# Improving Regression Testing in Continuous Integration Development Environments

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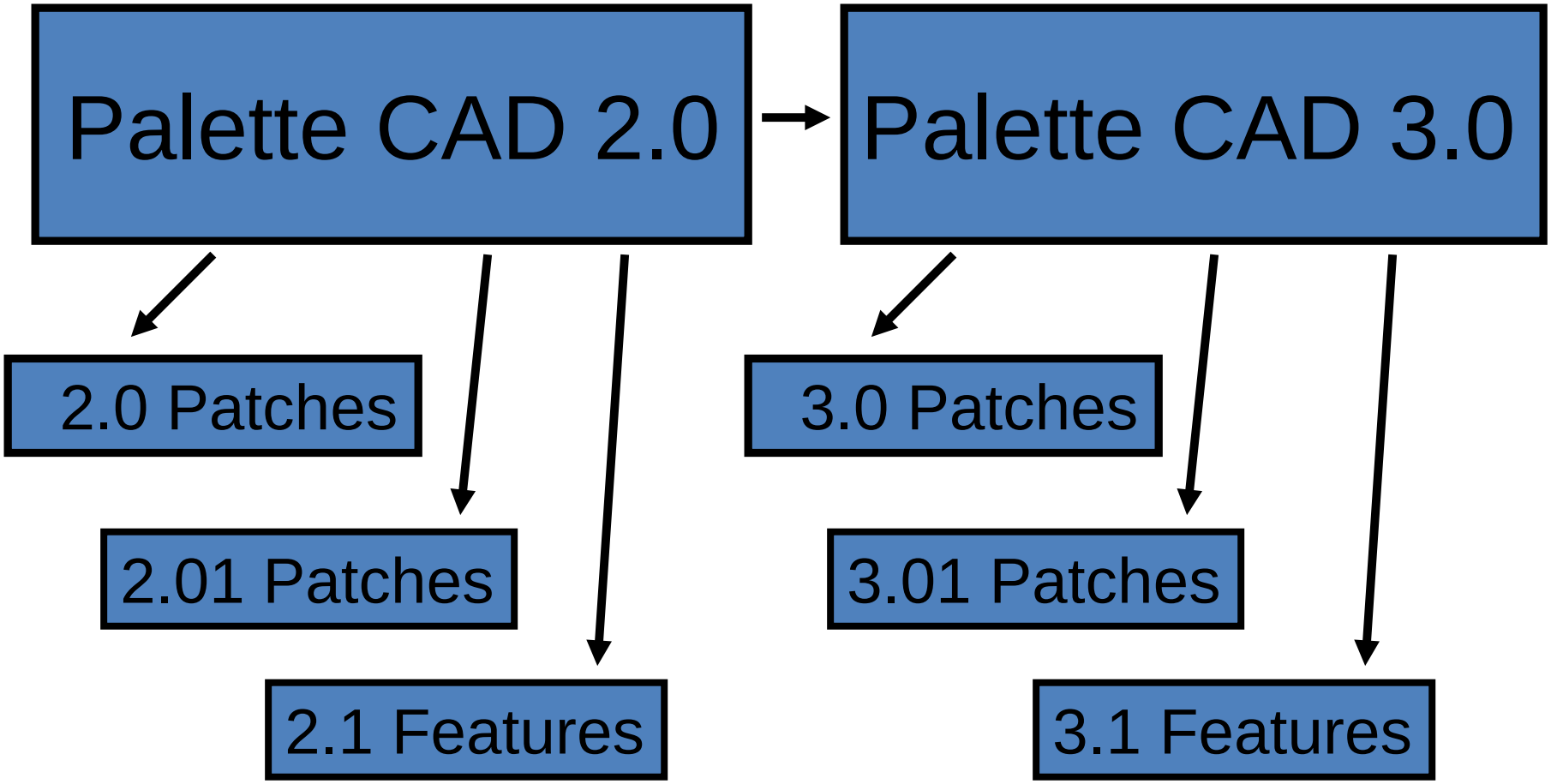
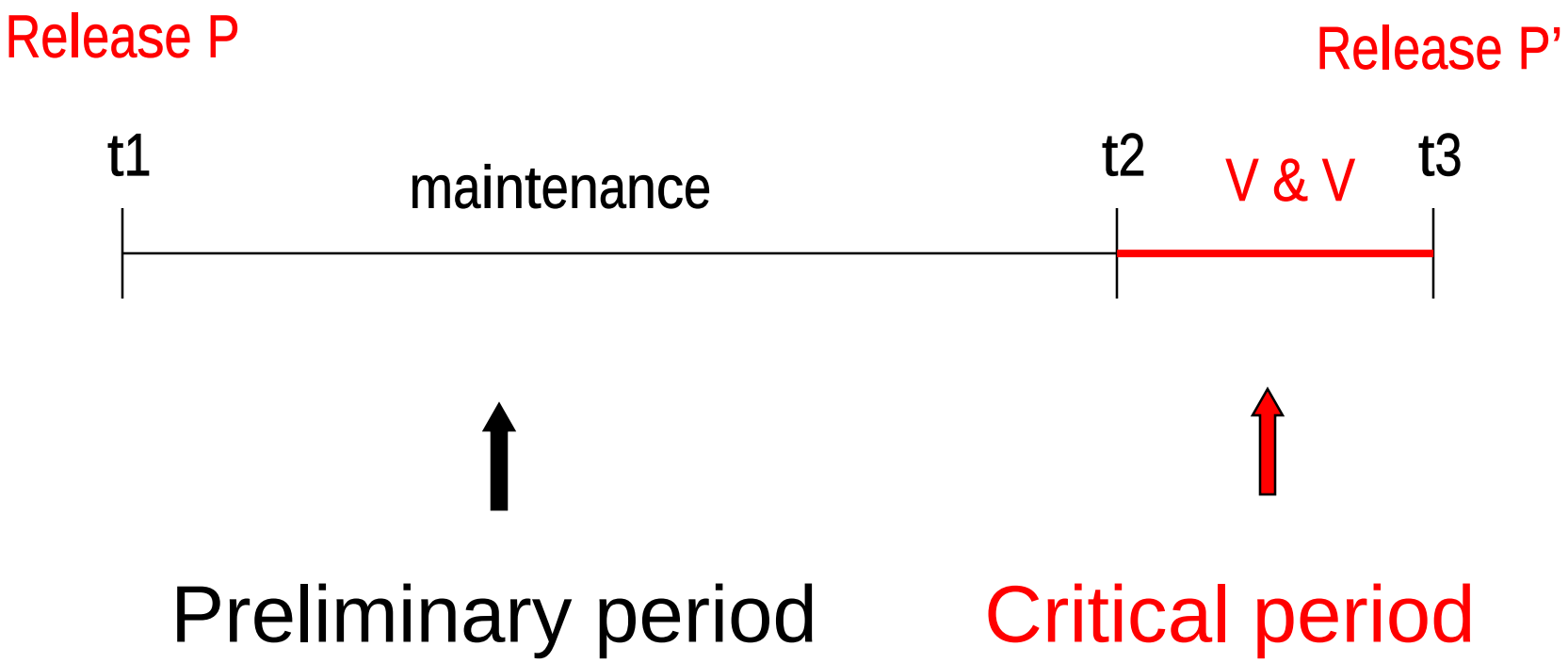
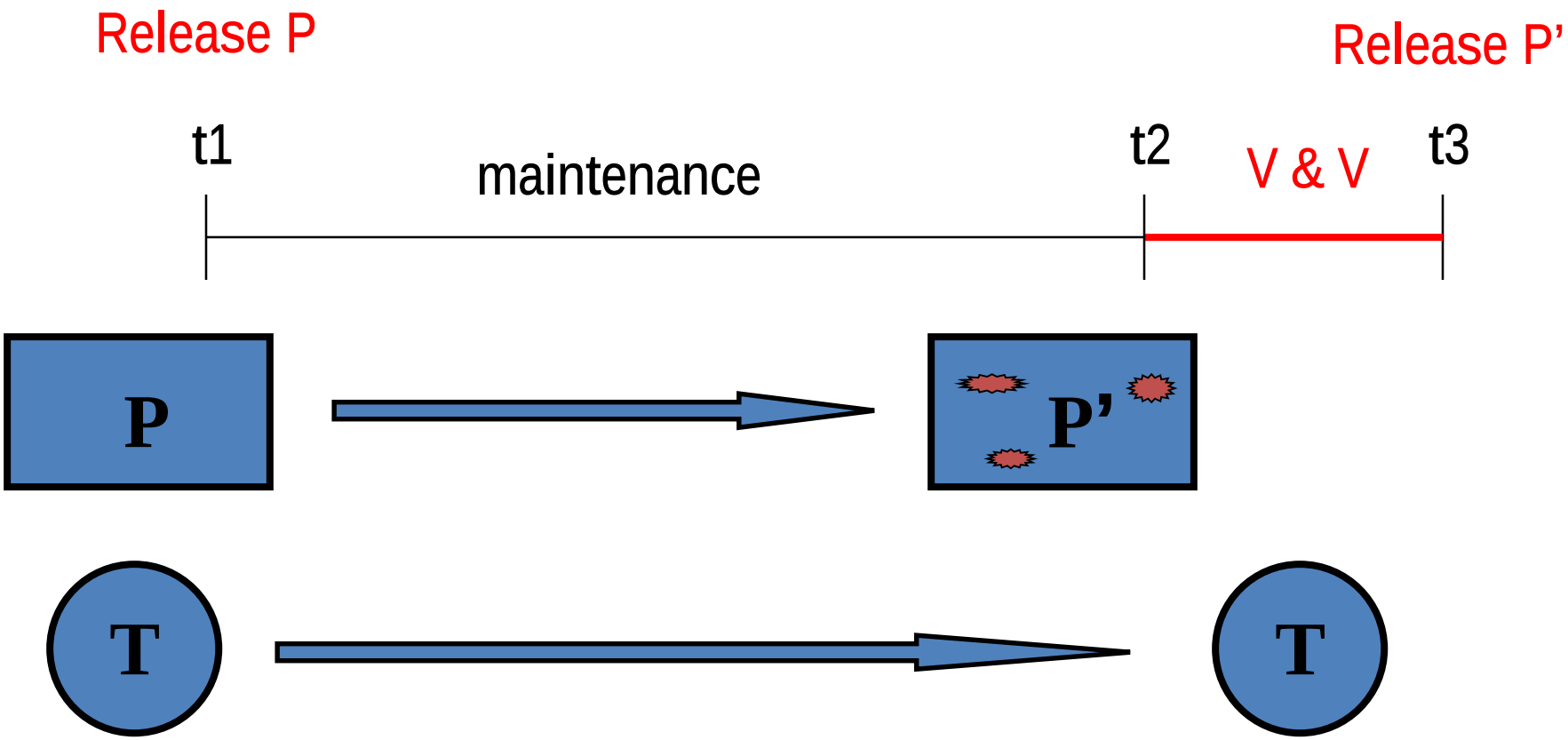
# Software Evolution



