Automatic Reliability Testing for Cluster Management Controllers

Xudong Sun Wenqing Luo Jiawei Tyler Gu Aishwarya Ganesan
Ramnatthan Alagappan Michael Gasch Lalith Suresh Tianyin Xu

https://github.com/sieve-project/sieve

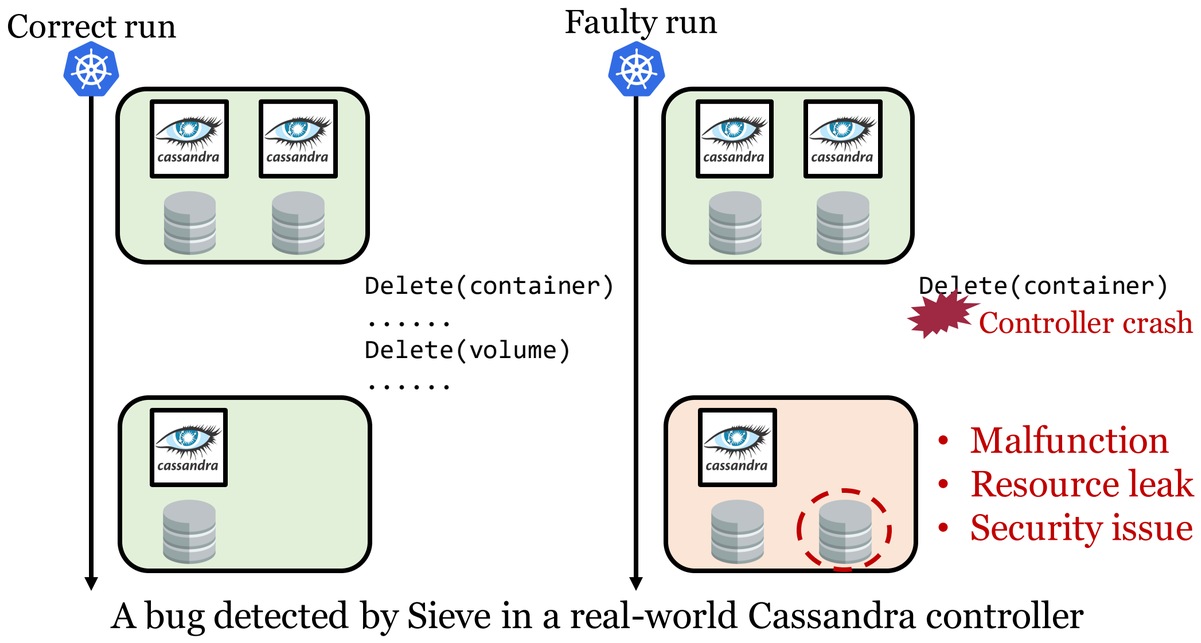
ARTIFACT EVALUATED usenix ASSOCIATION AVAILABLE
ARTIFACT EVALUATED usenix ASSOCIATION FUNCTIONAL
ARTIFACT EVALUATED usenix ASSOCIATION REPRODUCED

1. CONTRIBUTIONS

- Sieve: the *first* automatic reliability-testing tool for *unmodified* cluster management controllers
  - Perturbing the controller's view of the cluster state
  - Applying differential oracles to automatically flag buggy behavior
- Sieve has detected **46** *new* bugs (**35** confirmed and **22** fixed) in **10** popular controllers
  - Sieve can reliably reproduce the detected bugs

2. BACKGROUND & MOTIVATION

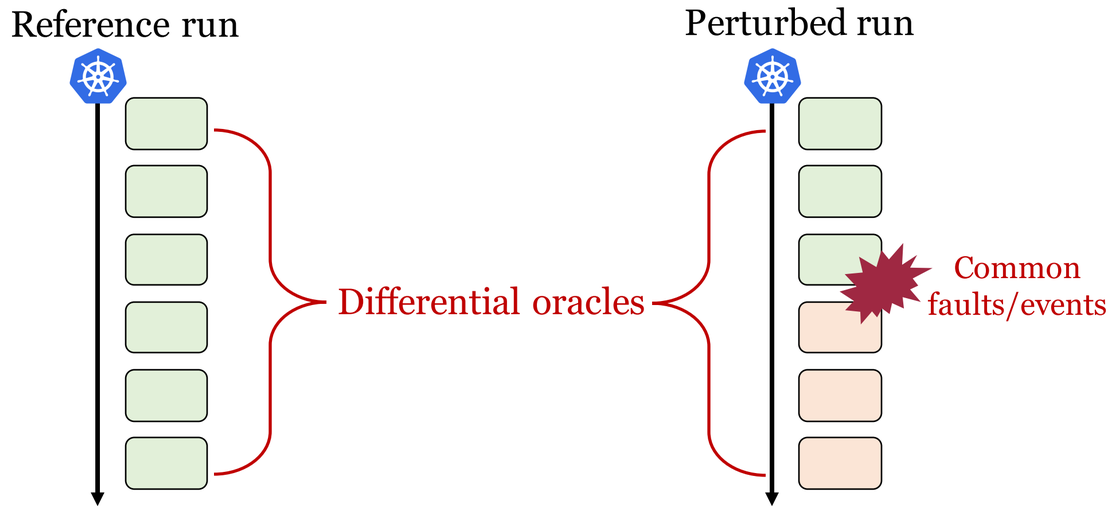
- Modern datacenter infrastructures are managed by cluster management controllers
  - Controllers implement **state reconciliation**
- Controller reliability is **critical** but **challenging**
  - Controllers run in distributed environments and need to tolerate unexpected faults, network issues, asynchrony, etc.



