# An Empirical Analysis of Flaky Tests

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# Typical Testing Scenario

Test Suite

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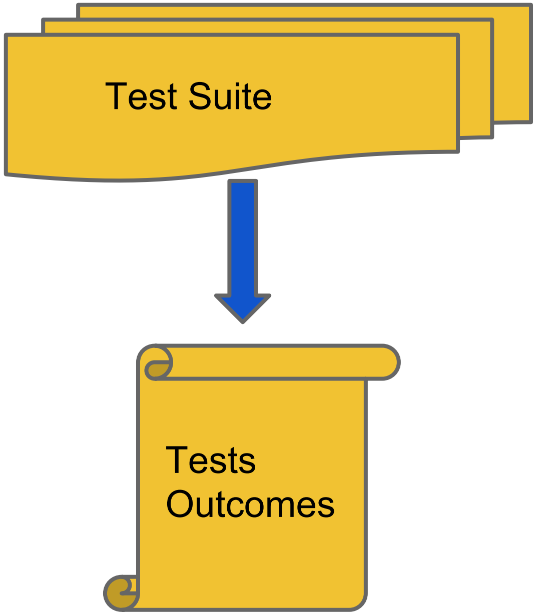

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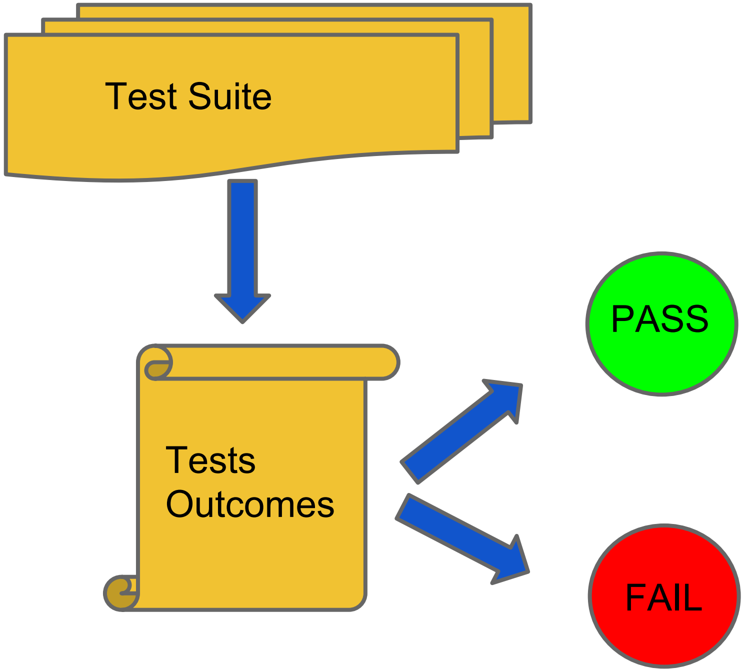

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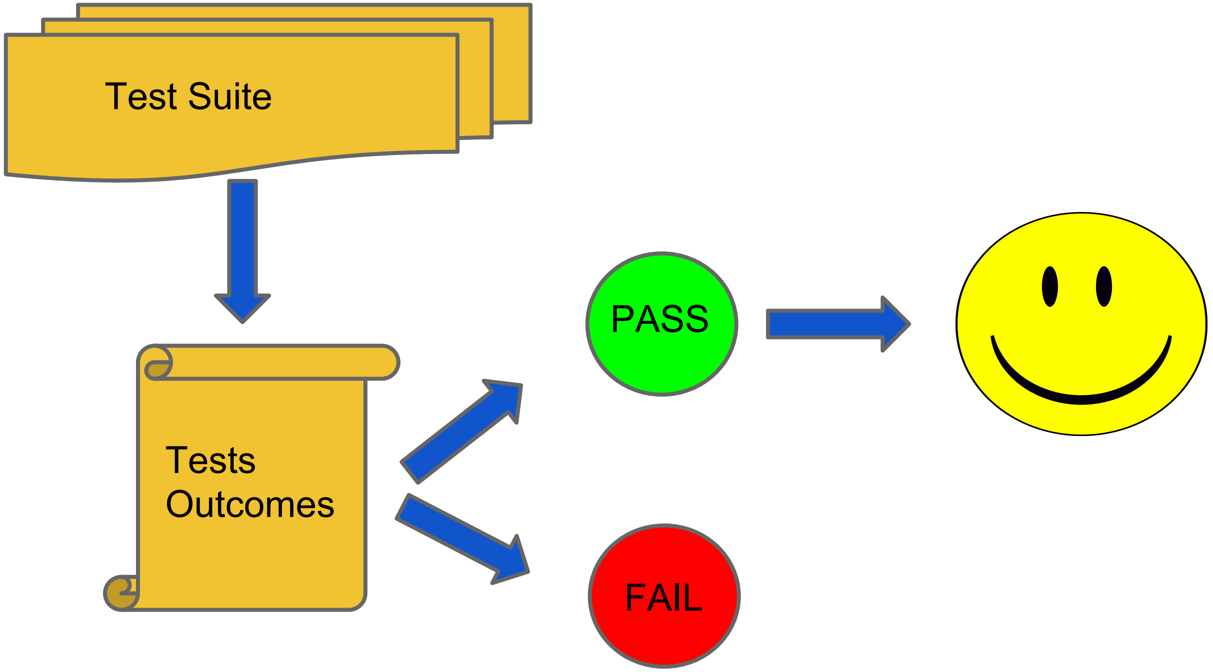

