The State of Continuous Integration Testing @Google

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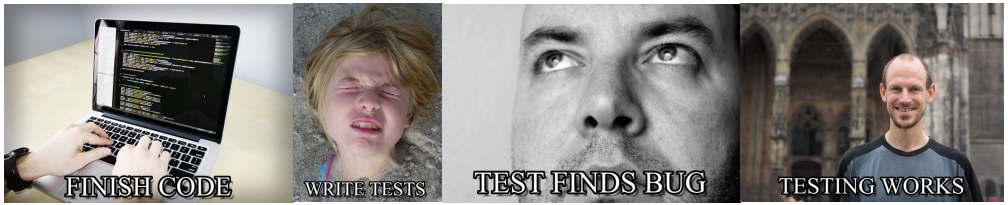
Testing Scale at Google

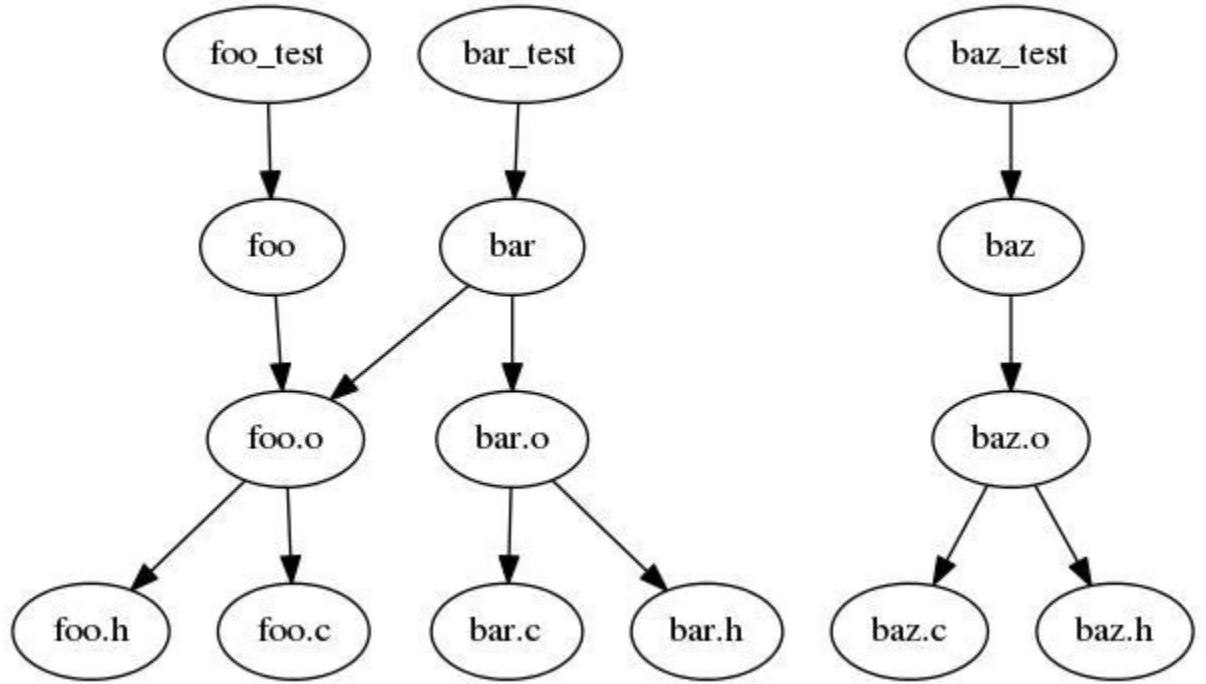
- 4.2 million individual tests running continuously
  - Testing runs before and after code submission
- 150 million test executions / day (averaging 35 runs / test / day)
- Distributed using internal version of bazel.io to a large compute farm
- Almost all testing is automated - no time for Quality Assurance
- 13,000+ individual project teams - all submitting to one branch
- Drives continuous delivery for Google
- 99% of all test executions pass



Testing Culture @ Google

- ~10 Years of testing culture promoting hand-curated automated testing
  - Testing on the toilet and Google testing blog started in 2007
  - GTAC conference since 2006 to share best practices across the industry
  - Part of our new hire orientation program
- SETI role
  - Usually 1-2 SETI engineers / 8-10 person team
  - Develop test infrastructure to enable testing
- Engineers are expected to write automated tests for their submissions
- Limited experimentation with model-based / automated testing
  - Fuzzing, UI waltkthroughs, Mutation testing, etc.
  - Not a large fraction of overall testing

Regression Test Selection (RTS)



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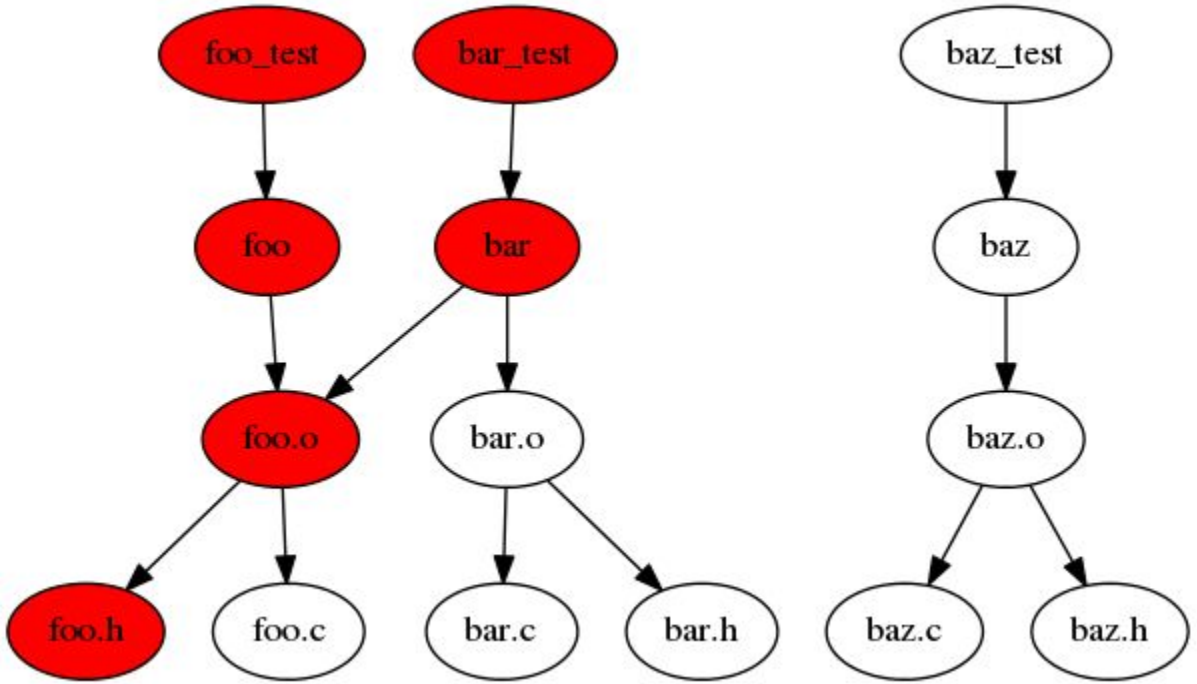