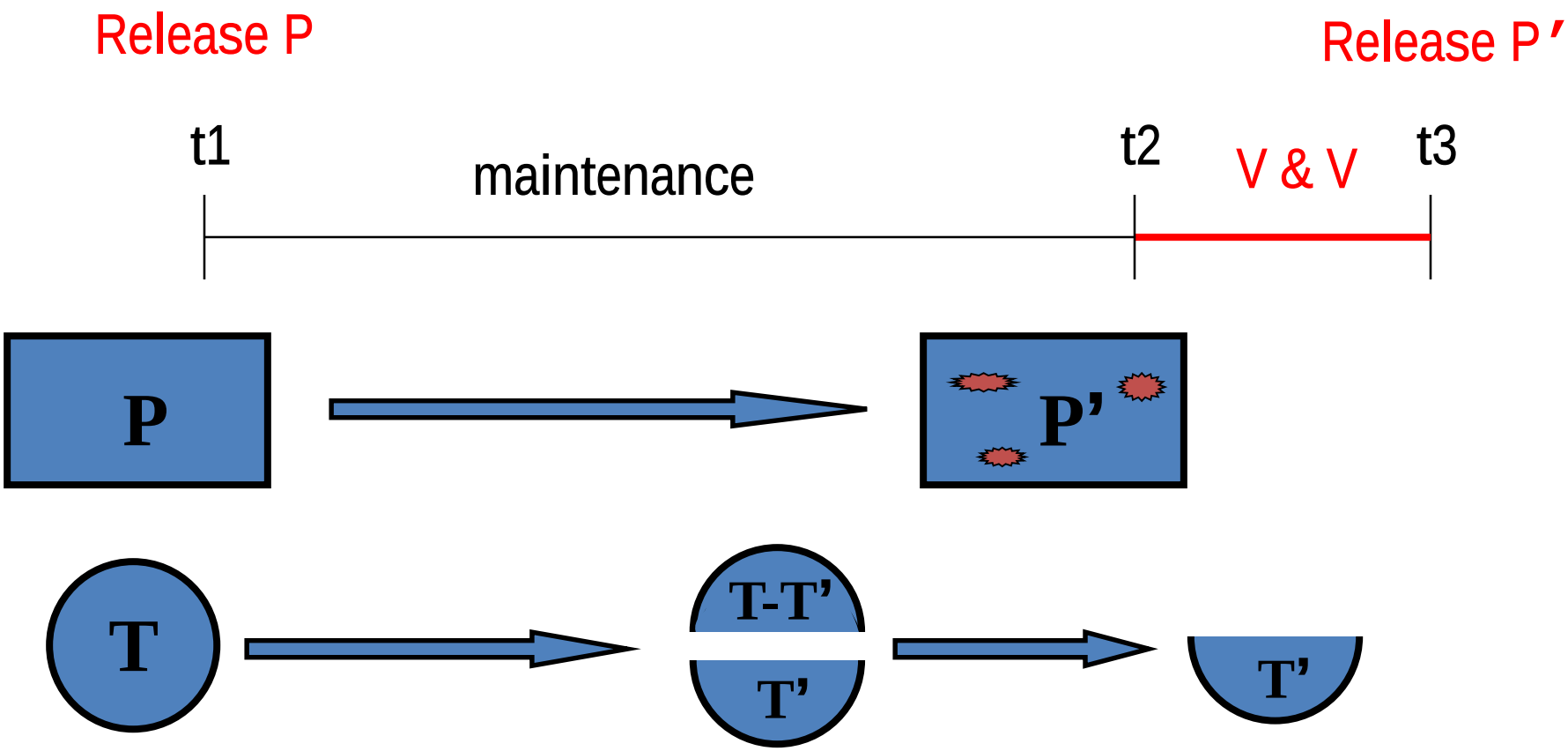
# Software Evolution: A Traditional Process Model