**No further inspection needed**

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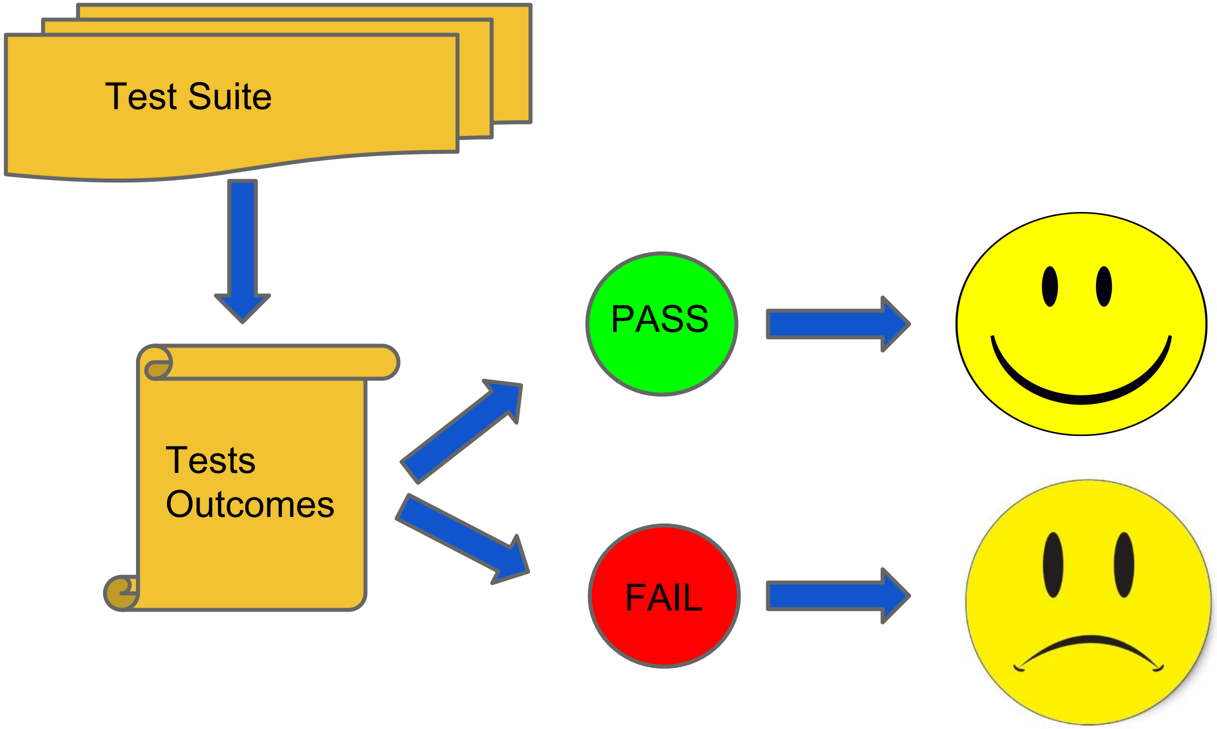

Test Suite

Tests Outcomes

PASS

FAIL

No further inspection needed

Inspect and fix bugs

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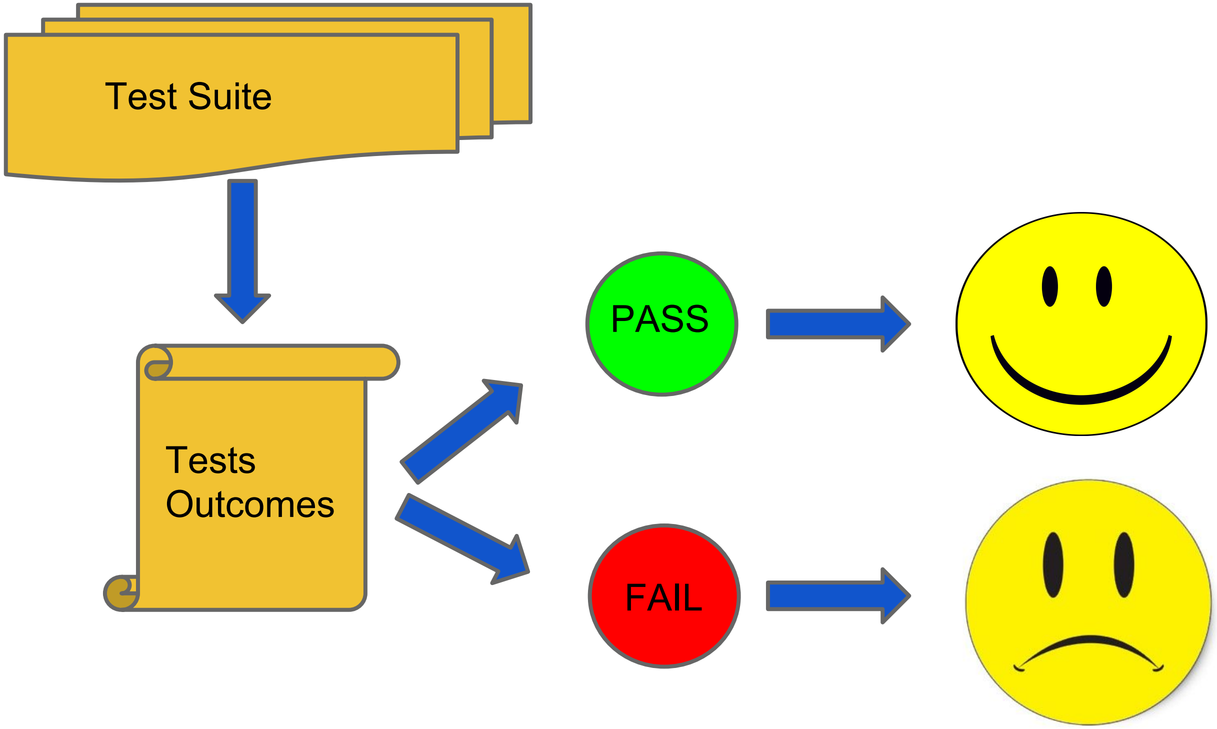