A bug detected by Sieve in a real-world Cassandra controller

3. KEY IDEAS

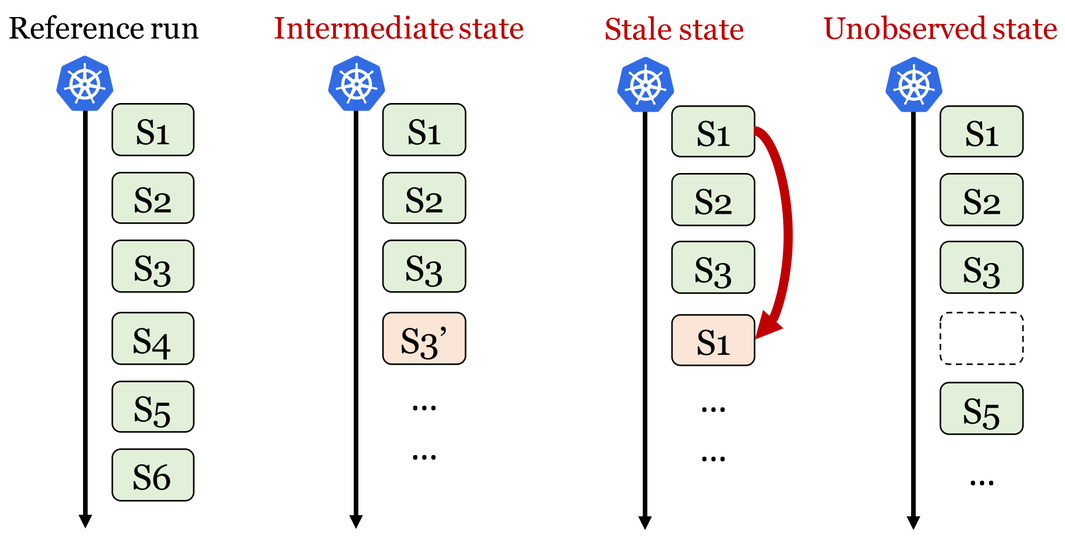
1. Perturbing the controller's view of the cluster state
   - Three perturbation patterns
   - Exhaustive perturbations for each pattern
   - Effective pruning of inefficient perturbations
2. Applying differential oracles to flag buggy behavior
   - Effective in flagging non-crashing symptoms
   - Checking both end states and state updates



- **Usability**: Applicable to unmodified controllers
- **Reproducibility**: Reliably reproduce detected bugs

4. PERTURBATION PATTERNS

- **Intermediate state:** crashing the controller in the middle of a reconciliation
- **Stale state:** making the controller operate on stale state by reconnecting it to a stale API server
- **Unobserved state:** making the controller miss a state by injecting delay to the controller



Generating tests to exhaustively cover all perturbations and pruning out ineffective perturbations.

5. EVALUATION

Applied Sieve to **10** popular Kubernetes controllers

Controller	Intermediate state bugs	Stale state bugs	Unobserved state bugs	Indirect bugs	Total
cass-operator	2	1	0	0	3
cassandra-operator	0	2	1	2	5
casskop	1	2	1	0	4
elastic-operator	0	2	0	0	2
mongodb-operator	2	3	1	3	9
nifikop	2	0	0	1	3
rabbitmq-operator	1	2	1	0	4
xtradb-operator	3	3	1	0	7
yugabyte-operator	0	2	1	2	5
zookeeper-operator	0	2	1	1	4
Total	**11**	**19**	**7**	**9**	**46**