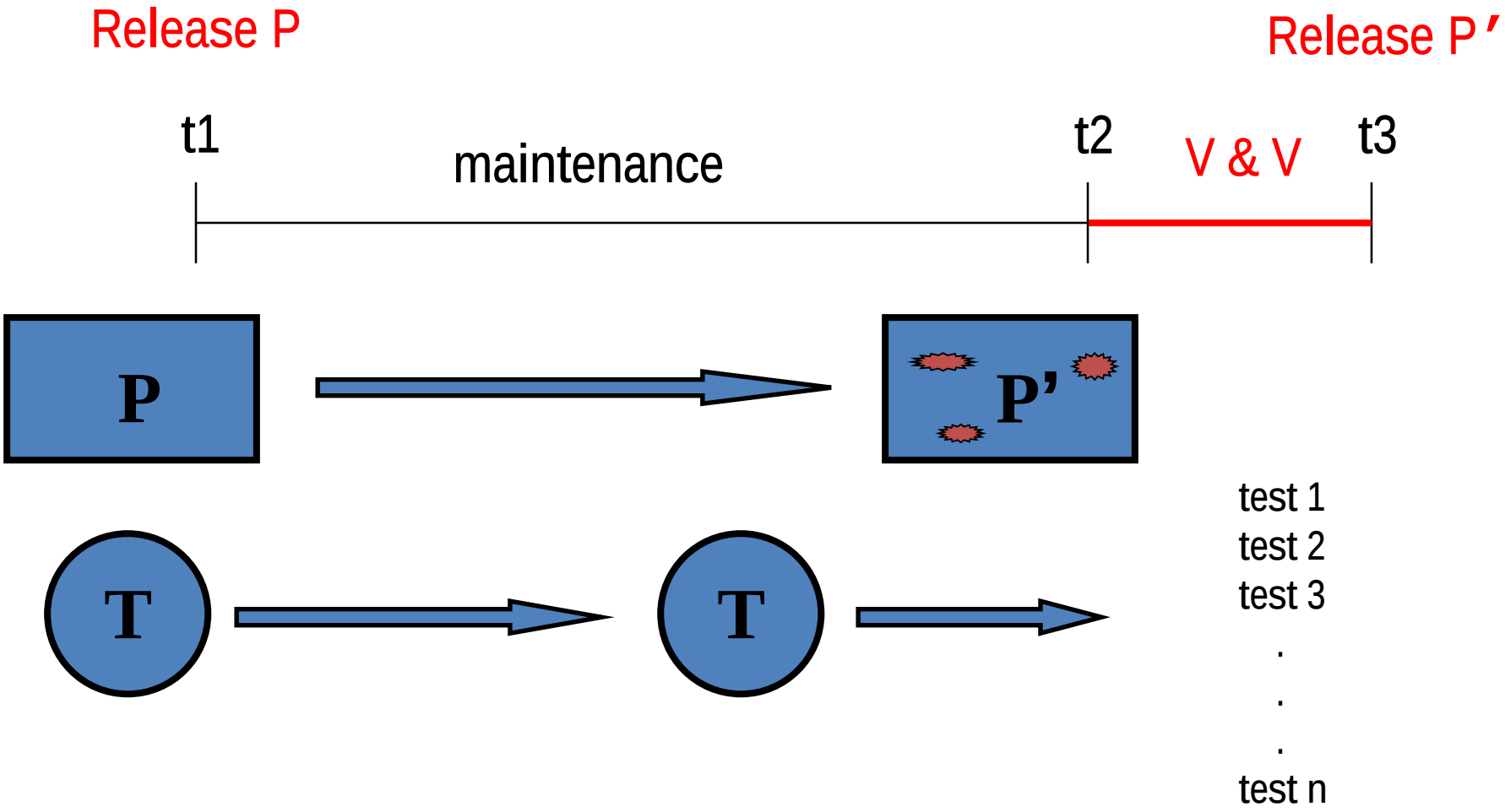
# Software Evolution with Regression Testing



