Earthquake: An Open-Source Framework of Implementation-Level Distributed System Model Checkers

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http://osrg.github.io/earthquake/

Problem: Real Distributed Systems in Clouds Are Bug-Prone

e.g. Cassandra, Flume, HBase, HDFS, MapReduce and ZooKeeper

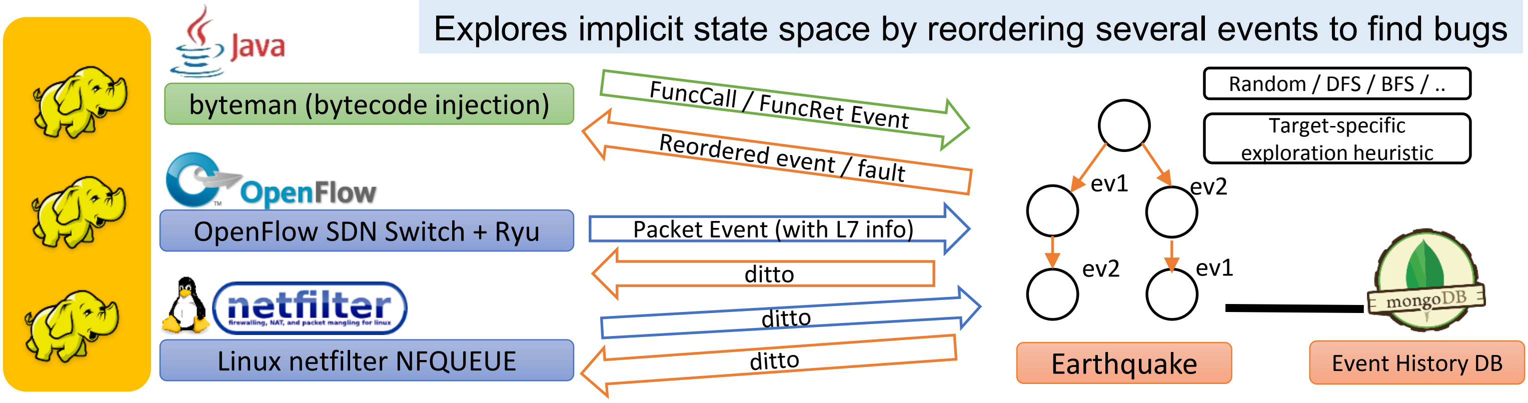
- 3 bug tickets per day on average [Gunawi et al. SoCC'14]
- Almost half of them takes over 1 month to debug

→ Cloud-computing business faces risk of unavailability and data corruption!

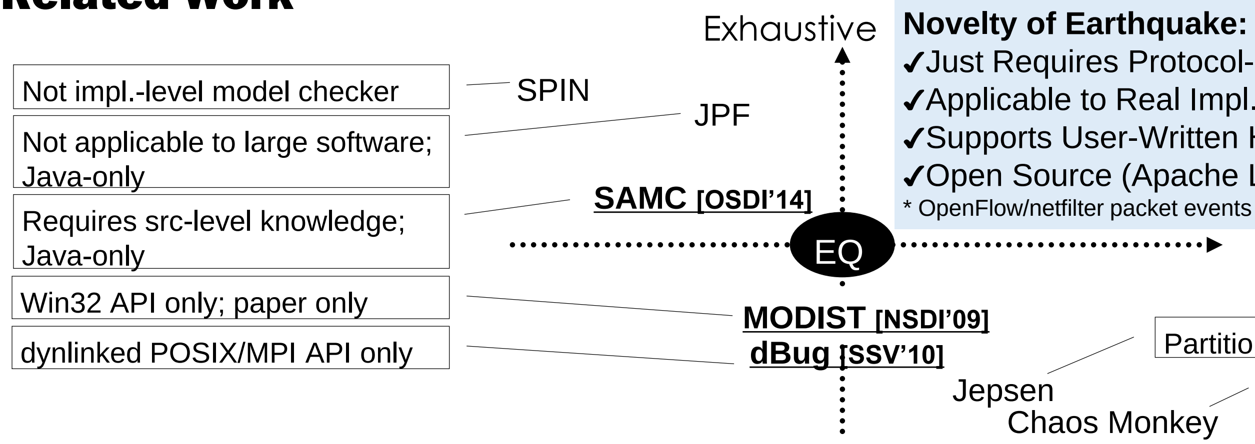
Our main scope of interest: distributed race condition, fault tolerance bug
(Such bugs are especially peculiar to distributed systems)

Solution: Model Checker for Unmodified Distributed Systems

Explores implicit state space by reordering several events to find bugs



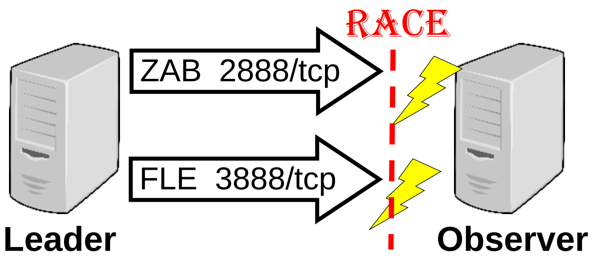
Related Work



Novelty of Earthquake:
- ✓Just Requires Protocol-Level Knowledge*
- ✓Applicable to Real Impl. in Any Language*
- ✓Supports User-Written Heuristic Plug-In
- ✓Open Source (Apache License 2.0)