- Found **46** new bugs (**35** confirmed; **22** fixed)
- Pruned out **46% - 99%** perturbations
- Tested each controller within a **nightly** run
- Low false-positive rate of **3.5%**

ARTIFACT EVALUATED usenix ASSOCIATION AVAILABLE

ARTIFACT EVALUATED usenix ASSOCIATION FUNCTIONAL

ARTIFACT EVALUATED usenix ASSOCIATION REPRODUCED

Automatic Reliability Testing for Cluster Management Controllers

Xudong Sun, Wenqing Luo, Jiawei Tyler Gu, Aishwarya Ganesan,
Ramnatthan Alagappan, Michael Gasch, Lalith Suresh, Tianyin Xu

UNIVERSITY OF ILLINOIS URBANA-CHAMPAIGN

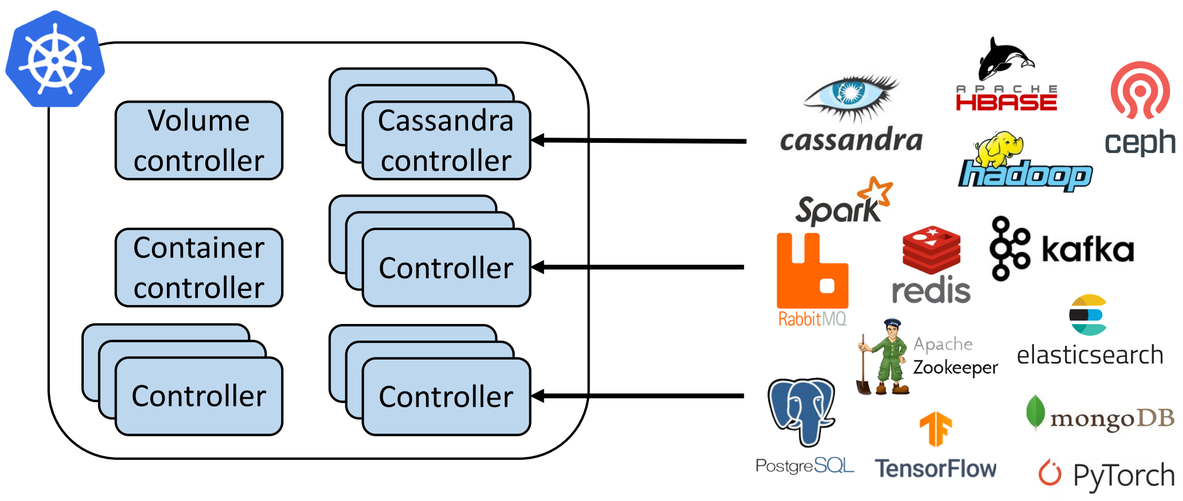
vmware

Contribution

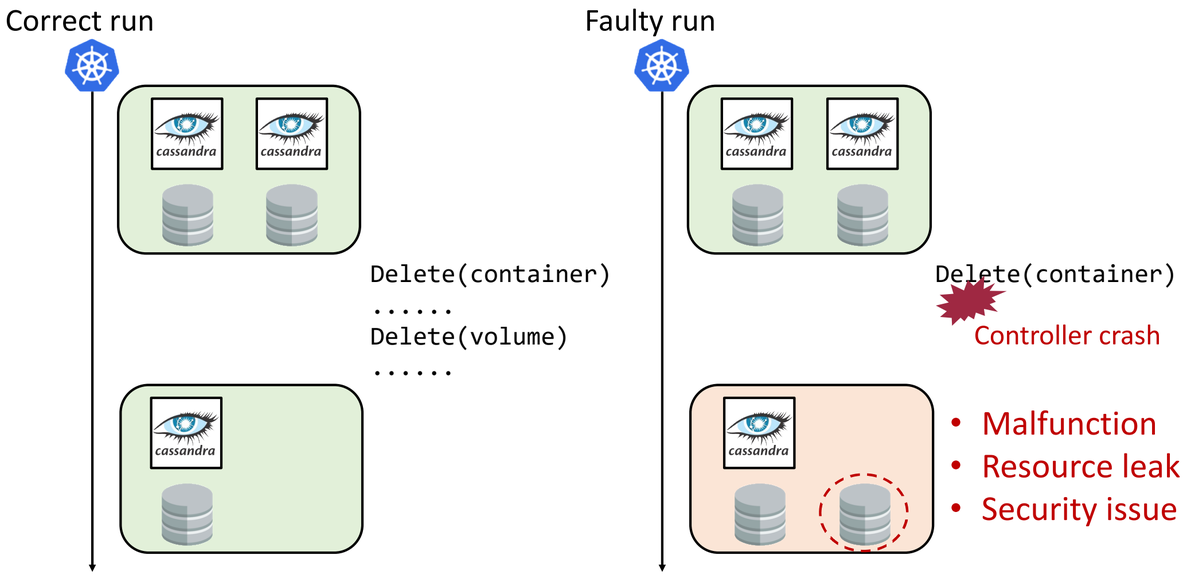
Sieve: an automatic reliability testing tool for cluster management controllers