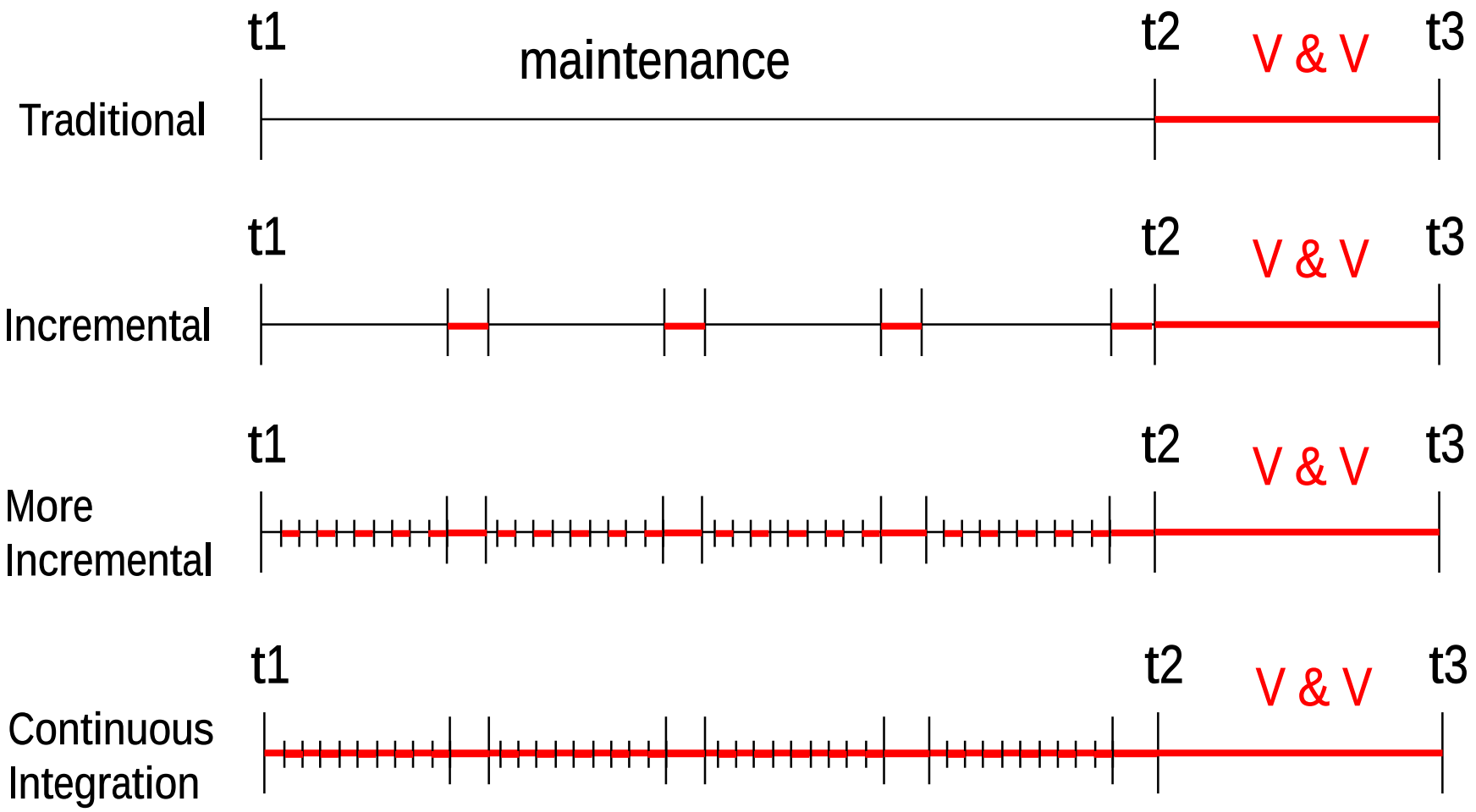
# Regression Test Selection (RTS)



# Test Case Prioritization (TCP)



# Software Evolution Process Models

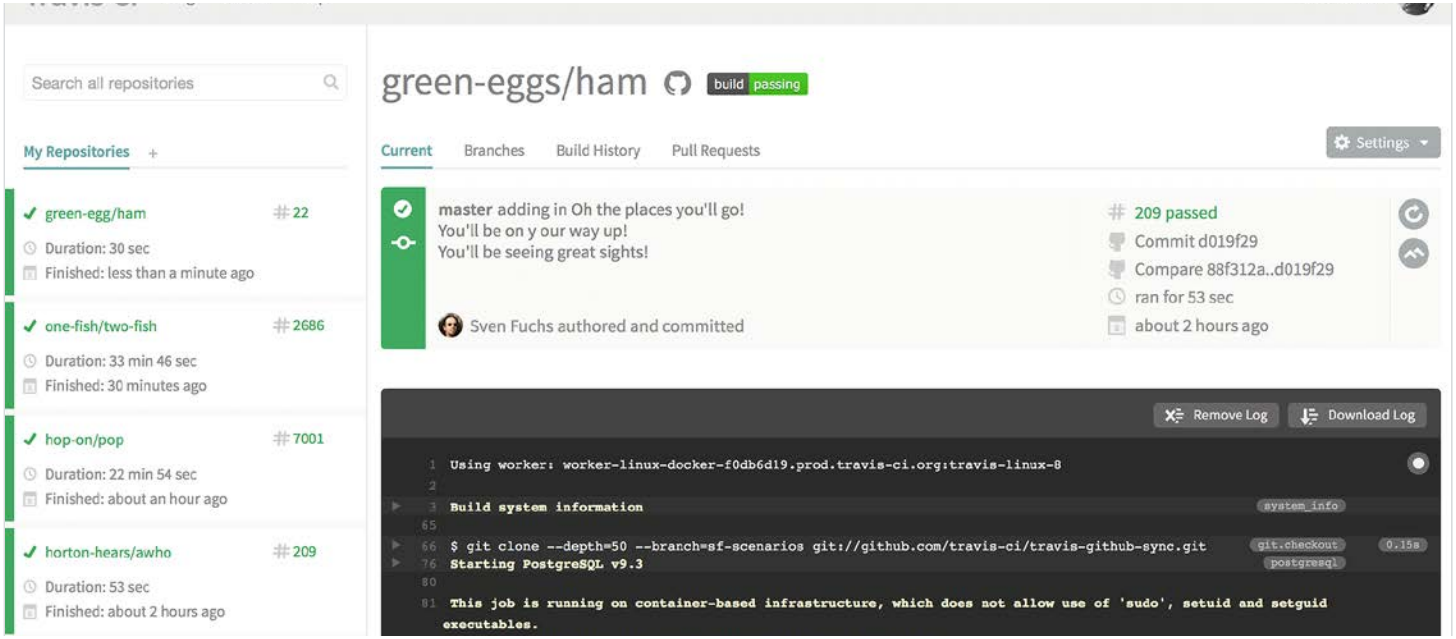


# Continuous Integration

# Continuous Integration

- Engineers merge code with the code base frequently; with each merge, tests are executed on changed and affected code
- Being practiced by major software organizations including Google, Facebook, Microsoft, Amazon, Twitter, and open-source projects like Firefox
- Supported by various tools including Travis CI, Jenkins, Atlassian, ThoughtWorks, and others