No further inspection needed

Inspect and fix bugs

**Key Assumption: Test outcomes are reliable**

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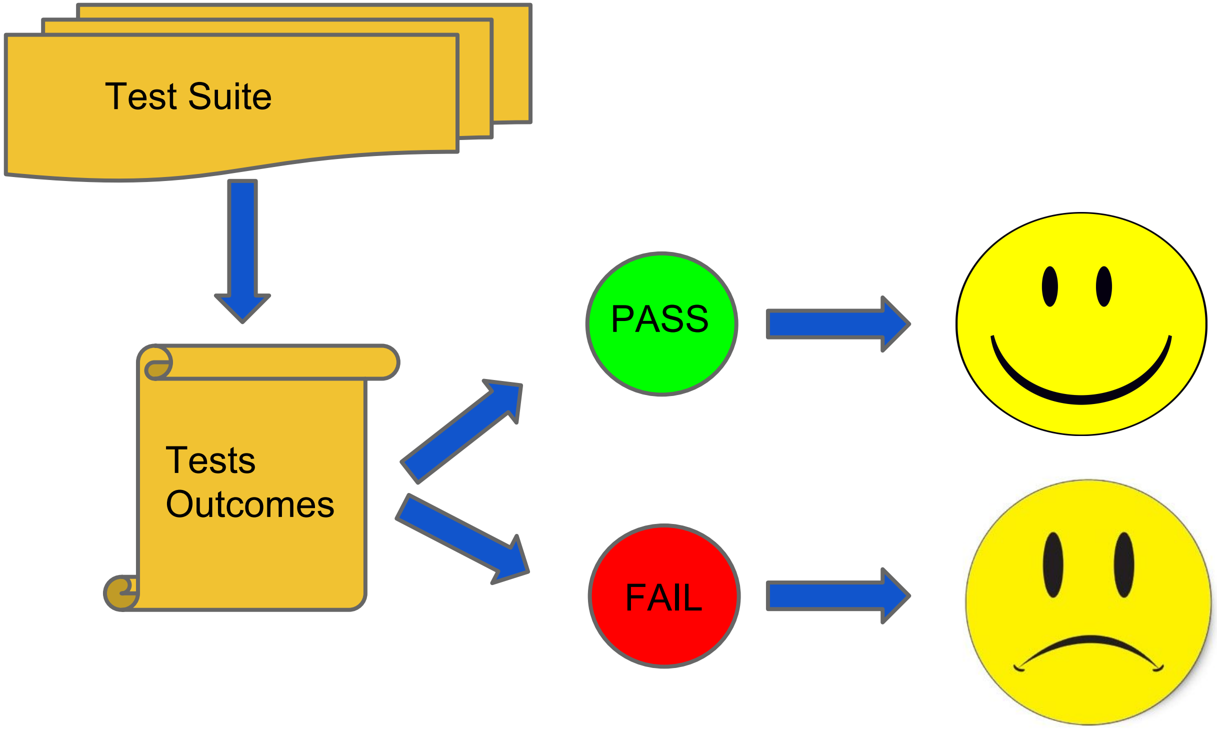


Test Suite

Tests Outcomes

PASS

FAIL

No further inspection needed

Inspect and fix bugs

**Key Assumption: T ✗ utcomes are reliable**

# Definition: Test Outcome Non-determinism

Test outcome non-determinism:

- Same code revision
- Same input and configuration
- Passes/fails non-deterministically

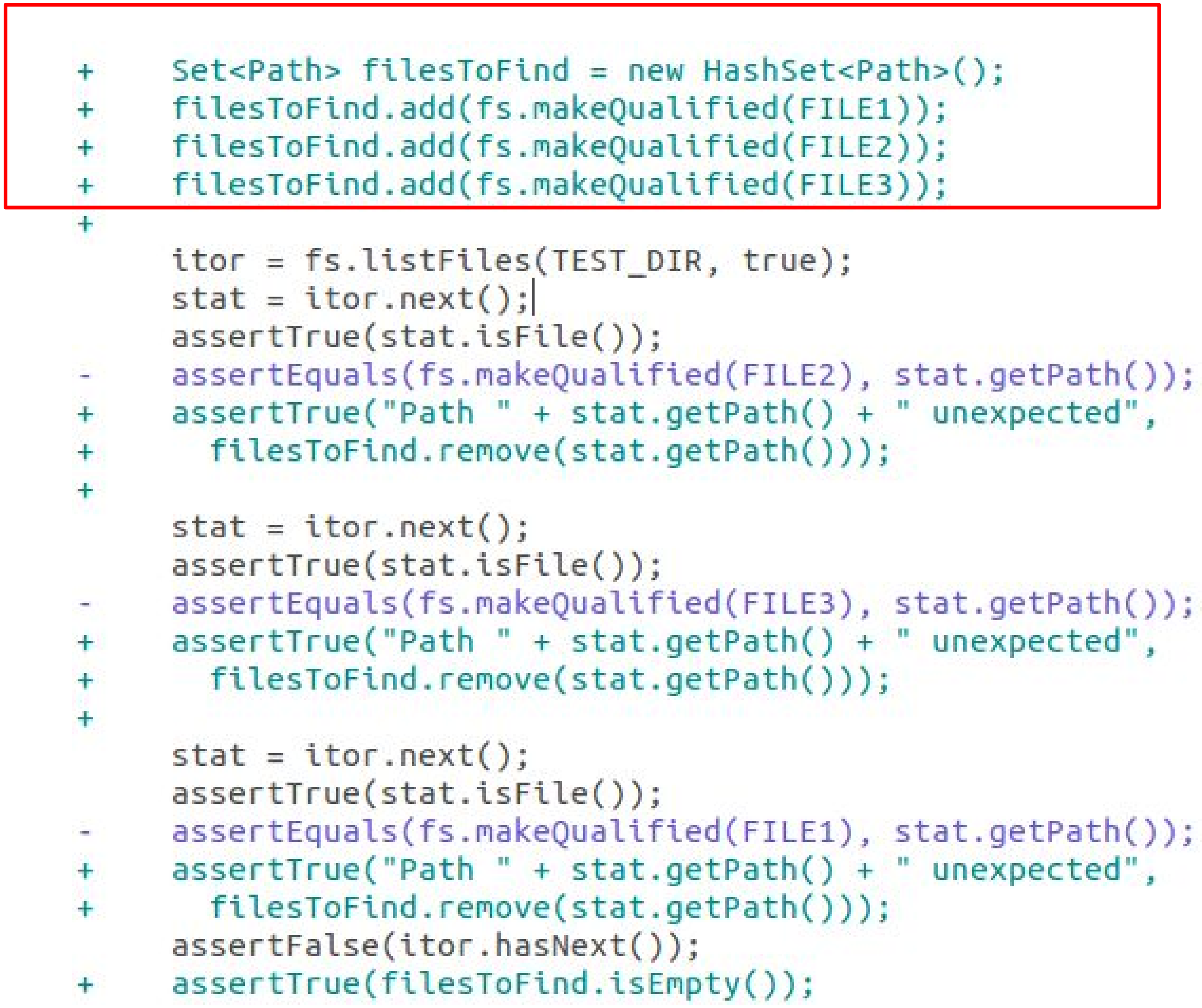
Such tests are a.k.a. flaky tests.