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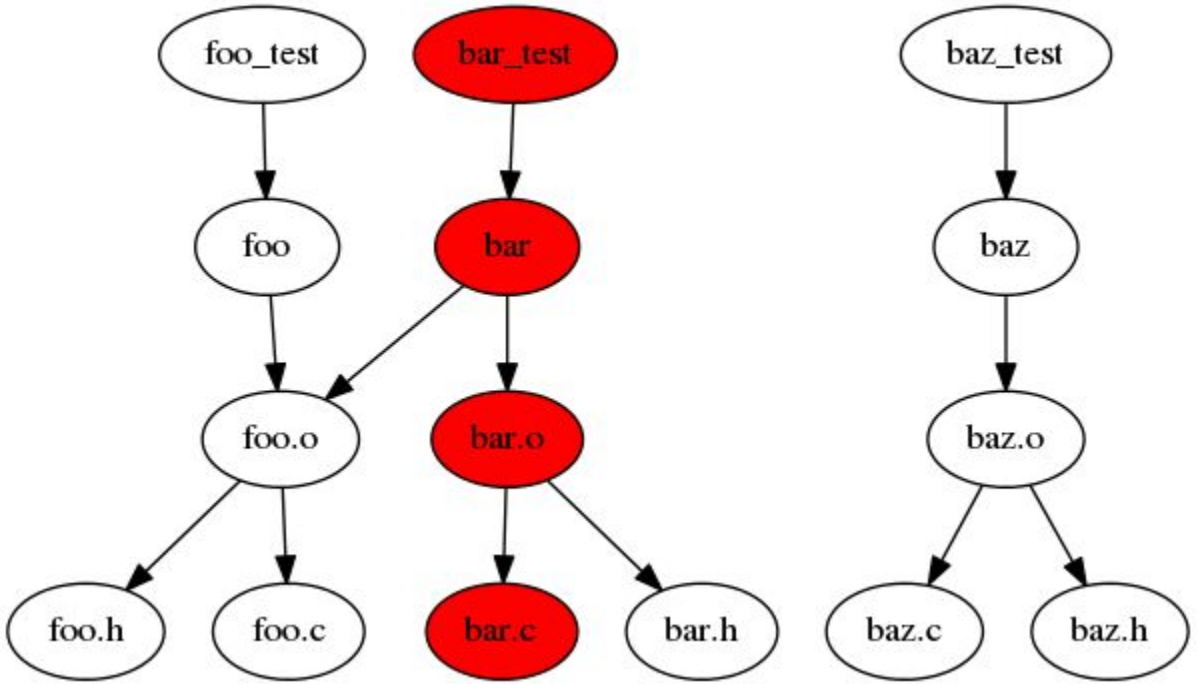
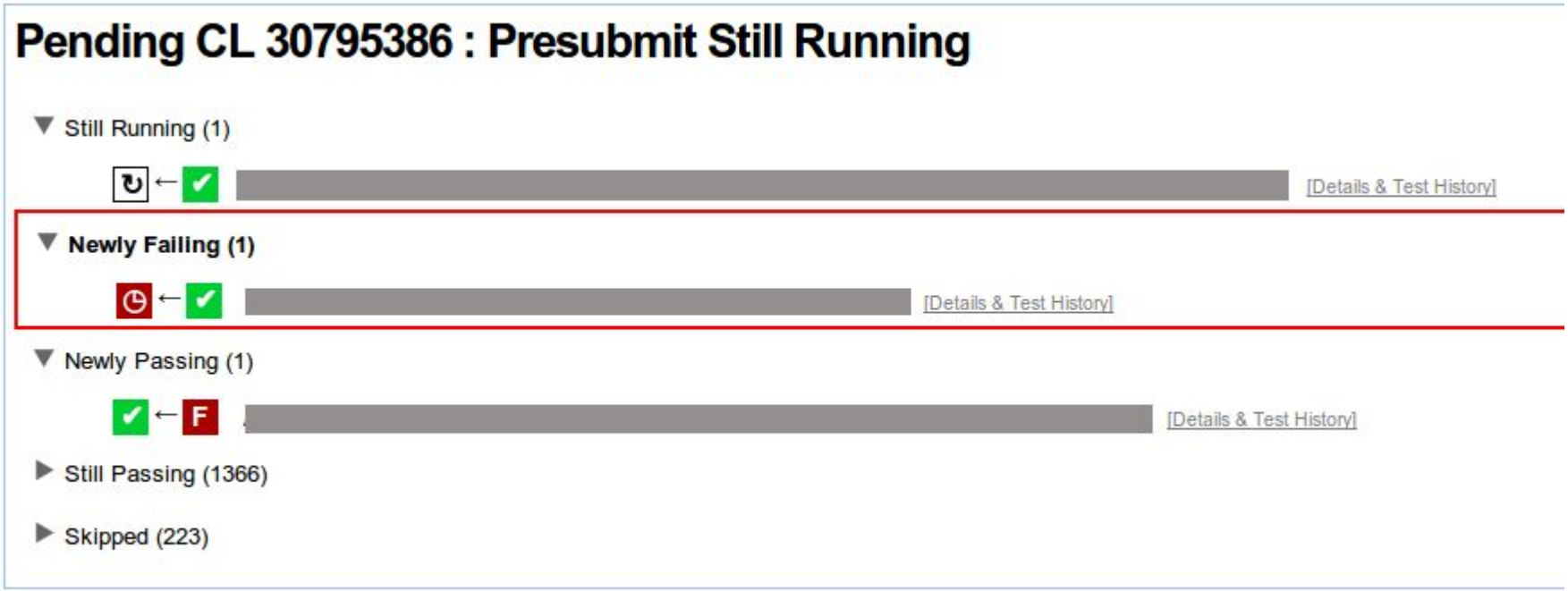


Presubmit Testing

- Uses fine-grained dependencies
- Uses same pool of compute resources
- Avoids breaking the build
- Captures contents of a change and tests in isolation
  - Tests against HEAD
- Integrates with
  - submission tool - submit iff testing is green
  - Code Review Tool - results are posted to the review

