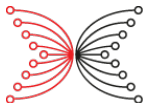


Building a Distributed System with Real-time Constraints

Using concurrent Functional Programming tools

Armando Santos

December 12, 2022 — Copyright © 2022 Well-Typed LLP



INPUT | OUTPUT

 **Well-Typed**
The Haskell Consultants

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

Formal Specification

Threat models

Non-realistic assumptions

Performance objectives

Refining step

Real time constraints

Concurrency

Operation & Performance

Implementation

Architecture & Design

Protocols

Scale

Exceptions & Corner cases

Testing

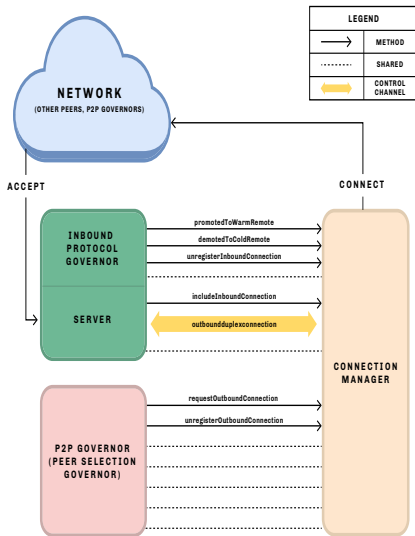
Properties

Simulation

Reliability

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

Strongly Statically Typed Purely Functional Programming with Haskell!

- ▶ Non-strict evaluation;
- ▶ **Type Safety**;
- ▶ **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).

Property based testing framework for Haskell.

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

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 (97.08s)
+++ 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 (100.91s)
+++ OK, passed 100 tests:
68% Simulated time <= 1H
41% N° Events >= 1000
8% Simulated time >= 5H
7% N° Events <= 100
7% Simulated time >= 10H
6% Simulated time >= 1 Day
2% N° Events >= 10000
target established public: OK (113.54s)
+++ OK, passed 100 tests:
71% Simulated time <= 1H
36% N° Events >= 1000
13% Simulated time >= 5H
10% Simulated time >= 10H
7% Simulated time >= 1 Day
5% N° Events >= 10000
2% N° 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% N° Events >= 1000
11% Simulated time >= 5H
13% Simulated time >= 10H
9% Simulated time >= 1 Day
7% N° Events <= 100
4% N° Events >= 10000

dns can recover from fails: FAIL (3800.64s)
*** Failed! Falsified (after 19 tests and 8874
shrinks):
<inputs>
<trace>
fromList [("test3",Time 30.037848276617s)] 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 issues, 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!