Building a Distributed System with Real-time Constraints

Using concurrent Functional Programming tools

Armando Santos

December 5, 2022 —

Introduction

Networking Team

Armando Santos
Well-Typed

Marcin Szamotulski
Input Output Global

Duncan Coutts
Well-Typed

Neil Davies
PNSol

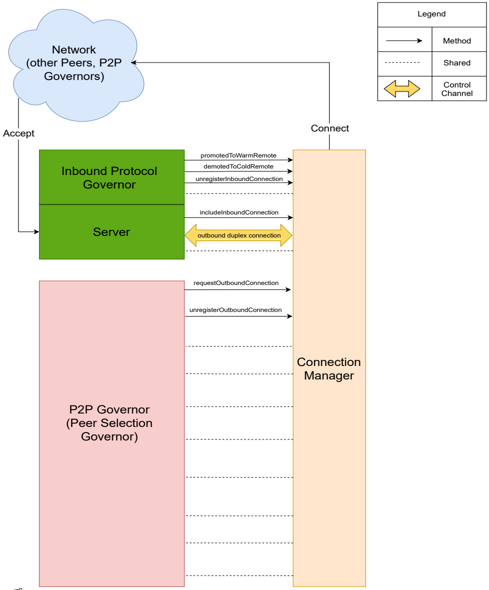
Peter Thompson
PNSol

What we are doing

Cardano Node

Ouroboros algorithm paper	Refining step	Implementation	Testing
Formal Specification		Architecture & Design	Properties
	Real time constraints		
Threat models		Protocols	Simulation
	Concurrency		
Non-realistic assumptions		Scale	Reliability
	Operation & Performance		
Performance objectives		Exceptions & Corner cases	CI

Decentralised Network



- Highly concurrent;
- Reliable and Robust;
- Predictable;
- Manage resource consumption;
- Thousands of SPOs;
- Has to run 24/7.

More details

To read more about this, check out our documentation at: https://github.com/input-output-hk/ouroboros-network/

How we are doing it

Functional Programming

Strongly Statically Typed Purely Functional Programming with Haskell!

- Non-strict evaluation;
- Type Safeness;
- Referential Transparency;
- STM;
- Explicit effects;
- More!

Typed Protocols

Internally developed (but open-source) library to specify end-to-end protocols at the type-level!

- Type Safe;
- Session Types;
- Deadlock free!
- Pure;
- Powerful (pipelining out of the box).

QuickCheck

Property based testing framework for Haskell.

- Input random generation;
- Shrinking;
- Reproducibility;
- Coverage checks.

IO Simulator

Simulation monad that is a drop-in replacement for IO (and other execution kernel primitives in Haskell)!

Internally developed (but open source) library to perform all kinds of IO Simulations, in particular:

- write network simulations, to verify a complex networking stack;
- write disk IO simulations, to verify a database implementation.

We’re using IO Simulator for…

- Early detection of critical races;
- Simulation of rare edge cases;
- Mocking and error injection;
- Simulate time passing;
- Looking for different schedules.

Most importantly:

- Performing tests using same codebase and
- Reproducing complex edge-case test failures.

```
Ouroboros.Network.Testnet
generators
diffusionScript fixupCommands idempotent: OK
+++ OK, passed 100 tests.
diffusionScript command script valid: OK
+++ OK, passed 100 tests.
no livelock: OK (97.68s)
+++ OK, passed 100 tests:
76% Simulated time <= 1H
20% Simulated time >= 5H
13% Simulated time >= 10H
12% Simulated time >= 1 Day
dns can recover from fails: OK (109.91s)
+++ OK, passed 100 tests:
68% Simulated time <= 1H
41% Nº Events >= 1000
8% Simulated time >= 5H
7% Nº Events <= 100
7% Simulated time >= 10H
6% Simulated time >= 1 Day
2% Nº Events >= 10000
target established public: OK (113.54s)
+++ OK, passed 100 tests:
71% Simulated time <= 1H
36% Nº Events >= 1000
13% Simulated time >= 5H
10% Simulated time >= 10H
7% Simulated time >= 1 Day
5% Nº Events >= 10000
2% Nº Events <= 100
established public peers (20244 in total):
77.391% No PublicPeers in Established Set
22.609% PublicPeers in Established Set
target active public: OK (107.08s)
+++ OK, passed 100 tests:
69% Simulated time <= 1H
36% Nº Events >= 1000
11% Simulated time >= 5H
10% Simulated time >= 10H
9% Simulated time >= 1 Day
7% Nº Events <= 100
4% Nº Events >= 10000
```

```
dns can recover from fails: FAIL (3800.64s)
*** Failed! Falsified (after 19 tests and 8874
shrinks):
<inputs>
<trace>
fromList [("test3",Time 30.037848276817s)] none of
these DNS names recovered
Final time: Time 101.088794689953s
TTL time: fromList [("test2",60s),("test3",5s)]
Number of recovered: 0
Use --quickcheck-replay=56892 to reproduce.
Use -p '/dns can recover from fails/' to rerun this
test only.
```

Conclusion

Best effort

- Complex systems spans performance characteristics we can not control;
- Functional Programming, namely Haskell and its concurrency tools helped us manage complexity;
- We do our best in searching through all state space efficiently;
- Well-founded confidence;
- Progress is achievable.

Far from perfect

We have had quite a few bugs, and we still do!

- 378 closed issues related with networking;
- 276 open ones (minor, good-to-have issues);
- 10% of the issues are related with simulation environment;
- About a handful of them were due to misplaced logging events.

Our CI test suite runs on average between 1 and 5 hours of simulated time per test per input per PR per OS. Which means:

- Assuming around 100 tests in our test suite and
- each test generates 100 random inputs;
- Assuming 3 PRs per week;
- Testing on Windows, OSX and Linux;
- Results on around 225 000 hours of simulated time per week!

Some examples of bugs found

Discovering rare events in the real world:

- Different scheduling found a edge case where state was being blindly overwritten
- Asynchronous exceptions on a blocking `finally` block
- Timeouts not being enforced withing reasonable bounds
- Pruning connections misbehavior in the presence of a TCP Simultaneous Open

Thank you!

INPUT | OUTPUT

Well-Typed