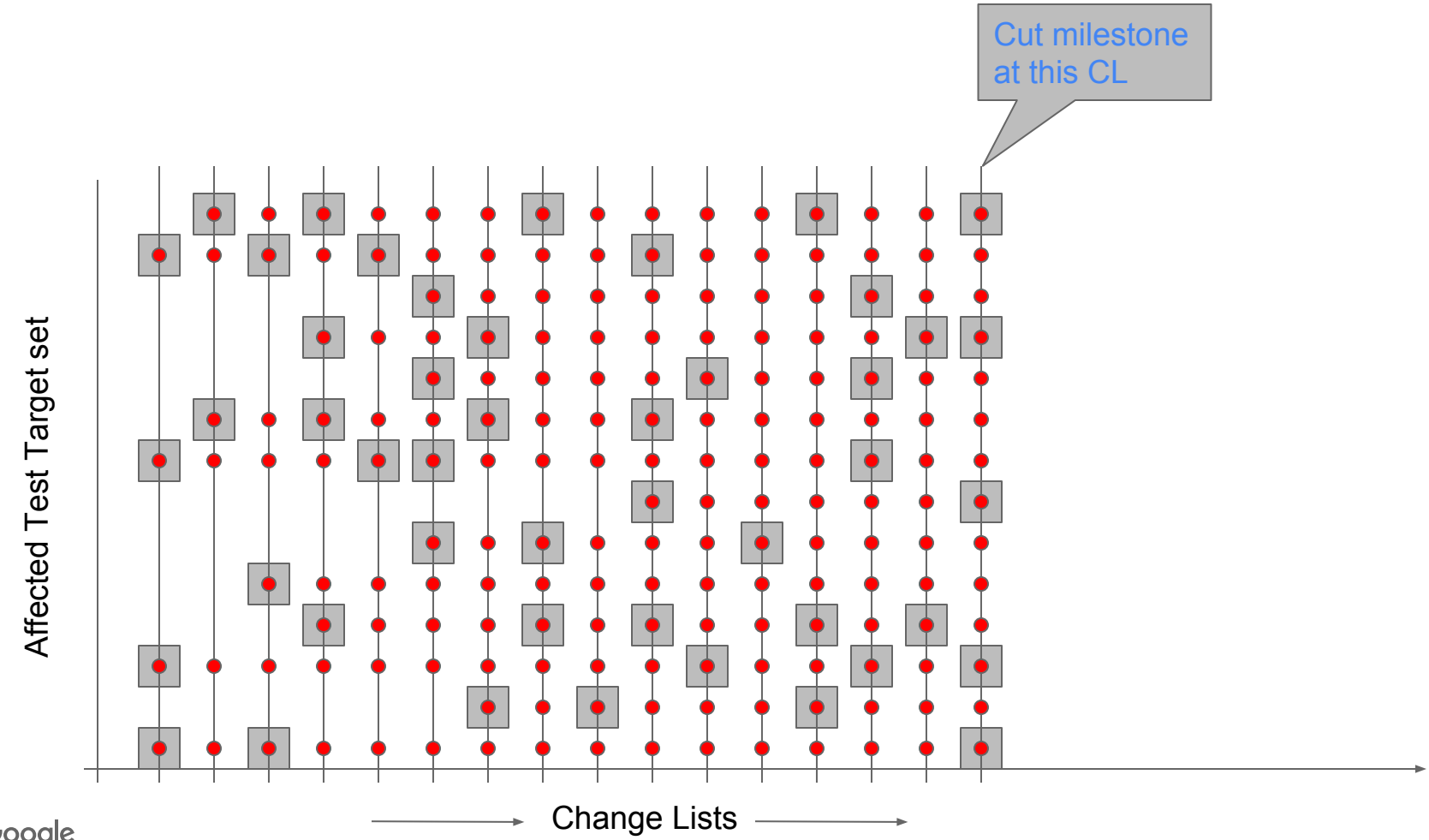
Example Presubmit Display

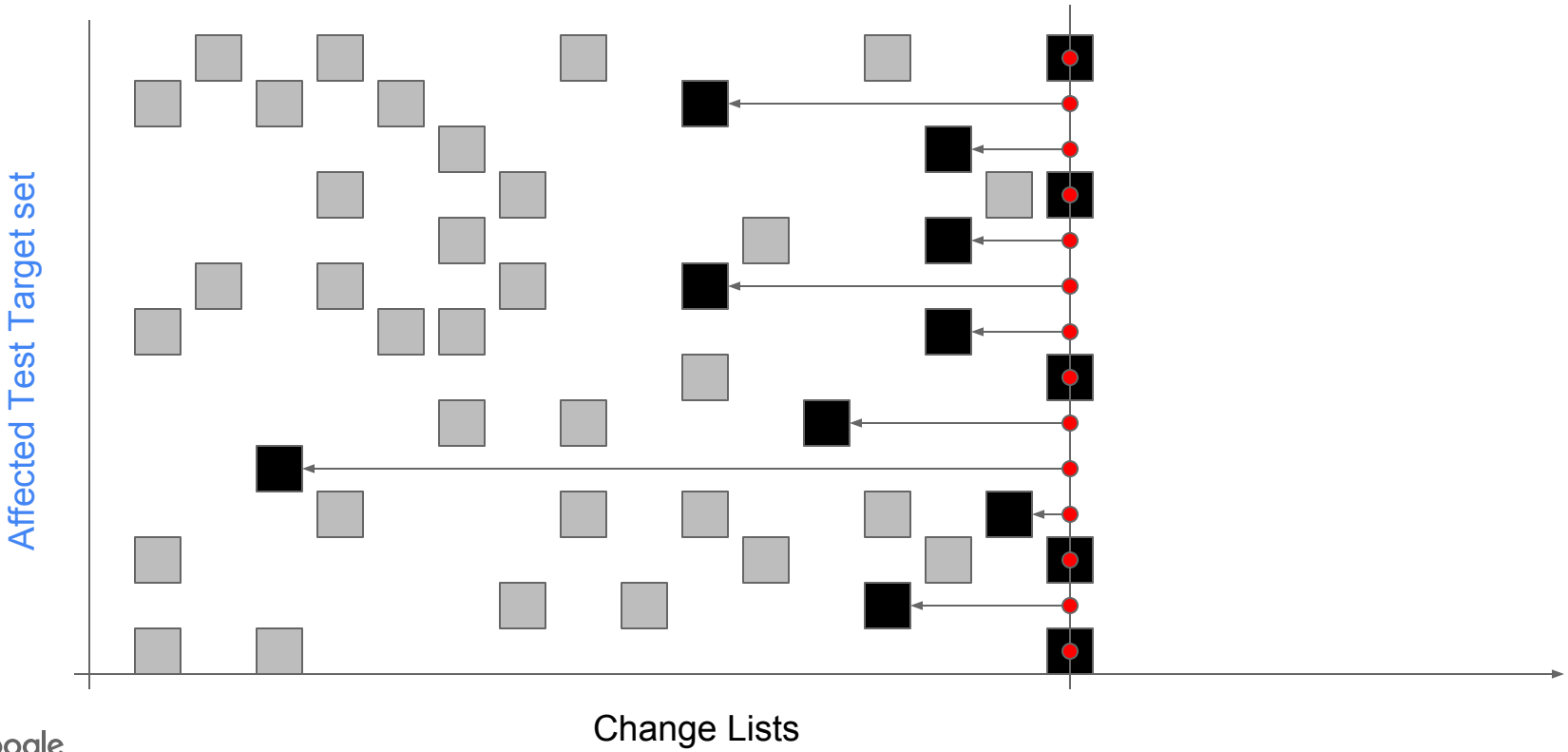


Postsubmit testing

- Continuously runs 4.2M tests as changes are submitted
  - A test is affected iff a file being changed is present in the transitive closure of the test dependencies. (Regression Test Selection)
  - Each test runs in 2 distinct flag combinations (on average)
  - Build and run tests concurrently on distributed backend.
  - Runs as often as capacity allows
- Records the pass / fail result for each test in a database
  - Each run is uniquely identified by the test + flags + change
  - We have 2 years of results for all tests
  - And accurate information about what was changed