# Flaky Test Example HADOOP-6933

```
@Test
public void testDirectory() throws IOException {
    …
    itor = fs.listFiles(DIR1, false);
    …
    assertEquals(fs.makeQualified(FILE2), stat.getPath());
    itor.next();
    assertEquals(fs.makeQualified(FILE3), stat.getPath());
    …
}
```

**“TestListFiles assumes a particular order of the files returned by the directory iterator. There's no such guarantee made by the underlying API, so the test fails on some hosts.”**

# Flaky Test Fix Example



```
+     Set<Path> filesToFind = new HashSet<Path>();
+     filesToFind.add(fs.makeQualified(FILE1));
+     filesToFind.add(fs.makeQualified(FILE2));
+     filesToFind.add(fs.makeQualified(FILE3));
+
      itor = fs.listFiles(TEST_DIR, true);
      stat = itor.next();
      assertTrue(stat.isFile());
-     assertEquals(fs.makeQualified(FILE2), stat.getPath());
+     assertTrue("Path " + stat.getPath() + " unexpected",
+       filesToFind.remove(stat.getPath()));
+
      stat = itor.next();
      assertTrue(stat.isFile());
-     assertEquals(fs.makeQualified(FILE3), stat.getPath());
+     assertTrue("Path " + stat.getPath() + " unexpected",
+       filesToFind.remove(stat.getPath()));
+
      stat = itor.next();
      assertTrue(stat.isFile());
-     assertEquals(fs.makeQualified(FILE1), stat.getPath());
+     assertTrue("Path " + stat.getPath() + " unexpected",
+       filesToFind.remove(stat.getPath()));
      assertFalse(itor.hasNext());
+     assertTrue(filesToFind.isEmpty());
```

# Flaky Tests are Harmful

- Undermine the value of test suite
  - Test failures no longer always indicate bugs
- Hide real bugs
  - Flaky test failures often get ignored
- Hard to reproduce and debug

# Flaky Tests are Everywhere

“If you do not have a flaky functional tests build, you are not doing anything real”

-- A ThoughtWorks Developer

TAP system at Google has 1.6M test failures in last 15 months, 73K (4.56%) are flaky failures

Our study found hundreds of distinct flaky tests from Apache projects

# Contributions of Our Work

- Raise awareness of flaky tests

- Provide 13 findings and implications for avoiding/manifesting/fixing flaky tests

- Propose research for handling flaky tests

- Provide a public dataset of flaky tests
  - Passed artifact evaluation
  - mir.cs.illinois.edu/farah/studied_flaky_commits.csv

# How Did We Find Flaky Tests?

- Search commit logs of all 151 Apache projects for “flak” and “intermit” keywords
    - 1129 commit messages
- Manually label likely distinct fixed flaky tests
    - 486 fixed flaky tests
- Sample and inspect 161 commits in more detail

# Research Questions

- Causes of flakiness:
  - Q1: What are the root causes of flaky tests?
- Introduction of flakiness:
  - Q2: How are flaky tests introduced?
- Manifestation:
  - Q3: How to manifest flaky tests?
- Fix strategy:
  - Q4: Does fixing flaky tests also change code under test (CUT)?
  - Q5: How to fix flaky tests?

More in our paper!

# Q1:
# What are the Root Causes of Flaky Tests?

# Async Wait

Test makes async calls but doesn’t wait for the result properly; example HBASE-2684:

```
@Test
public void testRsReportsWrongServerName() throws Exception {
  MiniHBaseCluster cluster = TEST_UTIL.getHBaseCluster();
  MiniHBaseClusterRegionServer firstServer =
       (MiniHBaseClusterRegionServer)cluster.getRegionServer(0);
  HServerInfo hsi = firstServer.getServerInfo();
  firstServer.setHServerInfo(...);

   // Sleep while the region server pings back
  Thread.sleep(2000);
  assertTrue(firstServer.isOnline());
  assertEquals(2,cluster.getLiveRegionServerThreads().size());
   ... // similarly for secondServer
 }
```

# Concurrency

- Flakiness caused by buggy thread interleavings (excluding Async Wait)
    - Data races
    - Atomicity violations
    - Deadlocks