# Travis CI

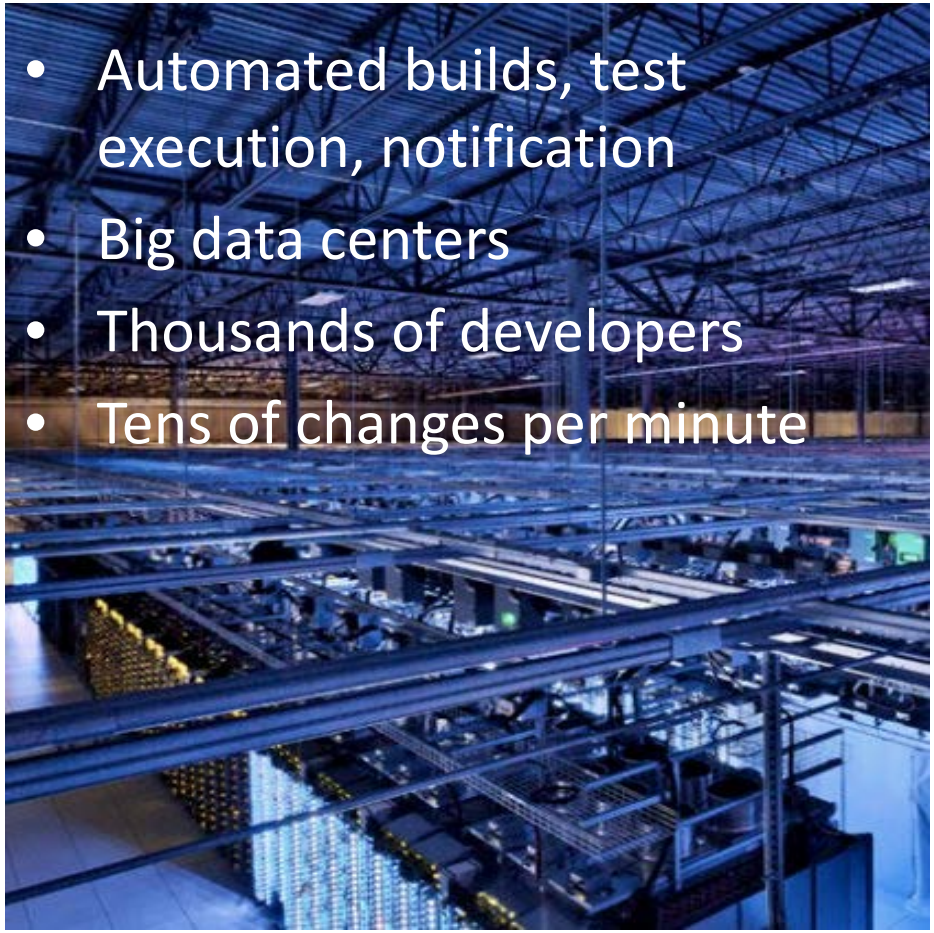


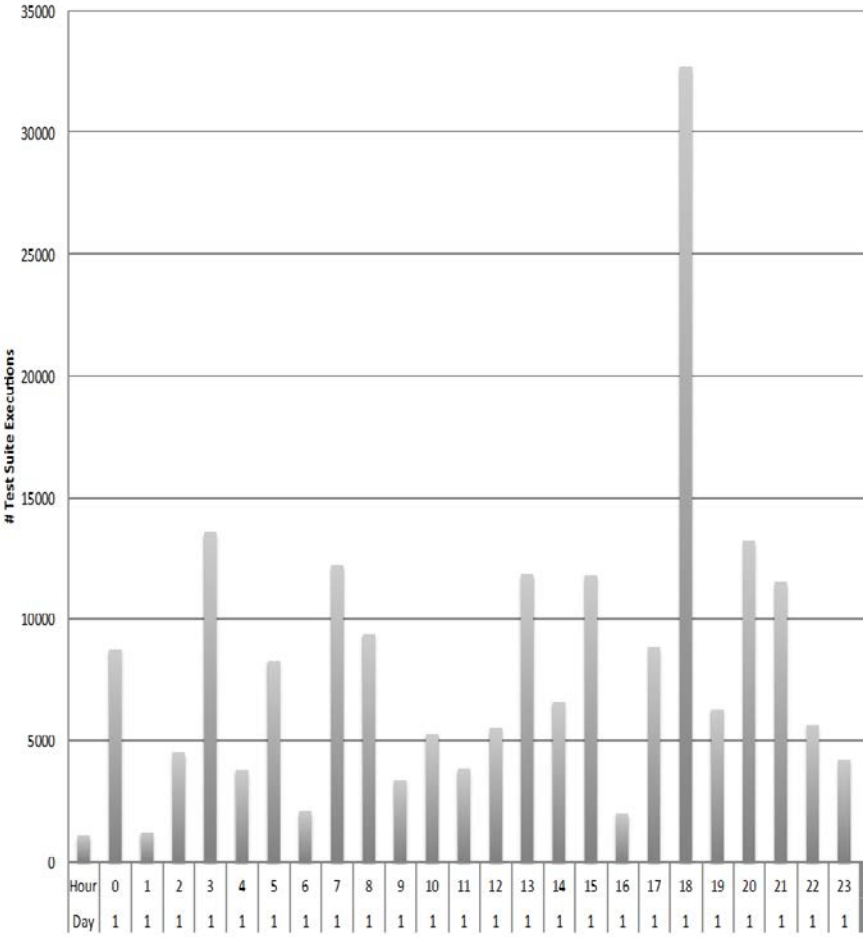

## The home of

Over 900k open source projects and 600k users are testing on Travis CI.