See: prior deck about Google CI System, See this paper about piper and CLs


Cut milestone
at this CL
Affected Test Target set
Change Lists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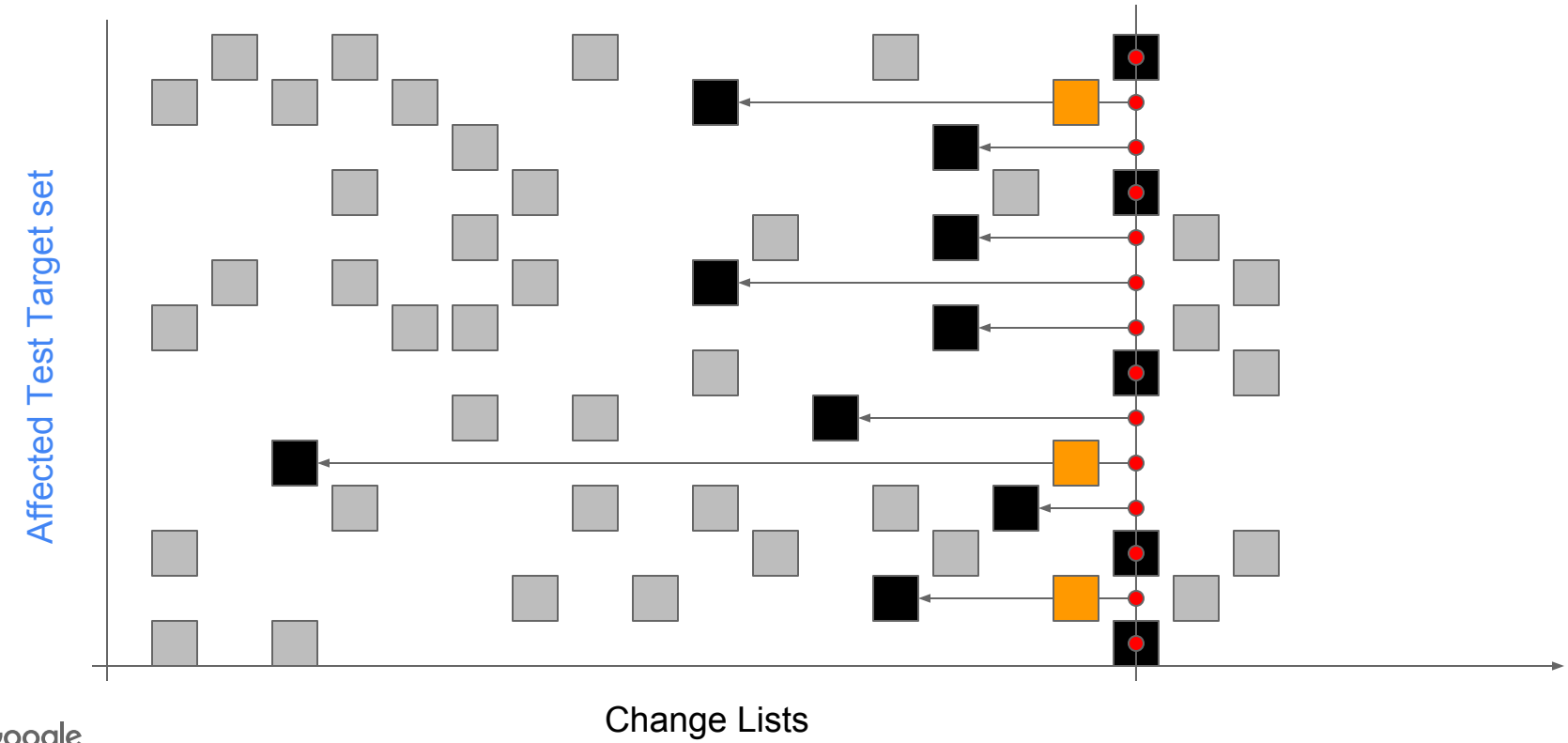