- Non-determinism could either come from test code or code under test

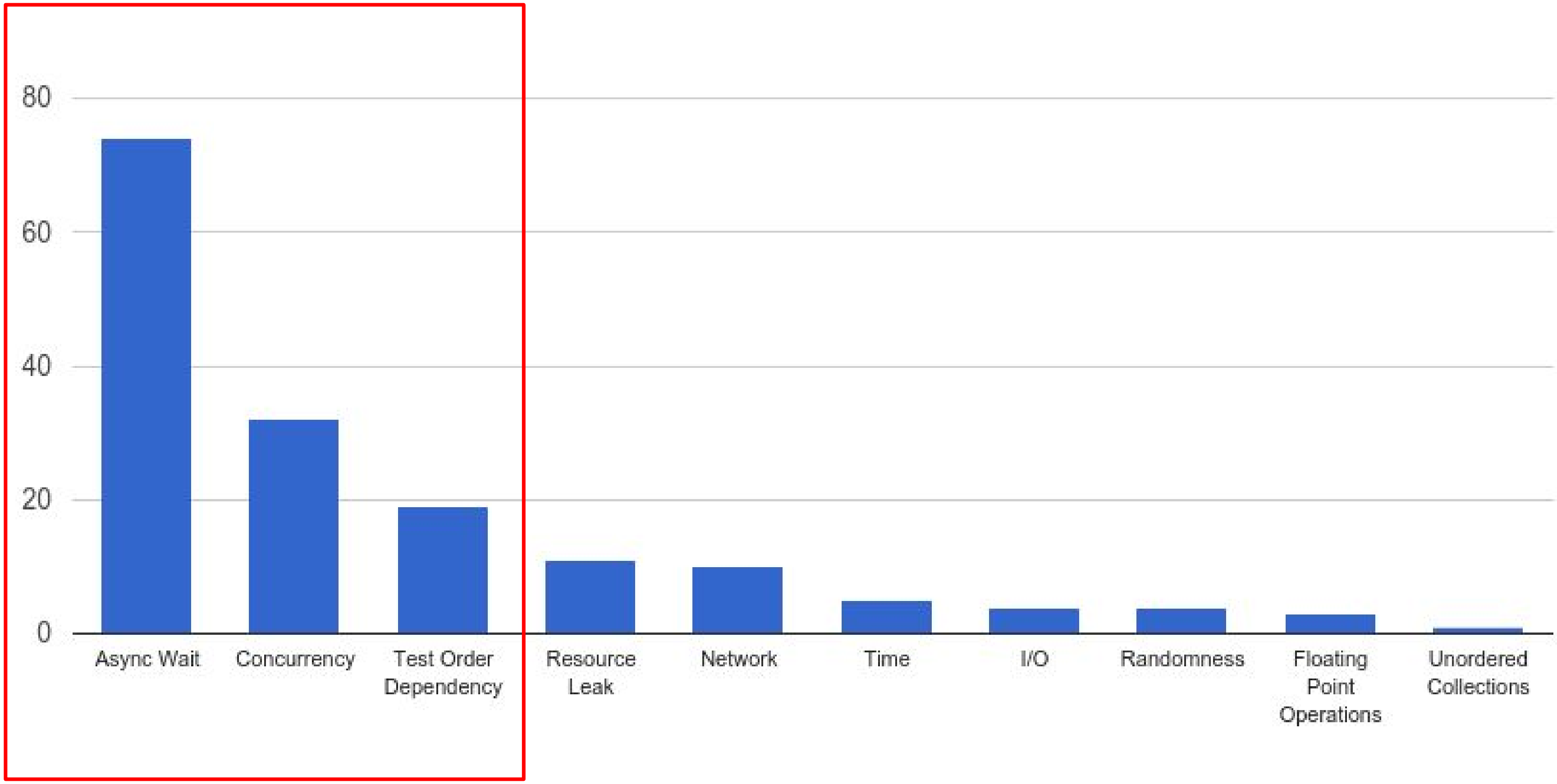
# Test Order Dependency

Dependency between tests and the result depends on running order; example HBASE-7113:

```
@Test
public void testGzipFilter() throws Exception {
 String path = "/" + TABLE + "/" + ROW_1 + "/" + COLUMN_1;
  ...
  Response response = client.put(path, headers, value_1_gzip);
  ...
}

@Test
public void testScannerResultCodes() throws Exception {
  ...
  Response response = client.post("/" + TABLE + "/scanner", headers,
     "<Scanner/>".getBytes());
  assertEquals(response.getCode(), 204);
...
}
```

# Root Causes Distribution



78%

# Other Root Causes

- Resource leak
- Network
- Time
- I/O
- Randomness
- Floating point operations
- Unordered collections

# Implication 1: Researchers Can Focus on the Top Categories of Flaky Tests First

# Q2:
# How are Flaky Tests Introduced?

# Collect Evolution Info

- Find out the first time the flaky test was written in VCS

- Manually reason about whether the test was flaky at that time

- If not, track changes in history to see how the test became flaky

# Flaky Tests Introduction

- Most (126 out of 161) flaky tests are flaky the first time they are written

- Flakiness is later introduced when:
  - A new test introduces dependency on old tests
  - Patching a bug/refactoring/adding new functionality

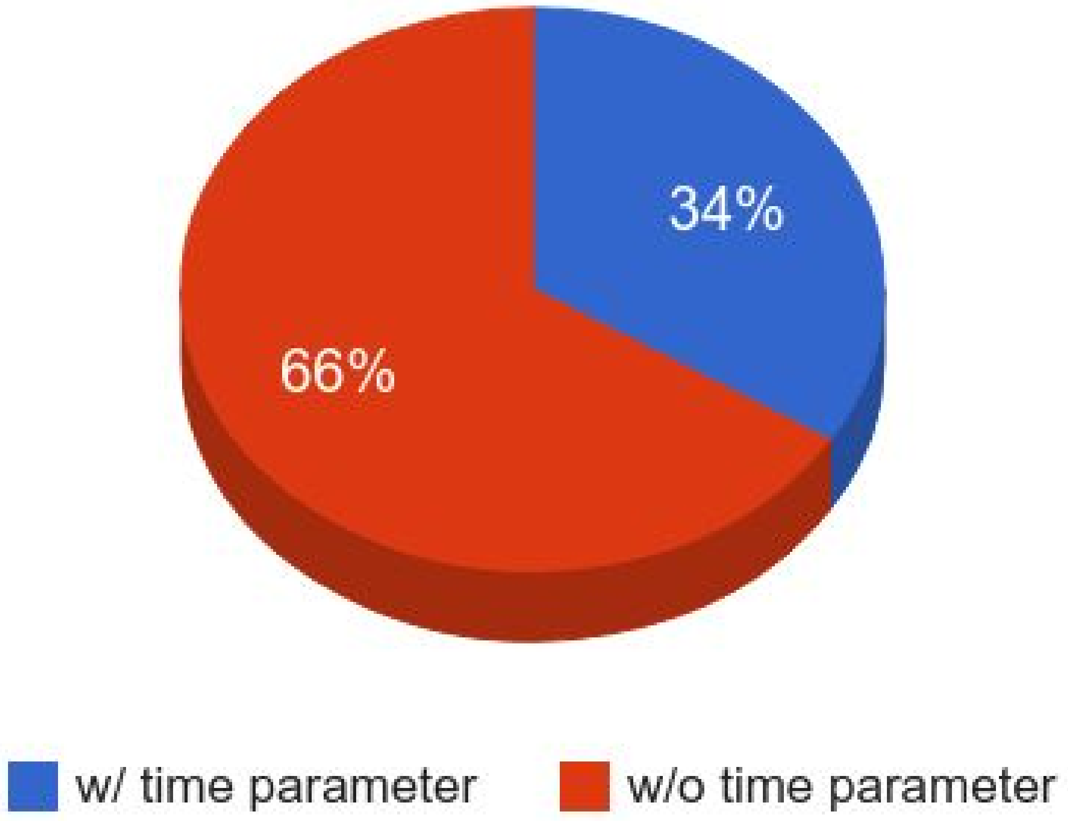
# Implication 2:
# Researchers Can Focus on Checking New Tests Extensively for Flakiness