* OpenFlow/netfilter packet events

Epic Win: Found Distributed Race Condition of Apache ZooKeeper



Bug: "Observer" node cannot be promoted to "Participant"

- The bug was marked **critical** by ZK community.
  We sent a bug-fix to ZK community and the fix was merged.
  https://issues.apache.org/jira/browse/ZOOKEEPER-2212
- With*out* Earthquake, the bug could *not* be reproduced in **5,000 experiments**. (about **60 hours**)

Earthquake is Available at Docker Hub!

```
$ docker run -i -t osrg/earthquake
```

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1. Introduction

Real implementation of distributed systems in clouds are bug-prone. Even matured and well unit-tested softwares (e.g. Cassandra, Flume, HBase, HDFS, MapReduce and ZooKeeper [1]), many bugs of them are being reported every day, and most of bugs need long time to get resolved. Such a bug exposes cloud-computing business to risk of unavailability and data corruption.

Some existing studies (e.g. [2]) showed that distributed system model checkers (DMCKs) are effective to find such implementation-level bugs, especially ones related to message ordering and fault-tolerance. DMCKs explore state space by permuting messages and injected fault events in several orders so as to find bugs. However, applying a DMCK to a real system is difficult, because DMCK requires plenty of implementation-specific, source code-level knowledge.

In this poster, we propose a new open-source DMCK named Earthquake. Earthquake is easy to use because it does not require source code-level knowledge, but only requires protocol-level knowledge to find bugs. If a user has source code-level knowledge, he/she can still make use of it for deeper state exploration.

2. Architecture

A typical configuration of Earthquake is shown in the other page.

Orchestrator (Core part of Earthquake): Receives several kind of events from Inspectors, permutes them, and send back to Inspectors. By default, Earthquake permutes events in random order. A user can write his/her own permutation heuristic plug-in to alleviate state explosion (as in SAMC [2]) and find bugs efficiently. He/she can also inject fault events (e.g., network partition, node crash and reboot) so as to test fault-tolerance of the target system.

Orchestrator also executes a workload script to run experiments, and a health check scripts to check whether the target system is hitting bugs.

Inspectors: Inspects the target system and send events to Orchestrator. Currently, we have two implementations of Inspectors:

> **Ethernet Inspector:** Inspects Ethernet packets and blocks them until Orchestrator allows to pass. A user is required to write his/her own Inspector to parse semantic information of the packets. Note that he/she does not need source-code level knowledge, but just needs protocol-level knowledge to write an Inspector. Furthermore, Ethernet Inspector is applicable to programs written in any language.
>
> Ethernet Inspector is implemented as a Ryu SDN [3] application. We also provide Linux Netfilter-based implementation for a case where Ryu cannot be installed.
>
> **Java Inspector:** Inspects Java function calls and blocks them as in packets in Ethernet Inspector. A user has to decide which functions to be inspected. This requires enormous source code-level knowledge as in existing works, but enables much more exhaustive state exploration than Ethernet Inspector. Java Inspector is implemented in Byteman [4], which enables dynamic patching to Java programs without any modification to the source codes.

These Inspectors are not exclusive. A user can use each of them or mix of them depending on his/her knowledge and intention.

History DB: Records ordering of events and allows a user to analyze which permutation of events triggers a bug.

3. Evaluation

We applied Earthquake to Apache ZooKeeper using Ethernet Inspector without any modification to ZooKeeper.

Earthquake successfully found a distributed race condition bug `ZOOKEEPER-2212` that had been previously unknown.

ZooKeeper was unintentionally dependent on a specific ordering of ZAB (ZooKeeper Atomic Broadcast) packets and FLE (Fast Leader Election) packets. When an observer in a ZooKeeper ensemble receives a specific kind of ZAB packet after receiving a specific kind of FLE packet, the observer stays at a weird state and cannot be promoted to a participant.

Although Earthquake does not fully control non-determinism, Earthquake can easily reproduce this bug in a few experiments. Without Earthquake, we were not able to reproduce the bug in 5,000 experiments. (About 60 hours)

4. Discussion

A major challenge still left is formulation of workloads.

We consider a good workload is the one that is unreliable, even though expected to happen in real business. For example, dynamic reconfiguration [5] is attractive in business, as it makes a cloud system tolerable to seasonal traffic spikes. However, real implementations of dynamic reconfiguration tend to be bug-prone due to complex state transitions. Actually, we found `ZOOKEEPER-2212` on the way of testing reconfiguration.

We are also groping for other good workloads.

5. Conclusion

Earthquake is a powerful, open-source DMCK framework for finding implementation-level bugs of distributed systems.

Earthquake is available for download under Apache License 2.0 at http://osrg.github.io/earthquake/. A tutorial for reproduction of `ZOOKEEPER-2212` is also included in this repository.

References

[1] Gunawi, et al. What Bugs Live in the Cloud? A Study of 3000+ Issues in Cloud Systems. In *SoCC '14.*

[2] Leesatapornwongsa, et al. SAMC: Semantic-Aware Model Checking for Fast Discovery of Deep Bugs in Cloud Systems. In *OSDI '14*.

[3] Ryu SDN Framework. http://osrg.github.io/ryu/

[4] Byteman. http://byteman.jboss.org/

[5] Shraer, et al. Dynamic Reconfiguration of Primary/Backup Clusters. In *ATC '12.*