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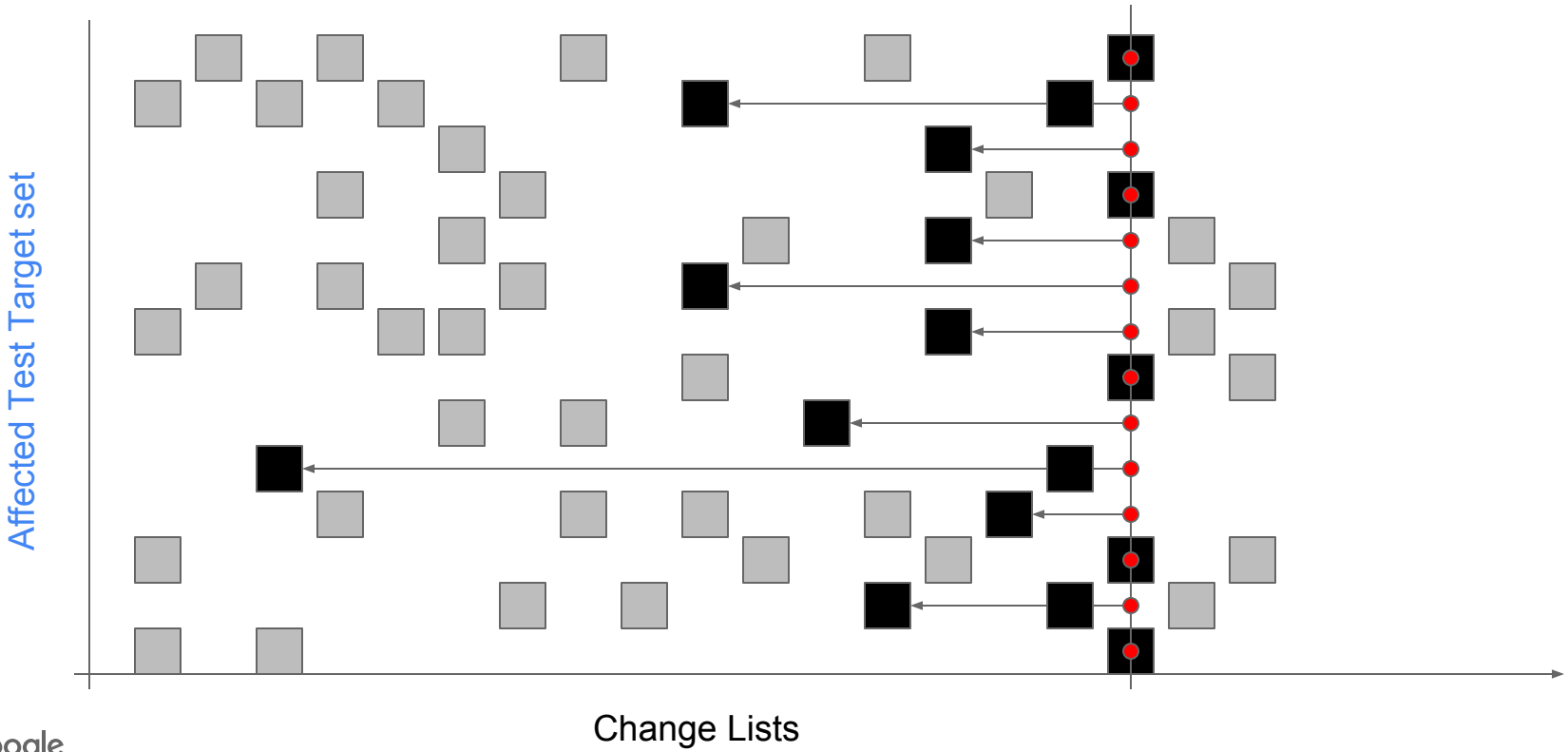
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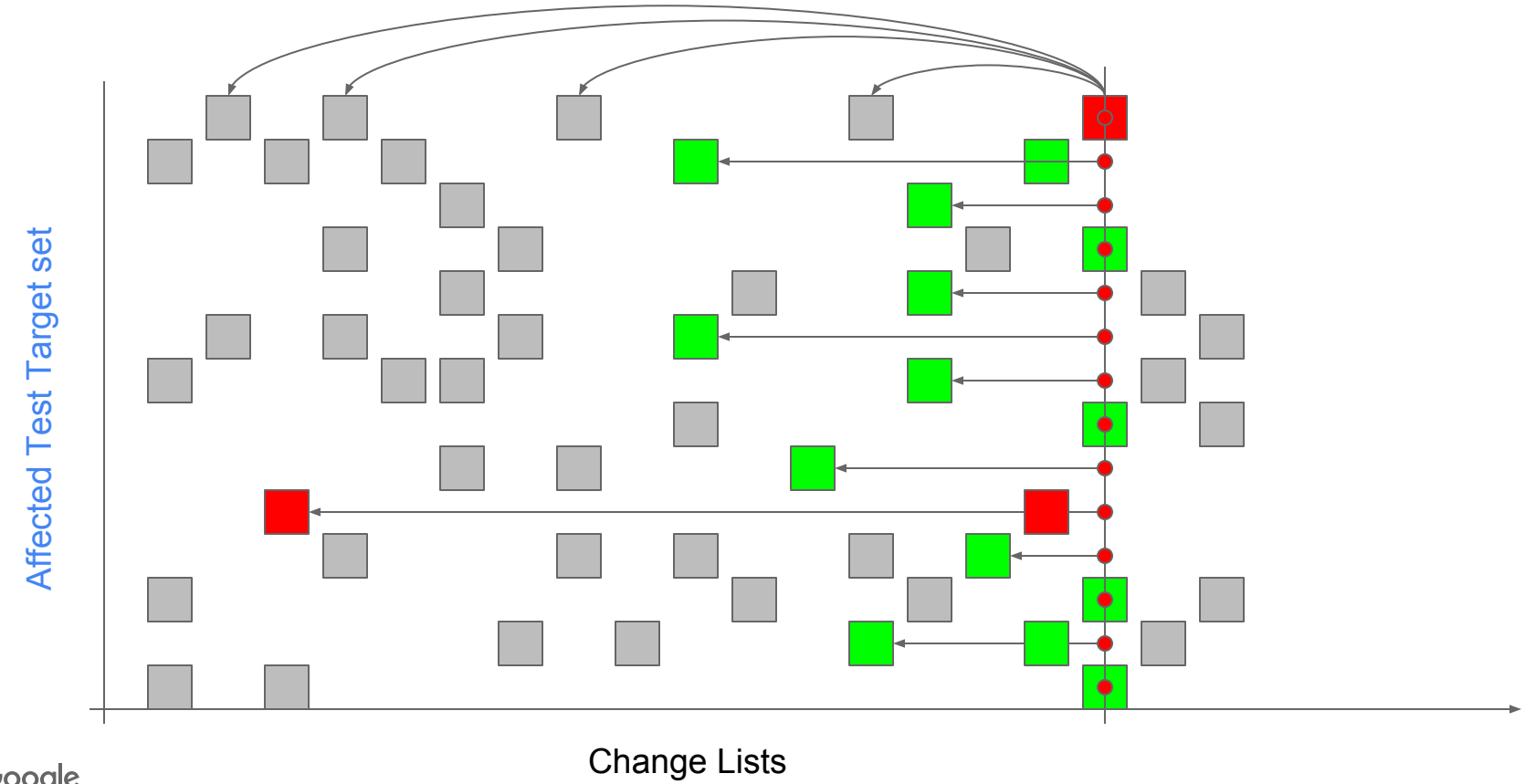
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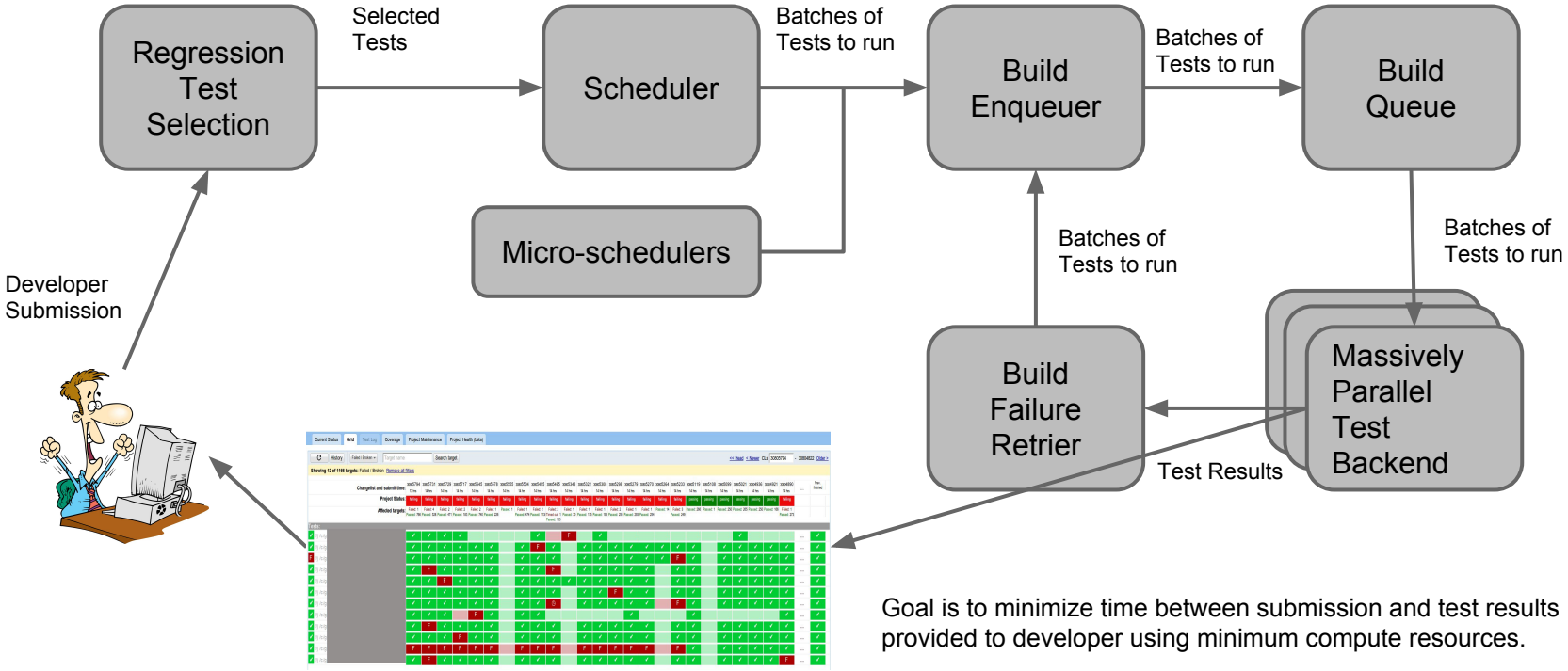
Life of a Test Execution