# Q3:
# How to Manifest Flaky Tests?

# Manifestation of Async Wait Flaky Tests

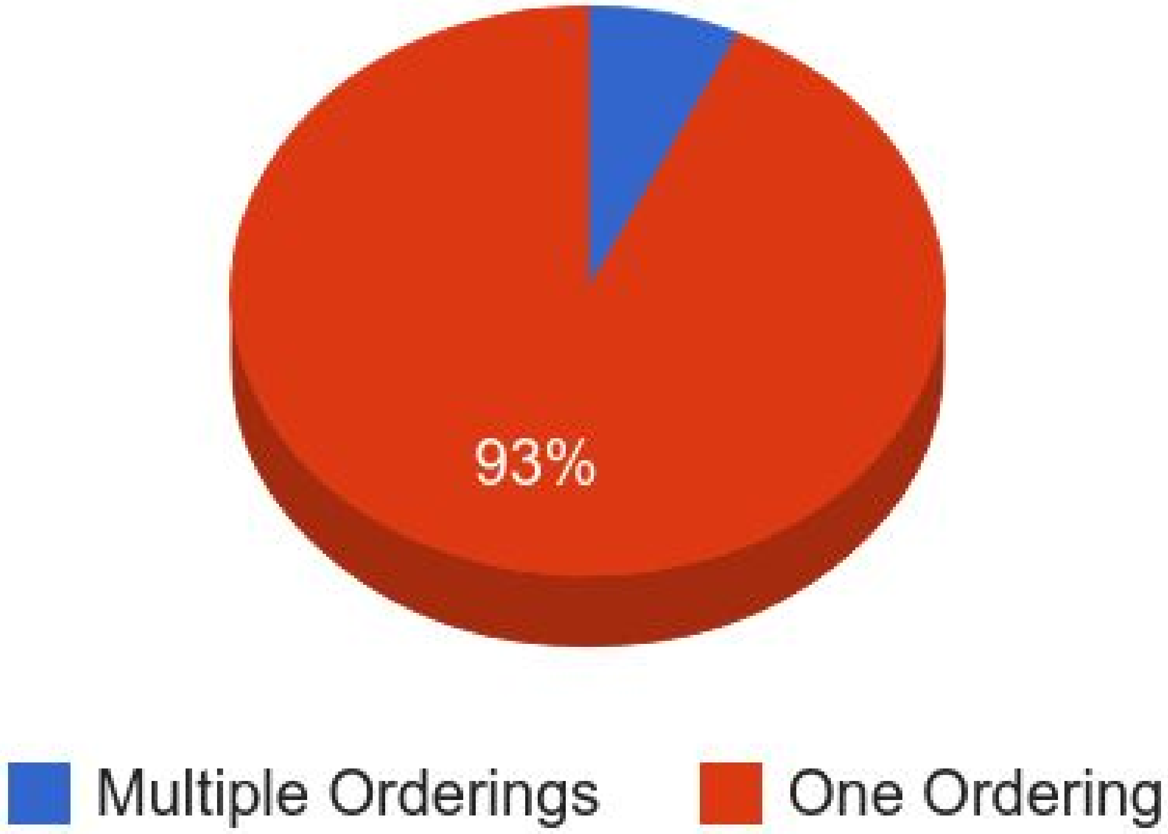
- Tests fail when the desired orderings are violated
  - One ordering VS multiple orderings
- sleep/waitFor are used to enforce orderings
  - W/ time parameter VS w/o time parameter
- Waiting for external resources VS resources controlled by the program