Background

Cluster Management Controllers

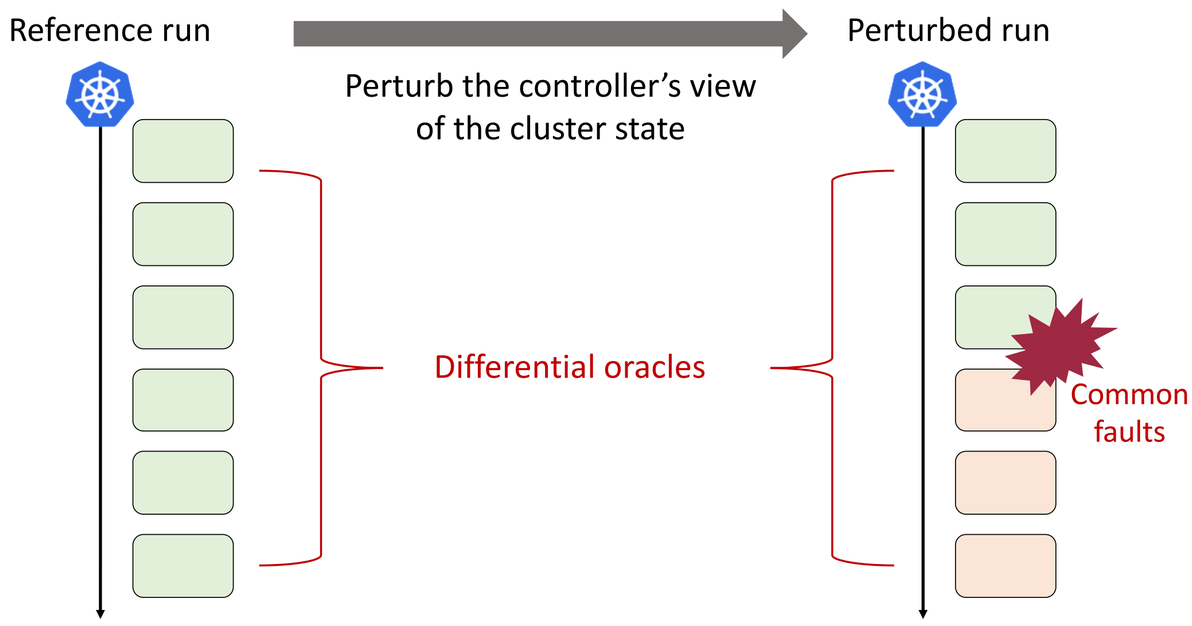


Controller reliability is critical but challenging!