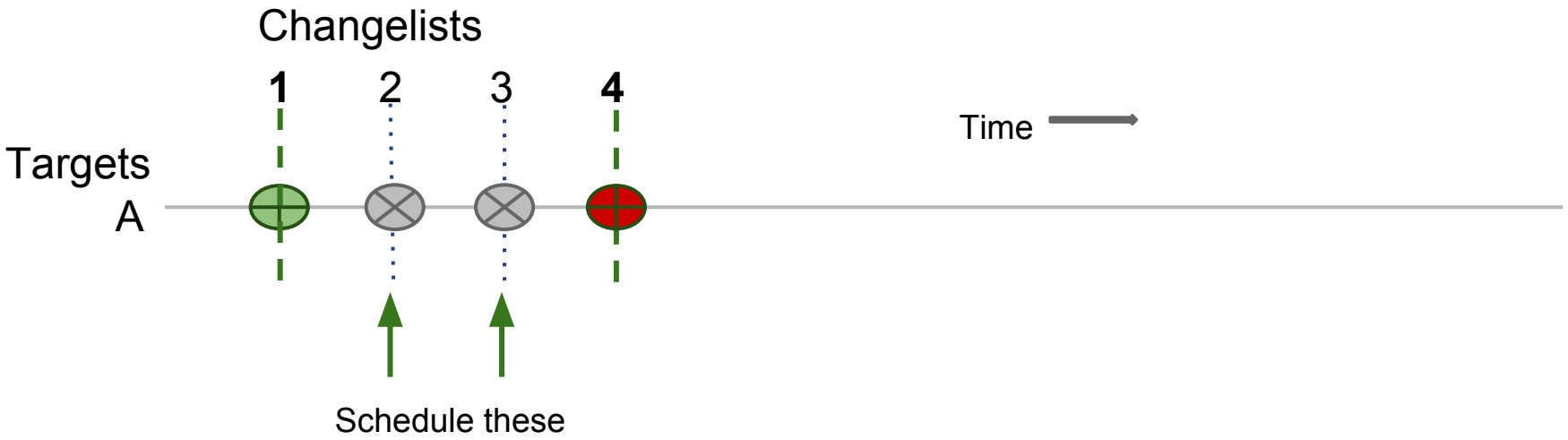


Goal is to minimize time between submission and test results provided to developer using minimum compute resources.

Micro-schedulers

- Selectively run any target at any CL
- Fill the gaps in the main scheduler
  - Missed targets
  - Not-yet-run targets
- Research hypotheses can be quickly tested

Cuprit Finding - Transition to Fail



Cuprit Finding - Transition to Fail

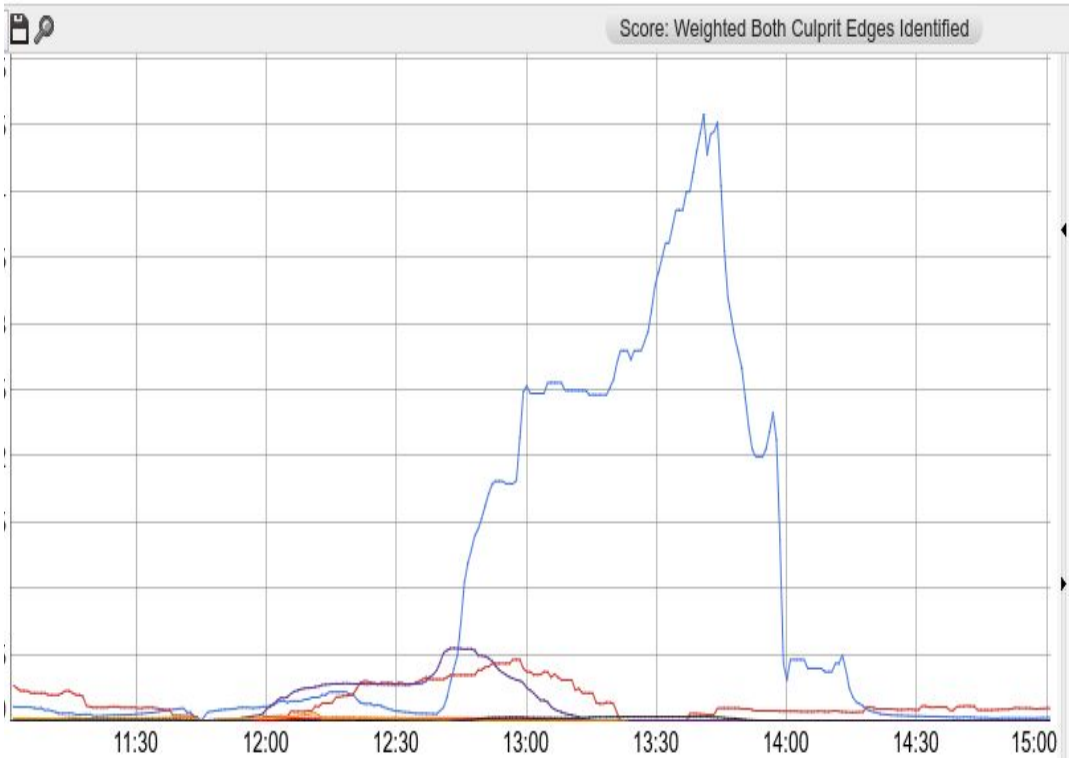
A: Change 3 broke test A.

Passed
Affected, but not run (yet)
Failed

Milestone
Non-milestone

Other micro-schedulers

- Culprit finder
  - Ranked culprit finder
  - Flakiness culprit finder
- Breakage predictor
  - Hot spots seeker
  - Brain-based predictor
  - Crowd sourcer
- Fix detector
- Auto-rollback



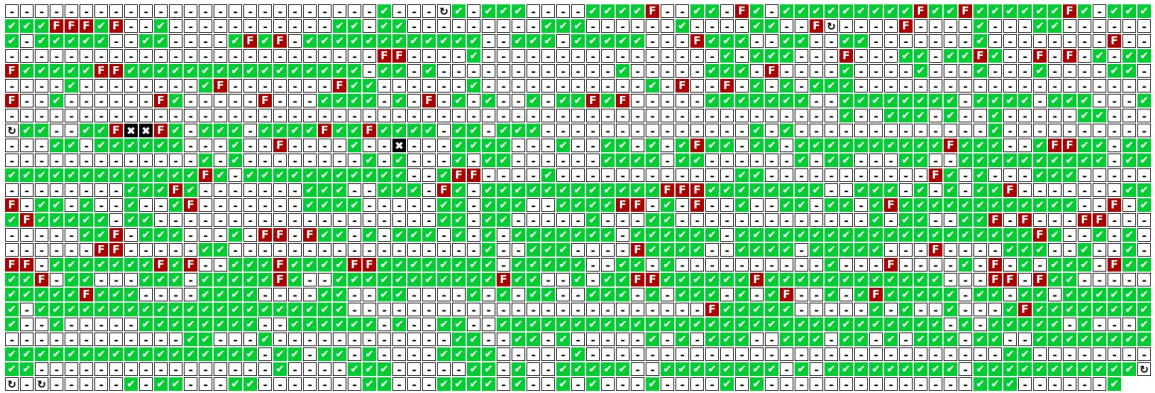
Analysis of Test Results at Google

- Analysis of a large sample of tests (1 month) showed:
  - 84% of transitions from Pass -> Fail are from "flaky" tests
  - Only 1.23% of tests ever found a breakage
  - Frequently changed files more likely to cause a breakage
  - 3 or more developers changing a file is more likely to cause a breakage
  - Changes "closer" in the dependency graph more likely to cause a breakage
  - Certain people / automation more likely to cause breakages (oops!)
  - Certain languages more likely to cause breakages (sorry)