# W/ Time Parameter VS W/O Time Parameter

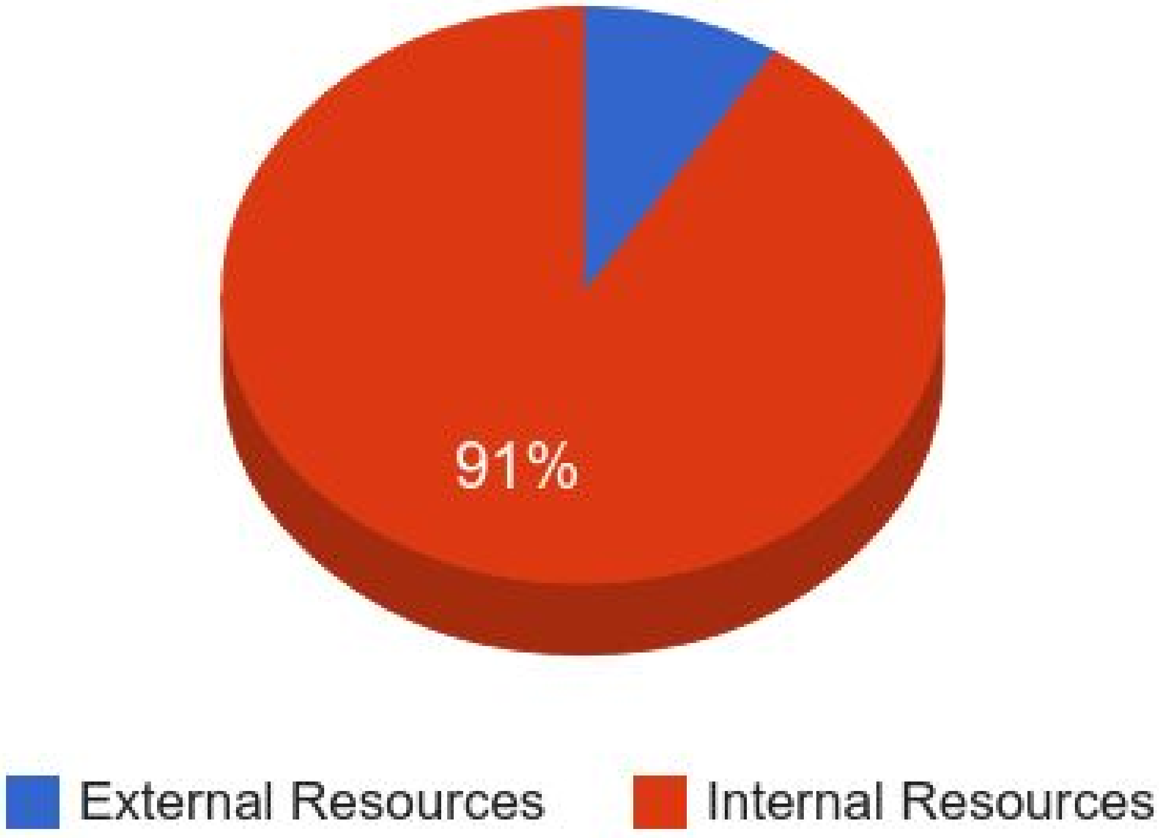


# Implication 3.a: Many Async Flaky Tests Can be Manifested by Changing Time Parameters to Order Enforcing Methods

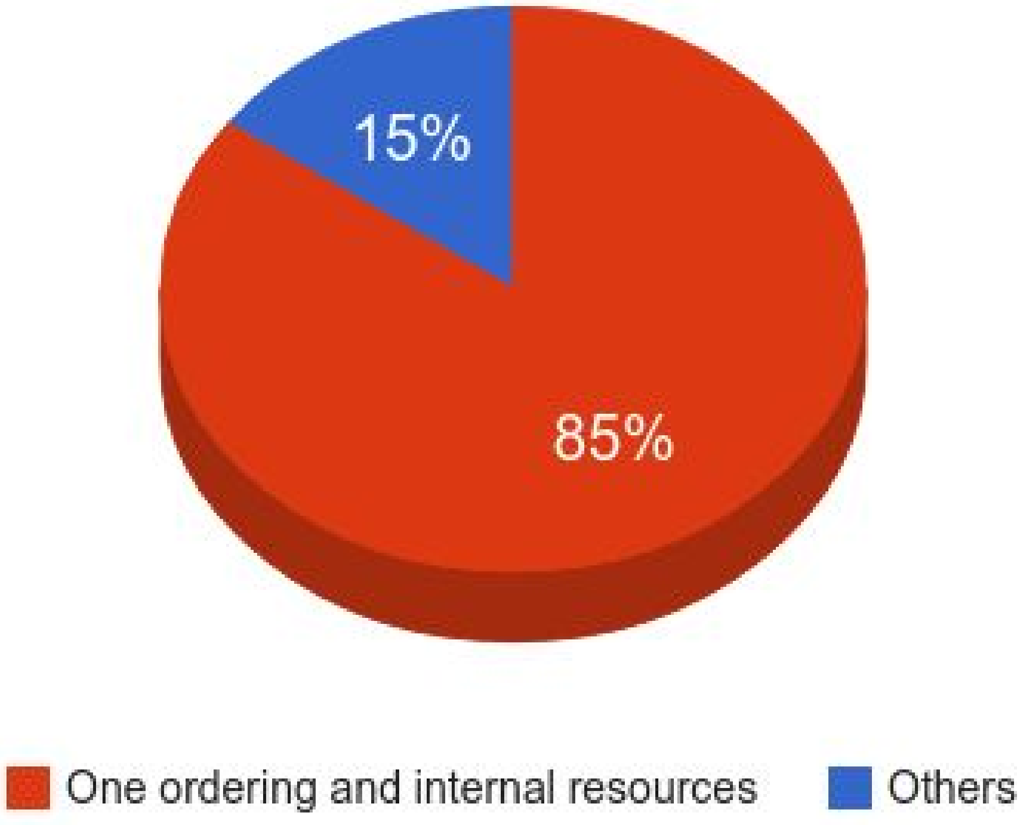
# One Ordering VS Multiple Orderings



# External  Resources VS Internal Resources



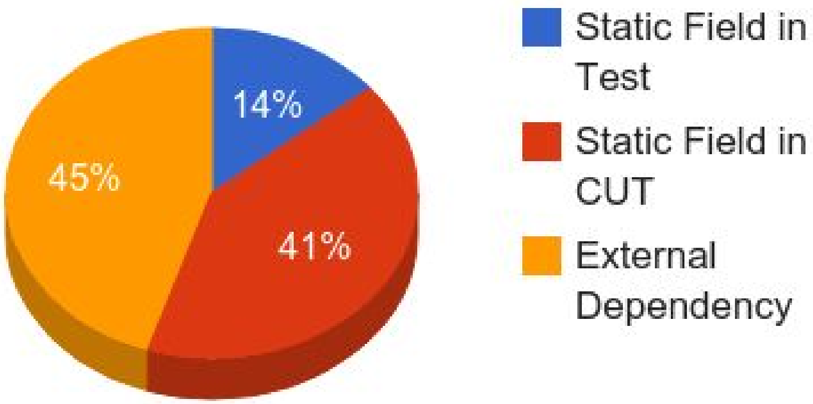
# One Ordering and Internal Resources VS Others



# Implication 3.b: Most Async Wait Flaky Tests Can be Manifested by Adding One Time Delay in Program

# Manifestation of Test Order Dependency Flaky Tests

- Various sources of dependency



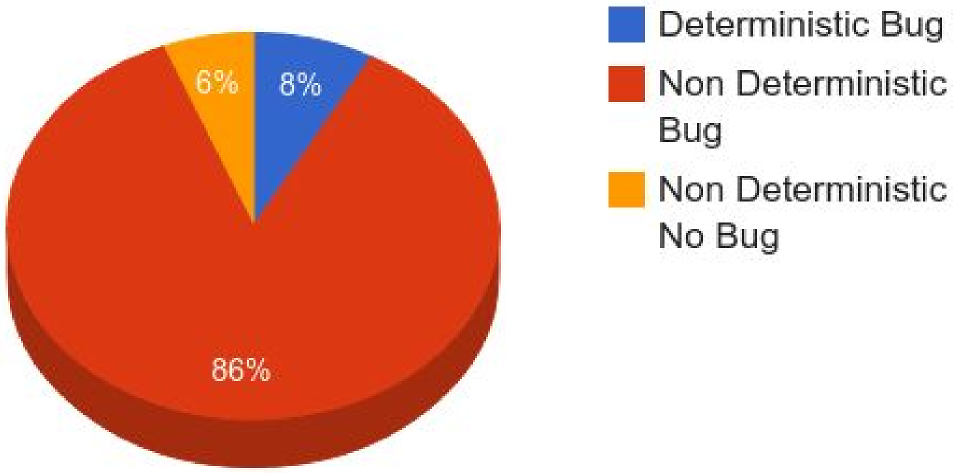
- Existing techniques focus on in-memory objects [Bell+Kaiser ICSE’14] or shuffling test runs explicitly [Zhang et al. ISSTA’14]

