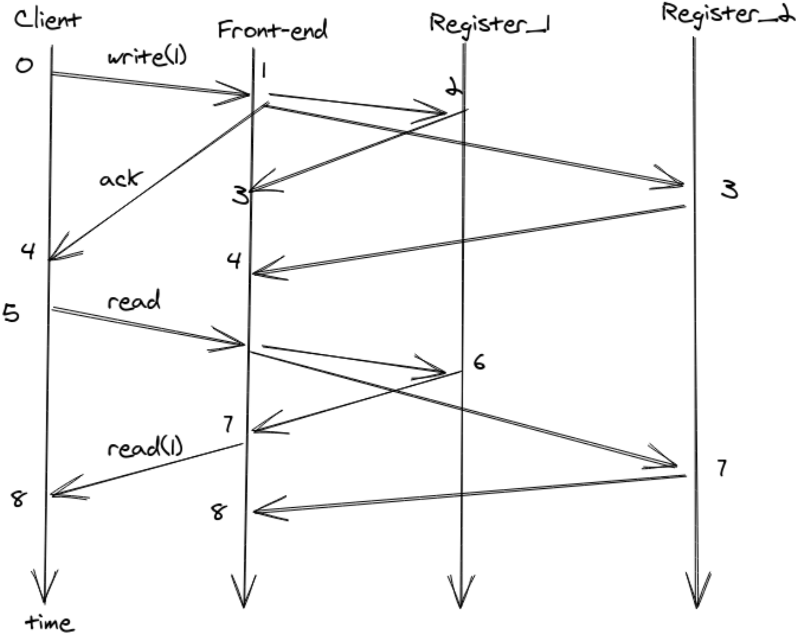
Demo: Super Naive Implementation

- The topology is 1 Frontend, 2 Register;
- Each register records a history of all writes;
- On client requests, the Frontend sends the request to both register and answer with the first one responding (what could possibly go wrong?);
- Network calls are assumed to work (naive).

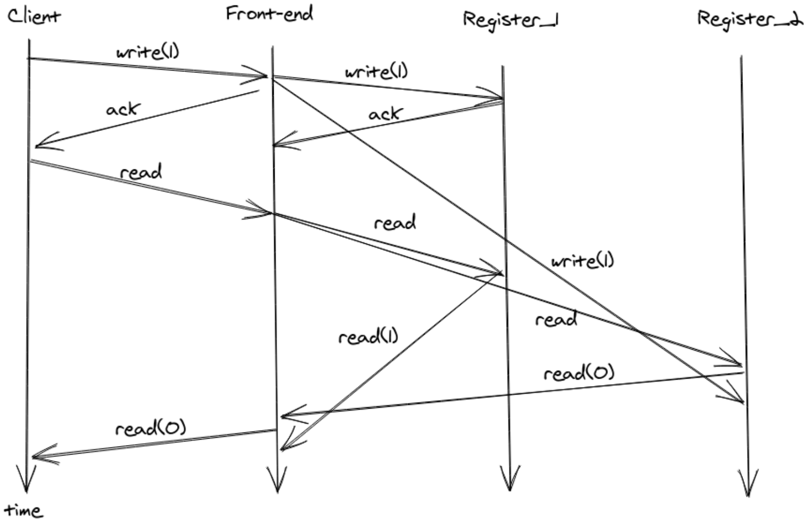
Demo: Resend logic

- Instead of trusting the first, lets wait for both;
- But now we need to have retries, since if one message gets dropped, we will get stuck;
- Introducing `ticks`.

Demo: shared register v1, success



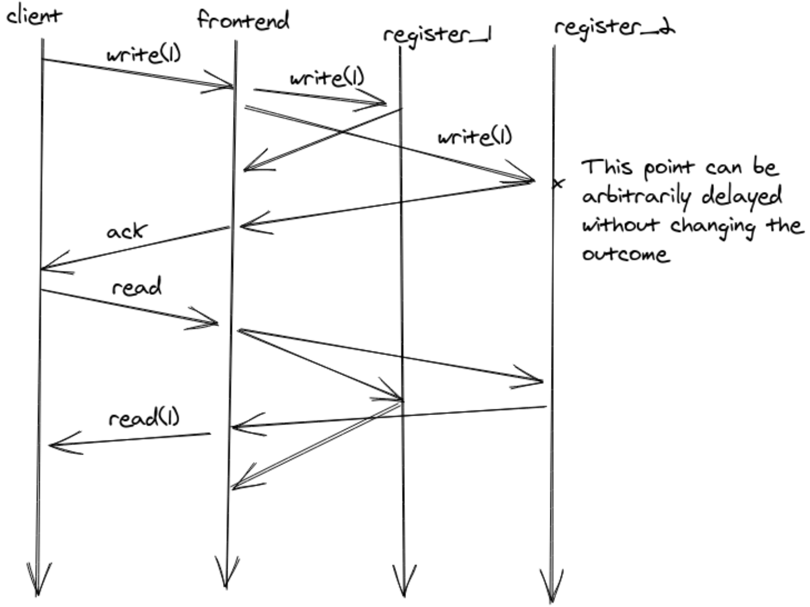
Demo: shared register v1, counterexample