See: prior deck about Google CI System, See this paper about piper and CLs

Flaky Tests

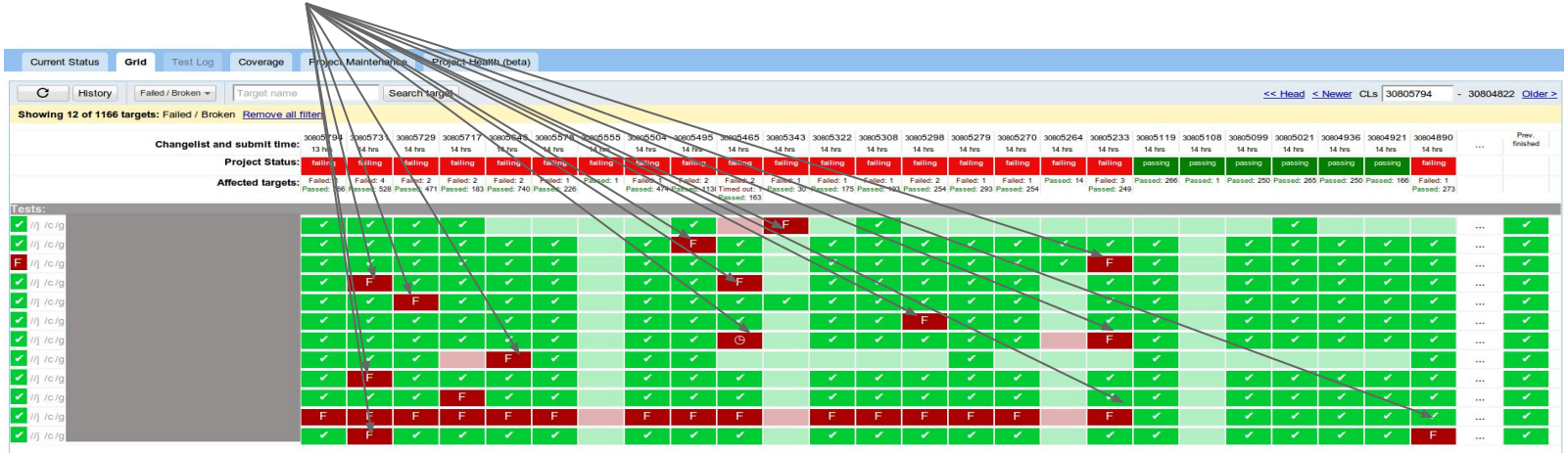
- Test Flakiness is a huge problem
- Flakiness is a test that is observed to both Pass and Fail with the same code
- Almost 16% of our 4.2M tests have some level of flakiness
- Flaky failures frequently block and delay releases
- Developers ignore flaky tests when submitting - sometimes incorrectly
- We spend between 2 and 16% of our compute resources re-running flaky tests



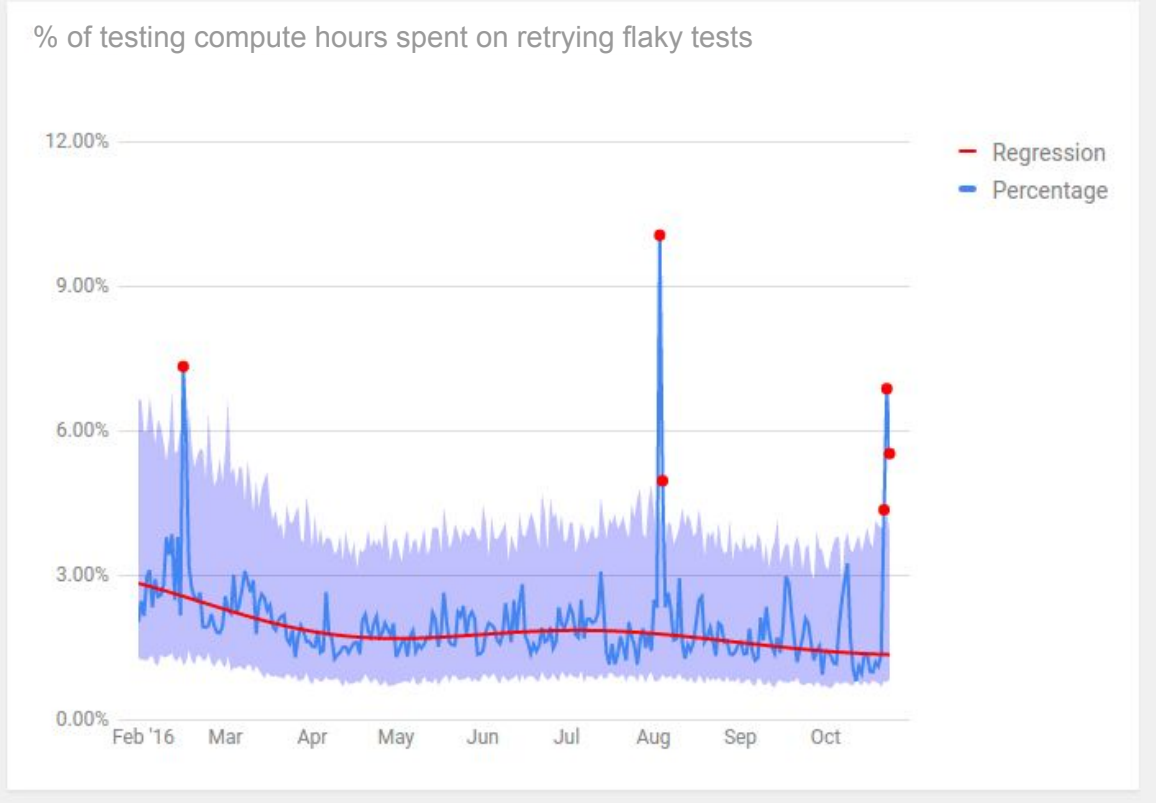
Flaky test impact on project health

- Many tests need to be aggregated to qualify a project
- Probability of flake aggregates as well
- Flakes
  - Consume developer time investigating
  - Delay project releases
  - Waste compute resources re-running to confirm

Flakes

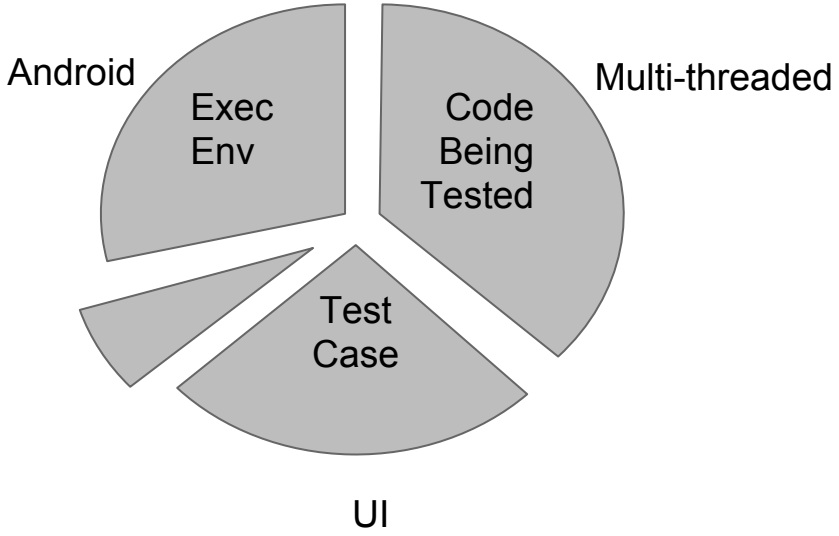


Percentage of resources spent re-running flakes



Sources of Flakiness

- Factors that cause flakes
  - Test case factors
    - Waits for resource
    - sleep()
    - Webdriver test
    - UI test
  - Code being tested
    - Multi-threaded
  - Execution environment/flags
    - Chrome
    - Android
  - ...