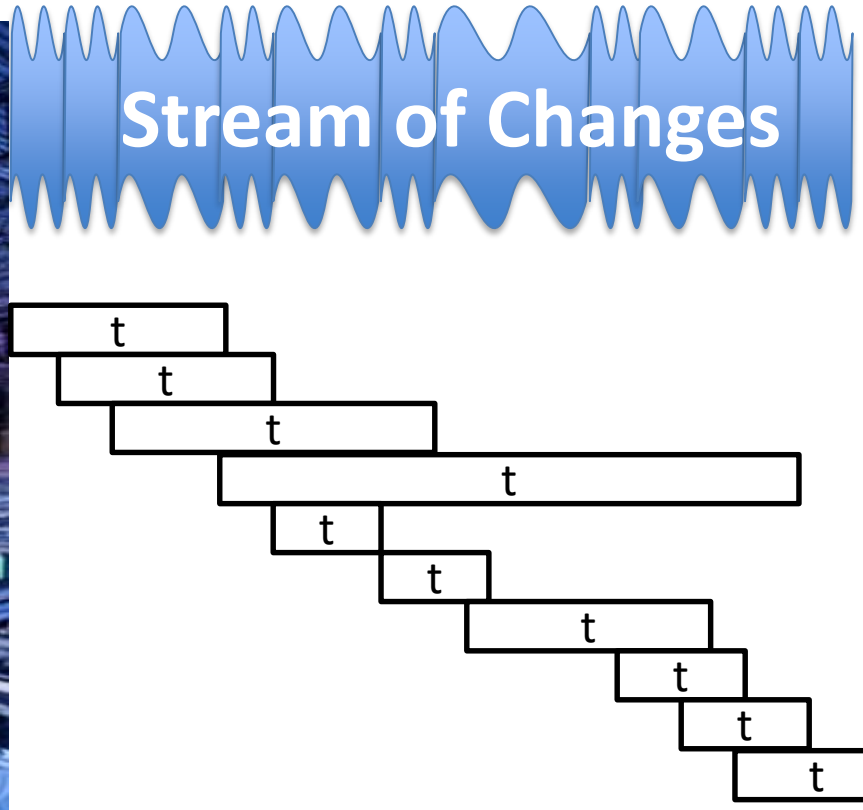
**932977**

# Continuous Integration at Google



# Continuous Integration at Google

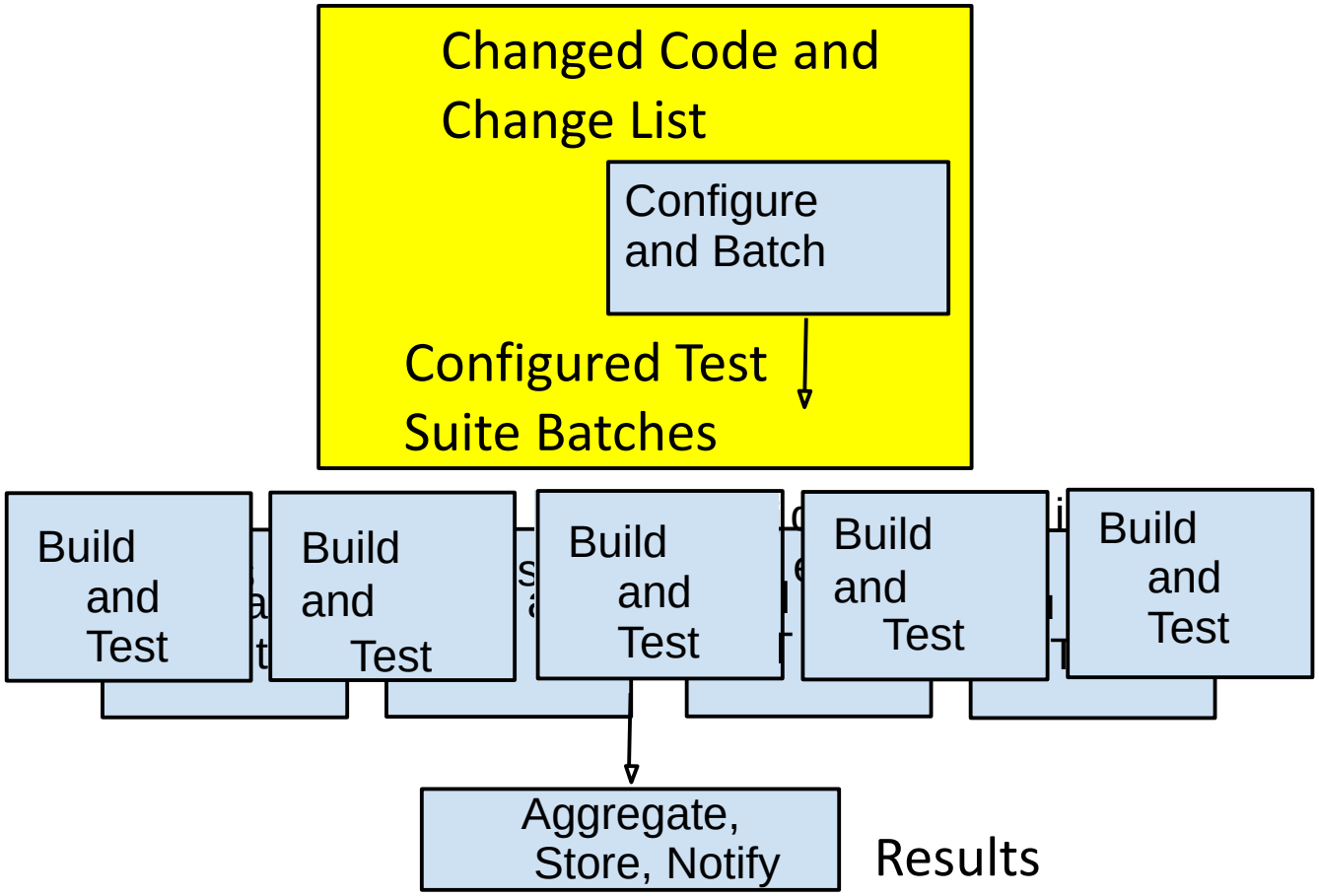



# The Speed and Scale of Google

- Single monolithic code tree, mixed languages
- Development on head; all releases from source at head
- More than 10,000 developers in more than 40 offices
- More than 13,000 projects under active development
- 800,000 builds per day
- 20+ code changes per minute
- More than 150 million test cases run per day

From “Testing at the speed and scale of Google”, Gupta, Ivey, Penix,
http://googletesting.blogspot.com/2014/01/the-google-test-and-development_21.html
(Numbers updated from “Taming Google-Scale Continuous Testing”, A. Memon et al., ICSE 2017)