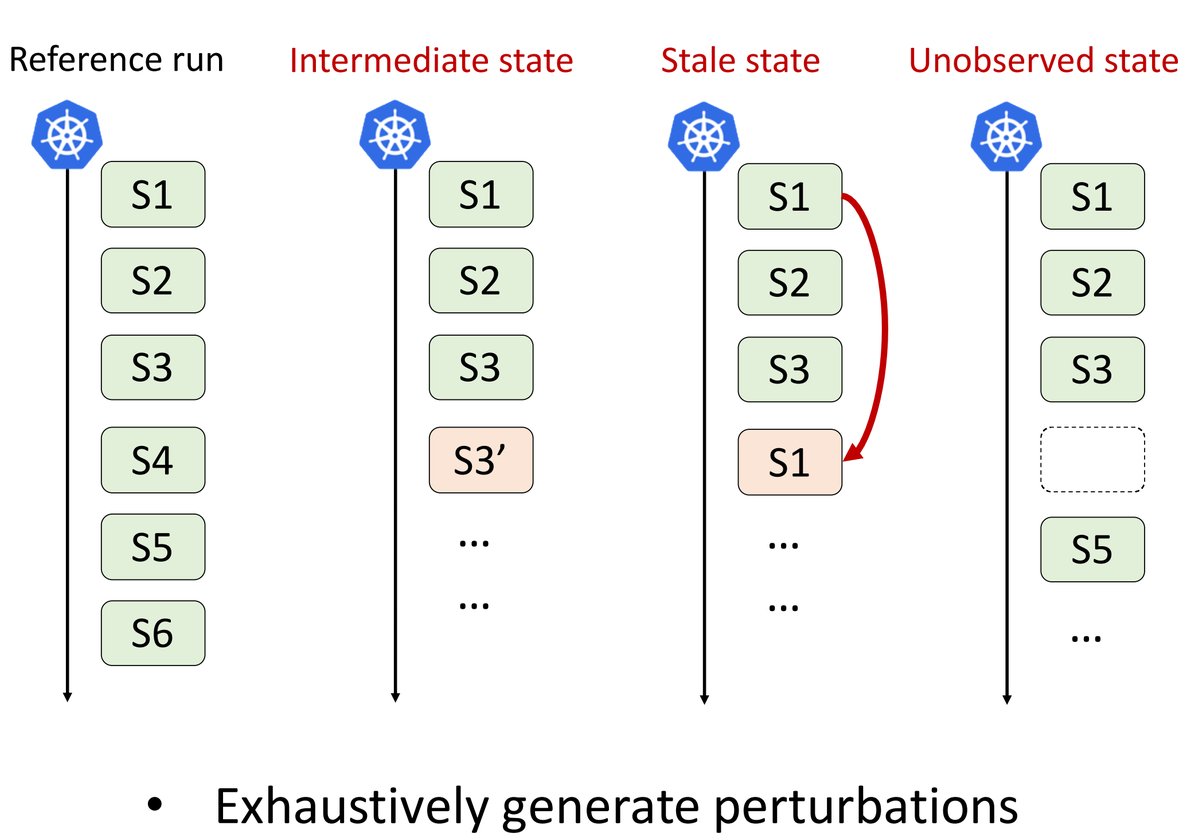
Key idea

Perturb the controller's view of the cluster state
Use differential oracles to flag bugs



- Reduce fault injection space
- Test controllers without knowing the internals
- Reliably reproduce the bugs

Perturbation patterns



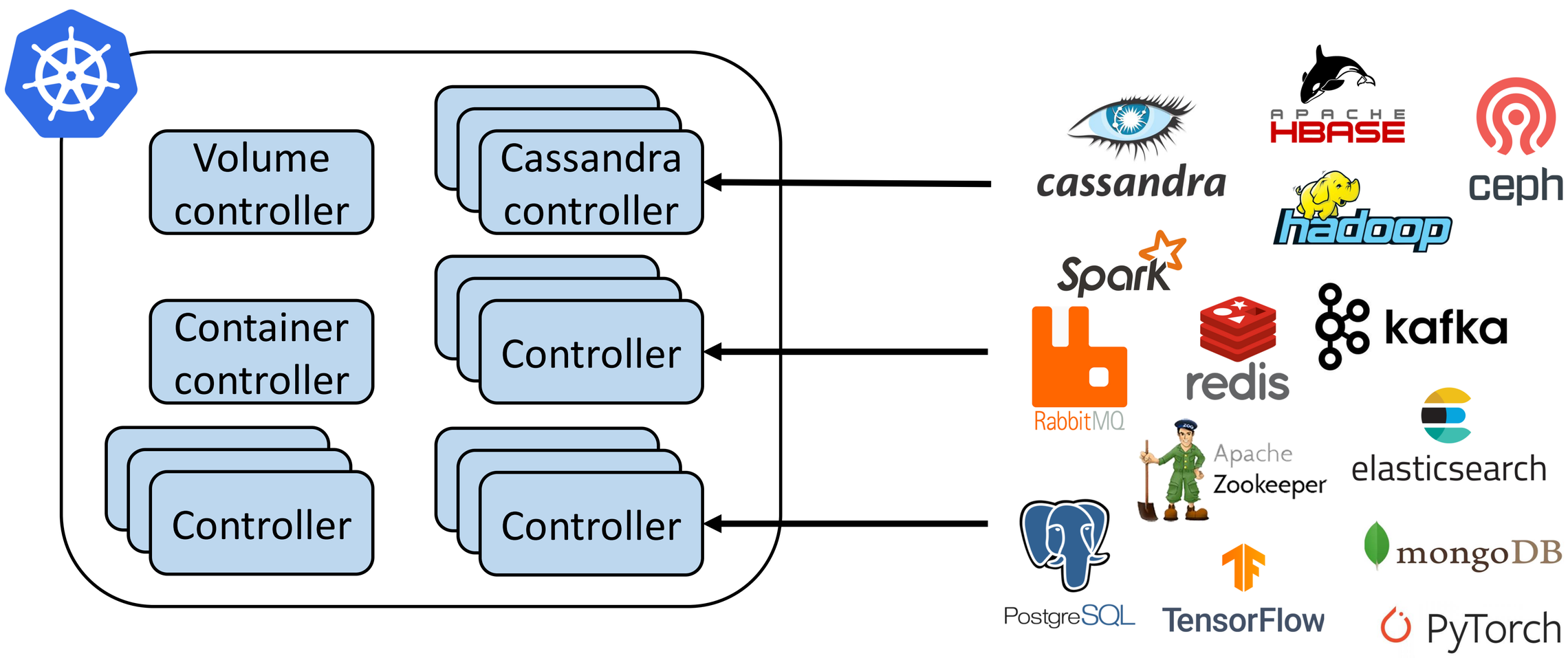
- Exhaustively generate perturbations
- Prune out ineffective perturbations