 See: https://pdfs.semanticscholar.org/02da/46889ee3c6bc44bfa0fc45071195781b99ce.pdf

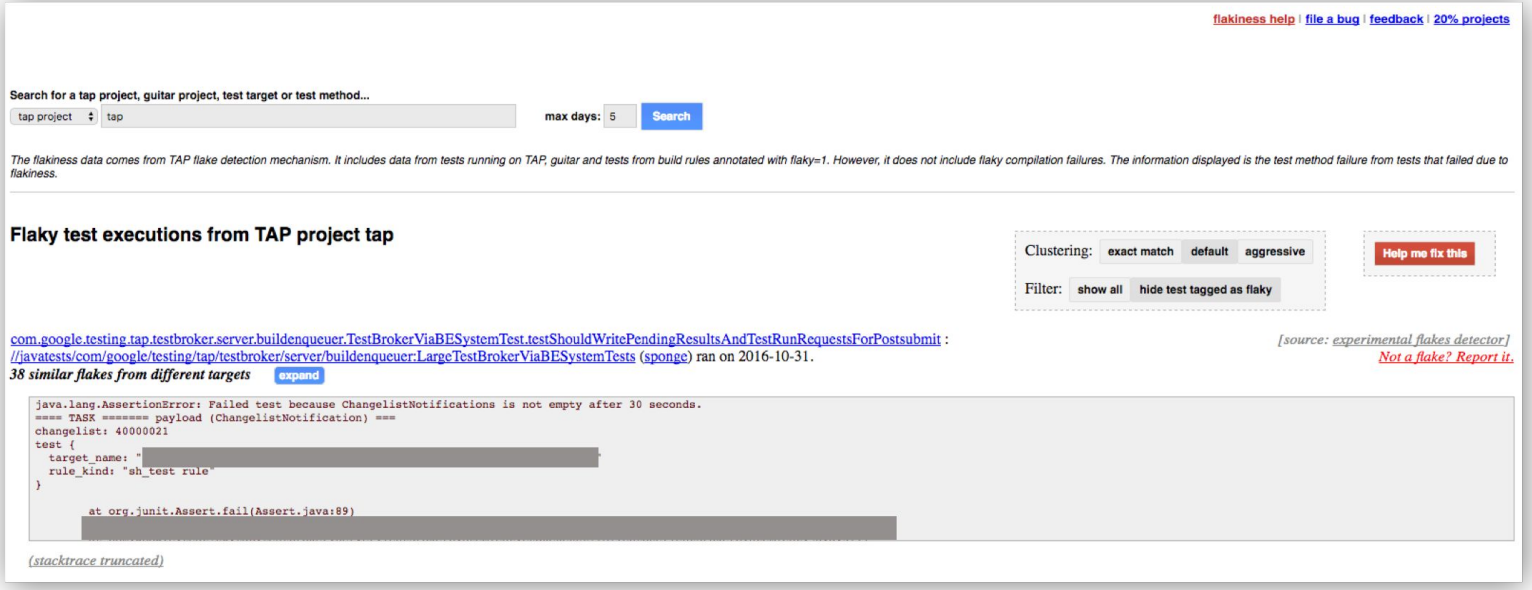
Flakes are Inevitable

- Continual rate of 1.5% of test executions reporting a "flaky" result
- Despite large effort to identify and remove flakiness
  - Targeted "fixits"
  - Continual pressure on flakes
- Observed insertion rate is about the same as fix rate

Conclusion: Testing systems must be able to deal with a certain level of flakiness. Preferably minimizing the cost to developers

Flaky Test Infrastructure

- We re-run test failure transitions (10x) to verify flakiness
  - If we observe a pass the test was flaky
  - Keep a database and web UI for "known" flaky tests



Google's Internal Development Systems

- Much of what Google uses internally is proprietary
- We have started open sourcing our tools starting with Bazel (bazel.io)
- Bazel is the same build tool that we use internally (with the Google proprietary parts removed)

An example bazel BUILD file

java/BUILD:

```
java_library(
    name = "mylib",
    srcs = ["my/webapp/TestServlet.java"],
    deps = [":javax.servlet.api"],
)

appengine_war(
    name = "myapp",
    jars = ["mylib"],
    resources = ["//dart:dart"],
    ...
)
```

dart/BUILD:

```
dart_library(
    name = "mylib",
    srcs = glob(["mylib/**/*.dart"]),
)
dart_library(
    name = "dart",
    deps = ["mylib"],
)
dart_test(
    name = "mydart_test",
    deps = ["dart", "mylib"]
    srcs = global(["mytests/**/*.dart"]),
)
```

rule's name

highly accurate dependencies

Tests appear with accurate dependencies

Enabling Google-Scale Research in Academia

- Most academic work tests hypotheses in open source projects
  - Limited codebase
  - No historical Pass / Fail results
  - Old projects with low churn rate / relevance

- What we are doing about it
  - Sponsor researchers to come in - student interns and visiting faculty
  - Test hypotheses against Google code base at scale
  - Full access to historic Pass / Fail data helps to test hypotheses
  - Publish results and relevant data sets
  - Creating API frameworks and extensibility (like micro-schedulers) to ease experimentation

Academic Research in Software Testing @ Google

- Join us for an internship or the Visiting Faculty Program!
  - Test hypotheses against real data at scale
  - Publish relevant papers
    - With sanitized data sets!
  - Test ideas more quickly
  - Make data from Google scale application development more widely available
- Participate in our journal club
  - Review relevant papers monthly
  - Paper authors often join the discussion
- Apply for a Google Faculty Research Award

Q&A

For more information:

- Google Testing Blog on CI system
- Youtube Video of Previous Talk on CI at Google

- Flaky Tests and How We Mitigate Them

- Why Google Stores Billions of Lines of Code in a Single Repo
- GTAC 2016 Flaky Tests Presentation
- (ICSE 2017) "Who Broke the Build? Automatically Identifying Changes That Induce Test Failures In Continuous Integration at Google Scale" by Celal Ziftci and Jim Reardon
- (ICSE 2017) “Taming Google-Scale Continuous Testing,” by Atif Memon, Zebao Gao, Bao Nguyen, Sanjeev Dhanda, Eric Nickell, Rob Siemborski and John Micco