# Continuous Testing Process

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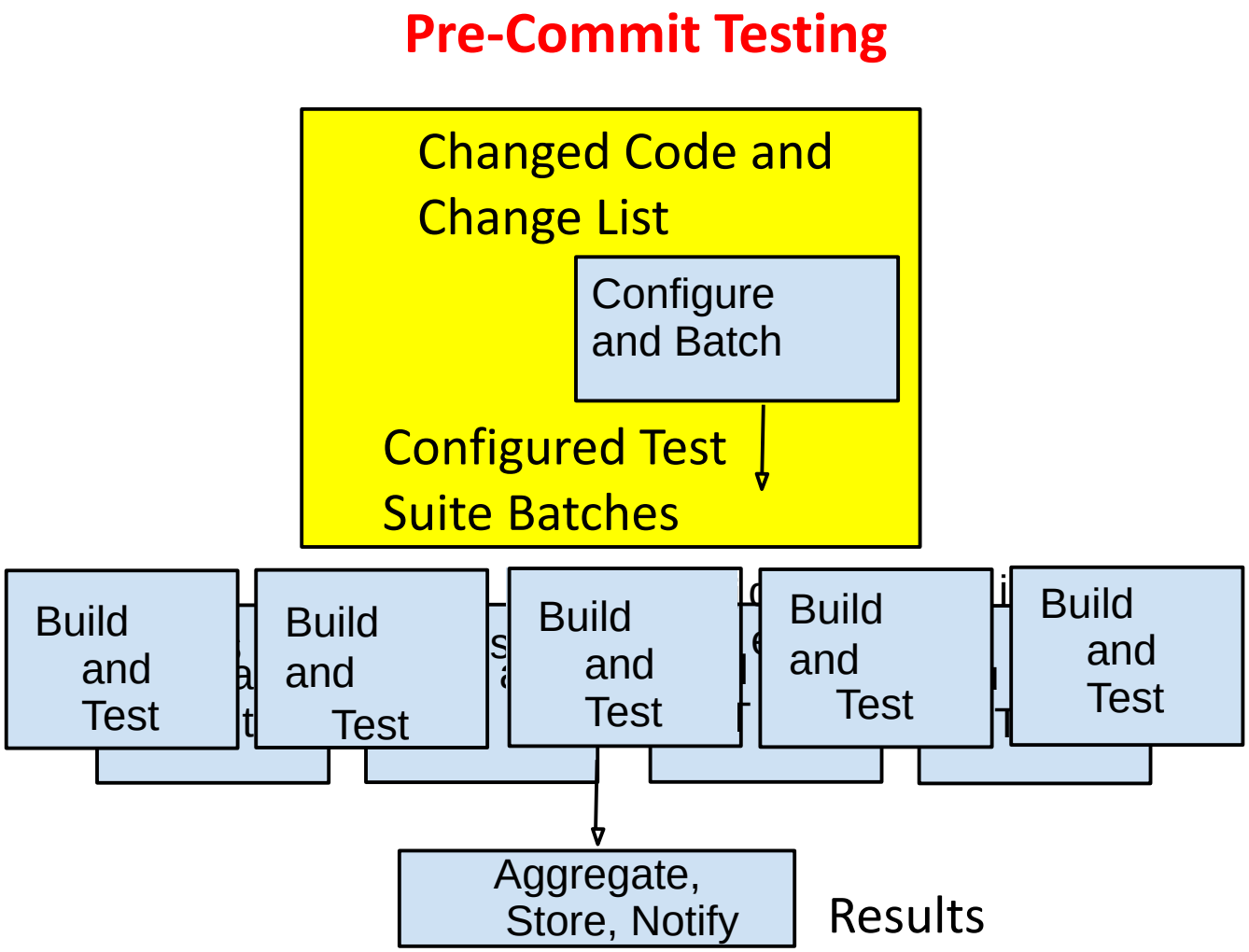


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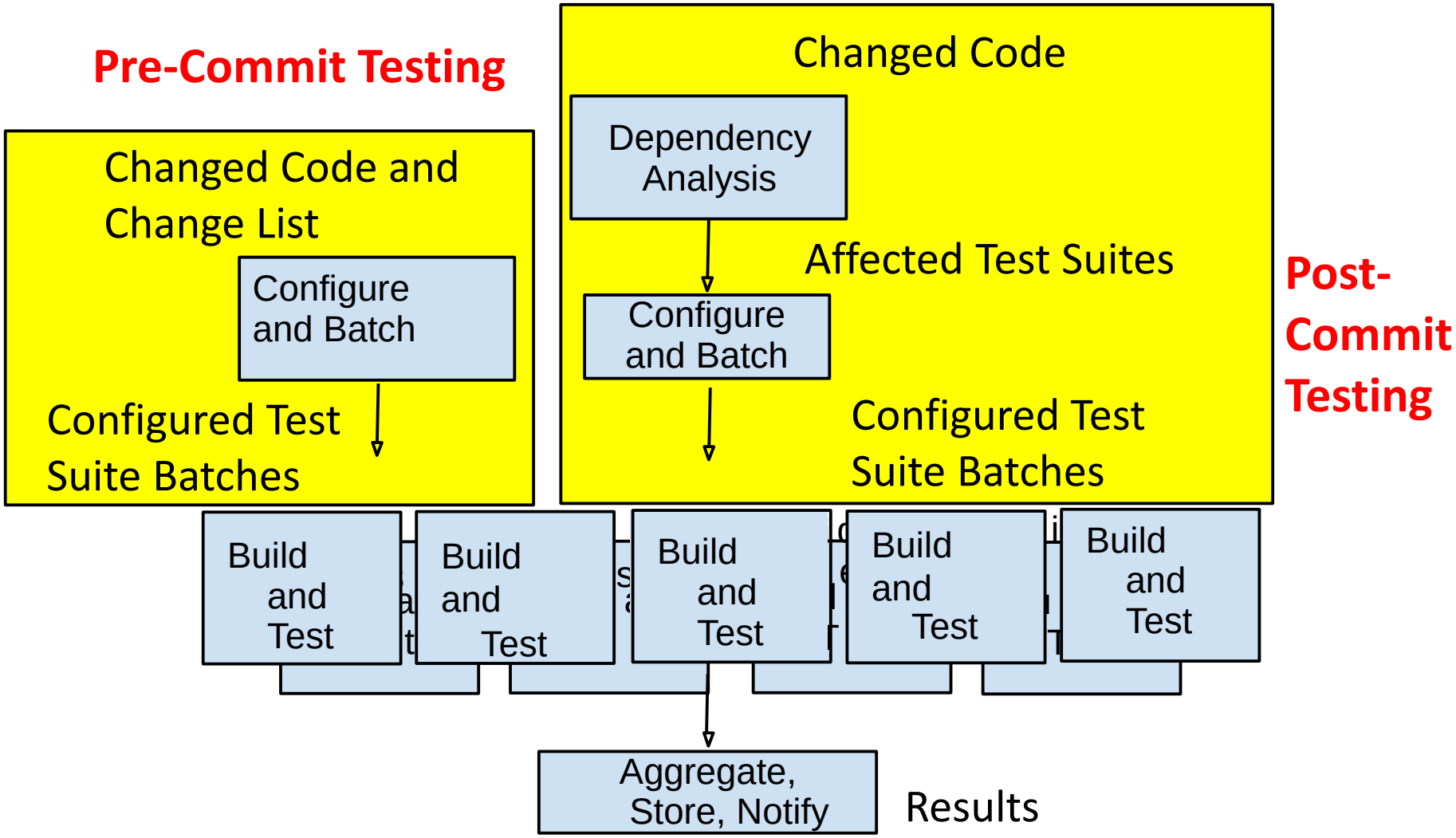