Evaluation results

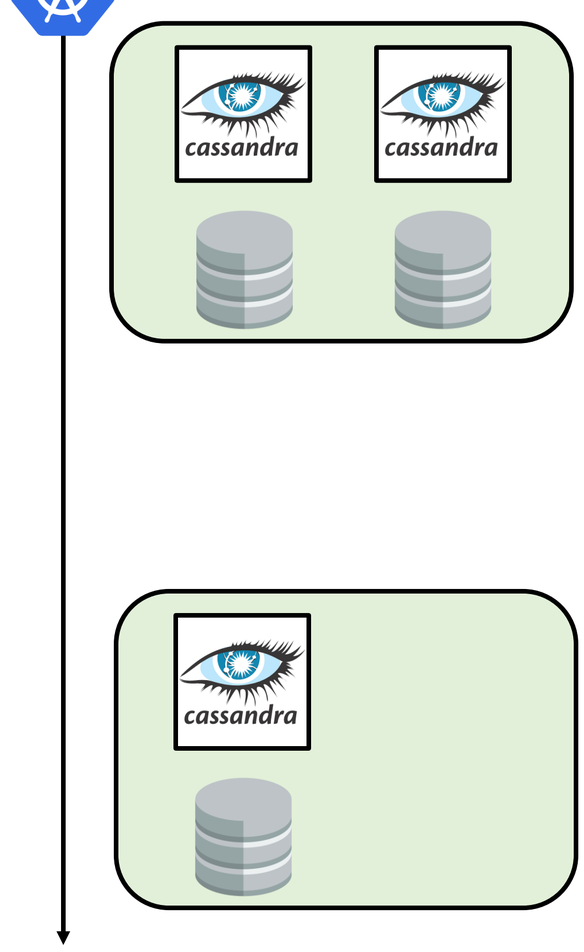
Controller	Intermediate state bugs	Stale state bugs	Unobserved state bugs	Indirect bugs	Total
cass-operator	2	1	0	0	3
cassandra-operator	0	2	1	2	5
casskop	1	2	1	0	4
elastic-operator	0	2	0	0	2
mongodb-operator	2	3	1	3	9
nifikop	2	0	0	1	3
rabbitmq-operator	1	2	1	0	4
xtradb-operator	3	3	1	0	7
yugabyte-operator	0	2	1	2	5
zookeeper-operator	0	2	1	1	4
Total	**11**	**19**	**7**	**9**	**46**

- Found 46 new controller bugs (35 confirmed; 22 fixed)
- Pruned out 46% - 99% perturbations
- Tested each controller within 7 hours (on 11 VMs)
- Low false-positive rate of 3.5%

Sieve is available on GitHub
https://github.com/sieve-project/sieve

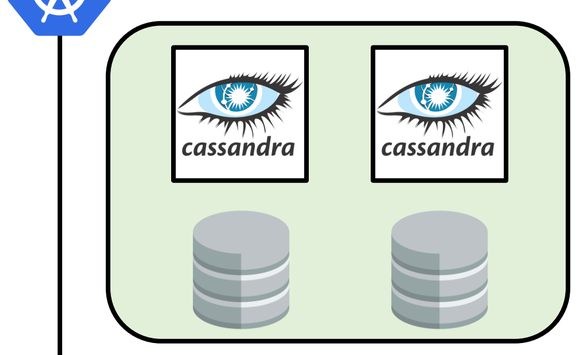

Volume controller
Cassandra controller
Container controller
Controller
Controller
Controller
Controller
cassandra
APACHE HBASE
ceph
hadoop
Spark
redis
kafka
RabbitMQ
Apache Zookeeper
elasticsearch
PostgreSQL
TensorFlow
mongoDB
PyTorch