# Implication 3.c: New Techniques for Modeling/Checking External Dependency Can be Useful

# Q4:
# Does Fixing Flaky Tests Also Change Code under Test (CUT)?

# Fixing Code Under Test

- 24% (38 out of 161) flaky tests are fixed by changing both test and CUT
- Changes to CUT:



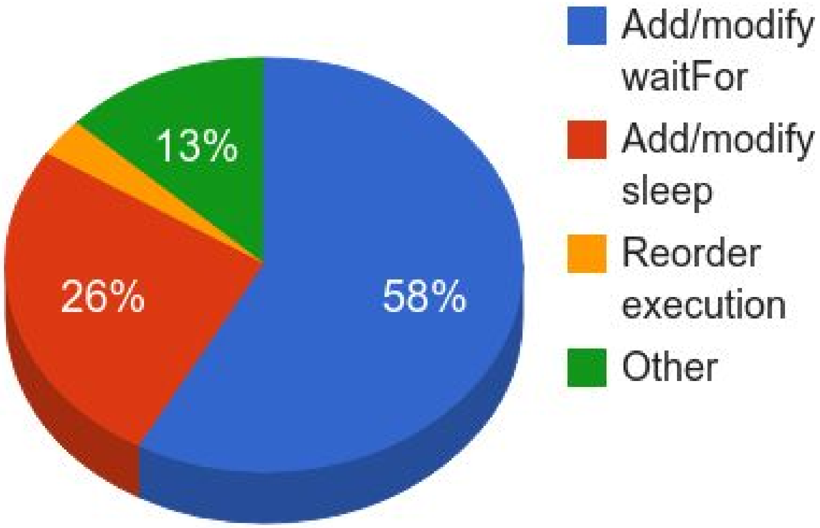
# Implication 4: Flaky Tests Are Still Valuable For Catching Bugs and Should Not be Ignored or Removed

# Q5:
# How to Fix Flaky Tests?

# Flaky Tests Fixes

- We studied how flaky tests got fixed
  - Fix strategies for top three categories
- How effective was each fix?
  - Remove - remove its flakiness completely
  - Decrease - decrease probability of test flakiness
- Study outcome
  - Good practice for fixing flaky tests
  - Automated techniques for fixing flaky tests

# Fix Async Wait Flaky Tests

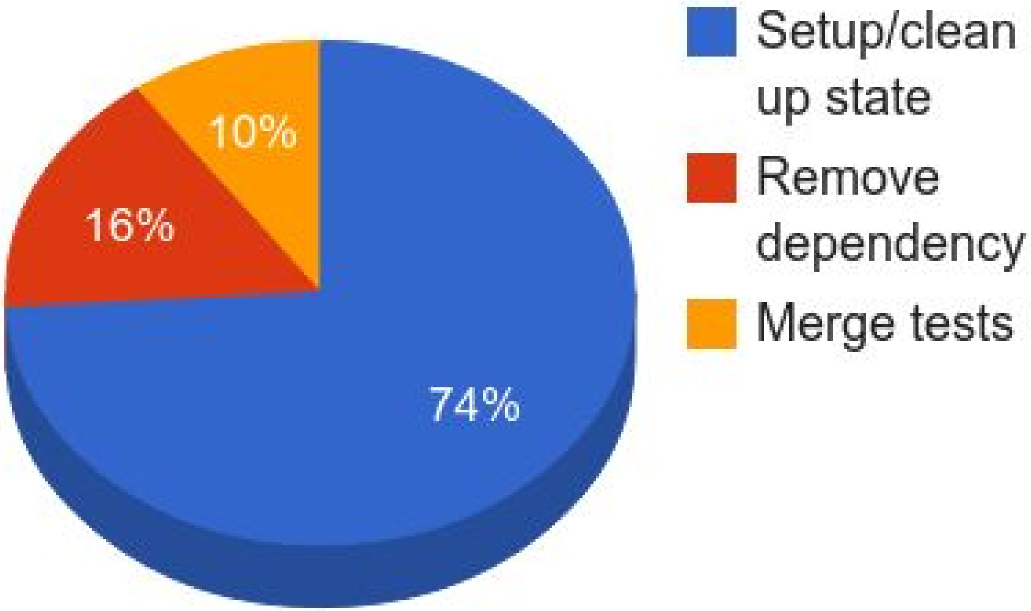


**Sleep and timed waitFor only decrease flakiness probability**

# Implication 5.a For Developers: Use waitFor to Fully Synchronize Code

# Implication 5.b For Researchers: Automatically Generate Order Enforcing Code by Comparing Events Order Between Passing and Failing Runs

# Test Order Dependency Fixes



# Implication 5.c For Developers:
# Identify Shared States in Test Execution and Maintain Them Clean

# Implication 5.d For Researchers: Model and Compare Program States and Automatically Generate Code in setUp/tearDown to Restore Shared States

# Threats to Validity

- Choice of projects
  - All Apache projects

- Selection criteria
  - Commit logs
  - Keywords “flak” and “intermittent”
  - Fixed flaky tests

- Manual inspection
  - Peer review for each flaky test

# Related Work

- Non-deterministic bugs and tests
  - GUI flaky tests [Memon+Cohen ICSE’13]
  - Test order dependency  [Zhang et al. ISSTA’14, Bell+Kaiser ICSE’14]
  - Concurrency bugs study [Lu et al. ASPLOS’08]
- Bug fixes
  - Bug fixes study [Bachmann et al. FSE’10, Murphy-Hill et al. ICSE’13]
  - Automatically fixing concurrency bugs [Jin et al. PLDI’ 11]
- Test fixes
  - Automatically repair broken tests [Daniel et al. ASE’09]

# Conclusions

- Flaky tests are harmful and pervasive in practice
- We studied and summarized common characteristics of flaky tests
  - Common root causes
  - Common manifestation methods
  - Common fixing strategies
- We believe our results provide both research insights and practice guidelines