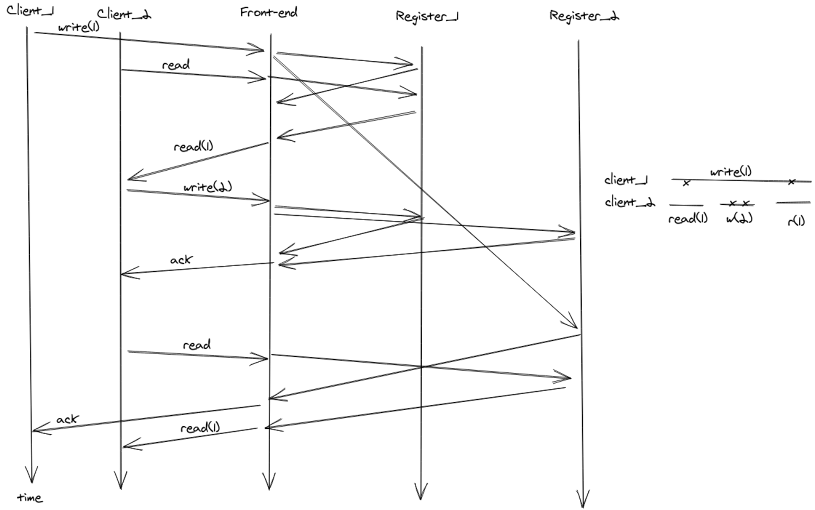
Demo: the testsuite of the SUT

- Show the code of `detsys/sut/register_test.go`;
- `go test`;
- Ensure that we find the problem.

Demo: shared register v2, success



Demo: shared register v2, counterexample



How does the Elle checker work?

How does lineage-driven fault injection work?

```
traces := []
faults := {}
result := ""

forever:
    inject(faults)
    success, trace := run(test)
    if !success:
        result := failure(faults)
        break
    traces.append(trace)
    faults := ldfi(traces)
    if faults is empty:
        result := "success"
        break
```

How does lineage-driven fault injection work? #2

```
fun ldfi(list of trace) -> set of fault

type trace =
  { message: Msg,
    from: Node,
    to: Node,
    at: Time }

type fault
  = omission { from: Node, to: Node, at: Time}
  | ...
```

How does lineage-driven fault injection work? #3

- `fun ldfi(traces: list of trace) -> set of fault`
- Each trace contains possible messages to drop, so create a big OR-formula like:

```
omission(msg0...) OR omission(msg1...) OR ...
```

- For each run/trace we gather more constraints, so create a big AND-formula between traces, e.g.:

```
(omission(msg0...) OR omission(msg1...) OR ...)
AND
(NOT(omission(msg0...)) OR omission(msg1...) OR ...)
AND ...
```

- Solve this CNF-formula using SAT solver
  - Minimal solution = smallest set of faults that can potentially break the test
  - No solutions = no set of faults can break this particular test case

How does lineage-driven fault injection work? #4

- Will this not go on forever?
- Stopping criteria via failure specification:
  - End time for finite faults, i.e. message omissions (EFF)
  - End of test time (EOT)
  - Max crashes (not implemented yet)
- Guarantee: given a program and a failure spec, either produce a set of faults which respect the failure specification and cause the program to fail, or certify that there are no faults for that failure specification which can cause the program to fail.

Next steps and future work

- Next steps
  - Regression tests;
  - Integration with Sean's work.
- Future work
  - Test case generation, including extending existing/already run test cases;
  - Support for deployment, for testing upgrades and backup/restore;
  - Integrate other parts of Assembly.

Summary

- We have seen how to solve the following problems of existing system tests:
  - Non-determinism and speed;
  - Weak guarantees;
  - Ephemeral;
  - Language specific.
- Key insights:
  - Treat system tests *themselves* as a long-running application;
  - Ask programmer to abstract away concurrency from programs, provide a bunch of tools for free in return.

Questions or comments?

References

Alvaro, Peter, Joshua Rosen, and Joseph M. Hellerstein. 2015. "Lineage-Driven Fault Injection." In *Proceedings of the 2015 ACM SIGMOD International Conference on Management of Data, Melbourne, Victoria, Australia, May 31 - June 4, 2015*, edited by Timos K. Sellis, Susan B. Davidson, and Zachary G. Ives, 331–46. ACM. https://doi.org/10.1145/2723372.2723711.

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