Correct run



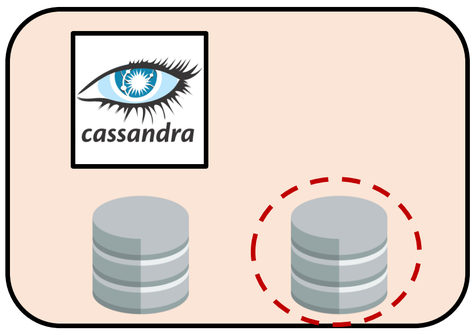

```
Delete(container)
......
Delete(volume)
......
```

Faulty run

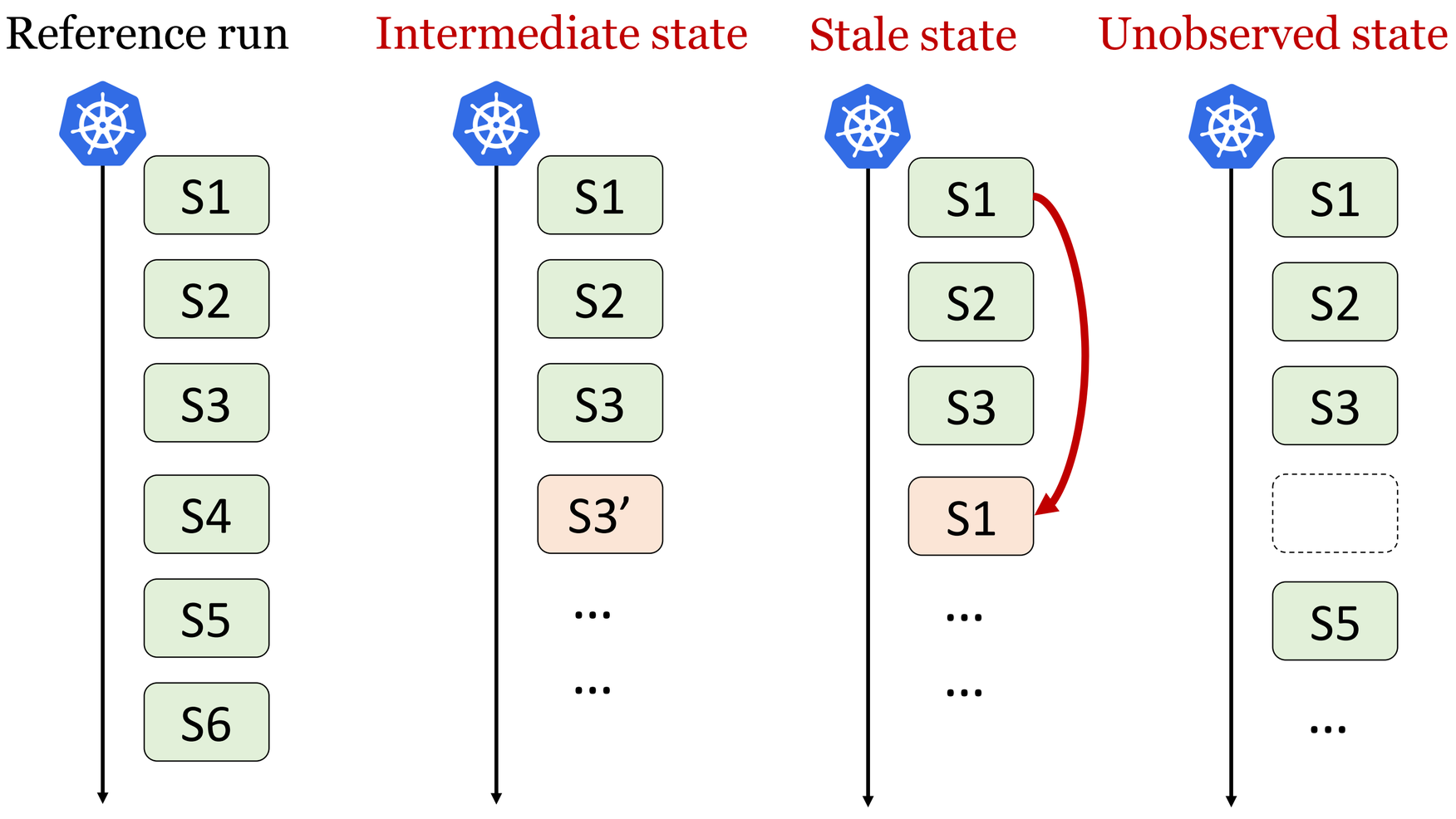


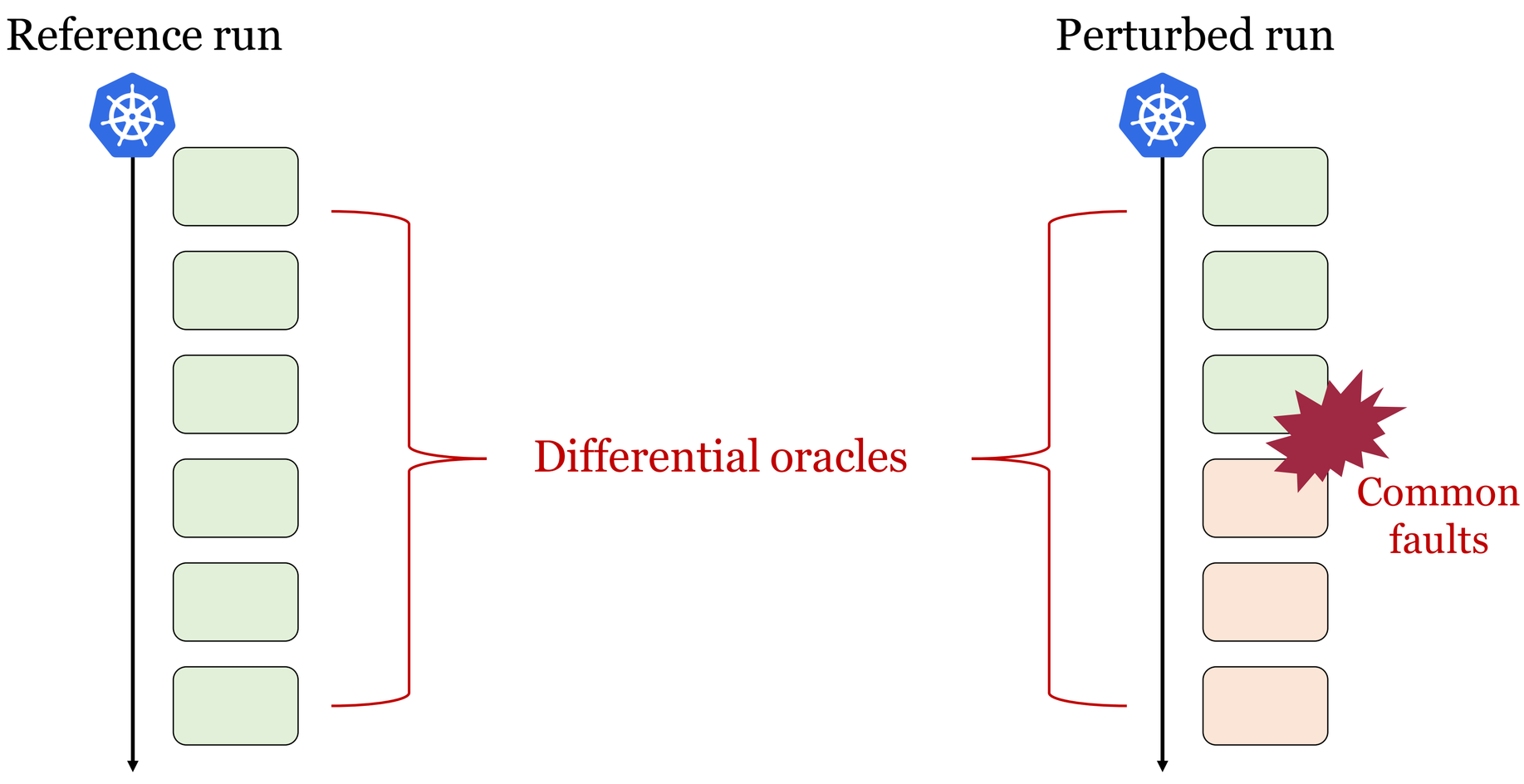

```
Delete(container)
```

Controller crash



- Malfunction
- Resource leak
- Security issue


Reference run
Intermediate state
Stale state
Unobserved state
S1
S2
S3
S4
S5
S6
S1
S2
S3
S3’
…
…
S1
S2
S3
S1
…
…
S1
S2
S3
S5
…


Reference run
Perturbed run
Differential oracles
Common faults

Controller	Intermediate state bugs	Stale state bugs	Unobserved state bugs	Indirect bugs	Total
cass-operator	2	1	0	0	3
cassandra-operator	0	2	1	2	5
casskop	1	2	1	0	4
elastic-operator	0	2	0	0	2
mongodb-operator	2	3	1	3	9
nifikop	2	0	0	1	3
rabbitmq-operator	1	2	1	0	4
xtradb-operator	3	3	1	0	7
yugabyte-operator	0	2	1	2	5
zookeeper-operator	0	2	1	1	4
Total	**11**	**19**	**7**	**9**	**46**