From "Testing at the speed and scale of Google", Gupta, Ivey, Penix,
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# Challenges for CI at Google

- Frequent builds (800,000 per day) and testing runs require non-trivial time and resources
- The volume of tests to be run (150 million per day) can delay the speed with which developers receive feedback
  - Developers must wait 45 minutes to 9 hours to receive testing results, despite the massive parallelism that is available.*
- Adding more servers won't solve the problem; testing keeps expanding until it swamps available resources*

*From "Taming Google-Scale Continuous Testing", A. Memon et al., ICSE 2017

# Regression Testing Approaches for Continuous Integration Environments*

# Part I: Pre-Commit

S. Elbaum, G. Rothermel, J. Penix, “Techniques for Improving Regression Testing In Continuous Integration Development Environments”, FSE 2014

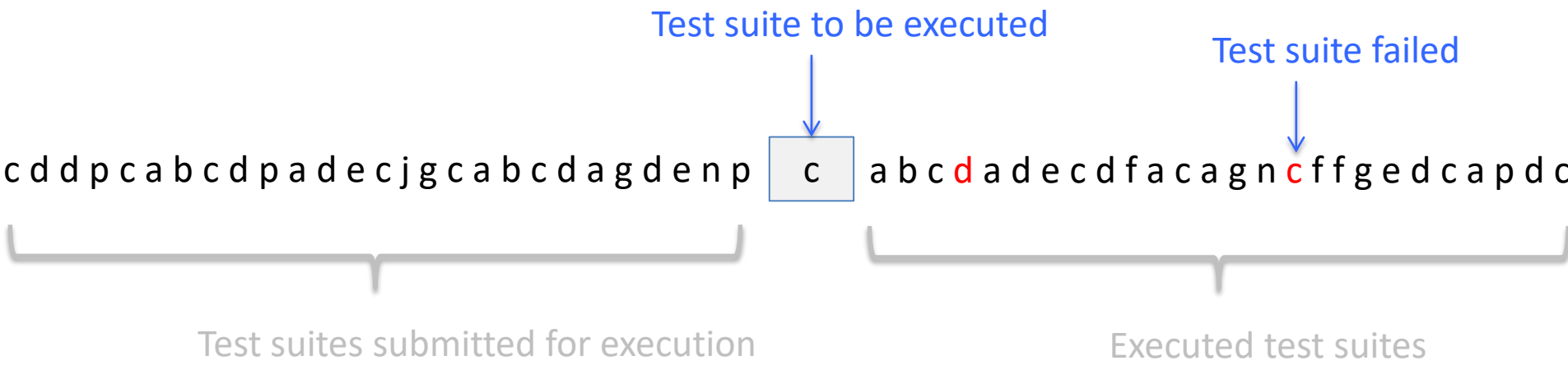
# Pre-Commit: Continuous-RTS

- Regression test selection
- At the level of test suites, not test cases
- Except that we cannot assume that:
  - We have reliable coverage information
  - We have time to perform heavyweight analyses
- Key insight: value of lightweight test history data
  - Test suite executions
  - Test suite failures

# Continuous-RTS Intuition

- If a test suite is new
  - Execute it
- If a test suite failed recently
  - May be associated with “hot” area, worth re-execution
- If a test suite has not executed in a while
  - Needs a “refresher”
- Else skip it

# Continuous-RTS Example



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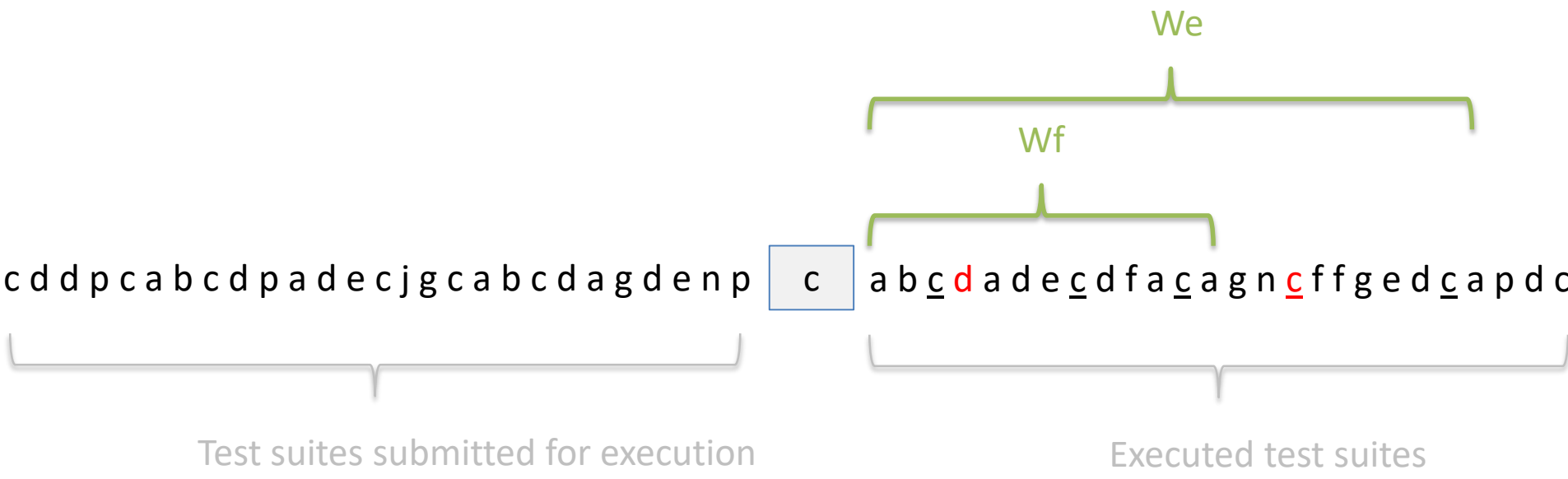

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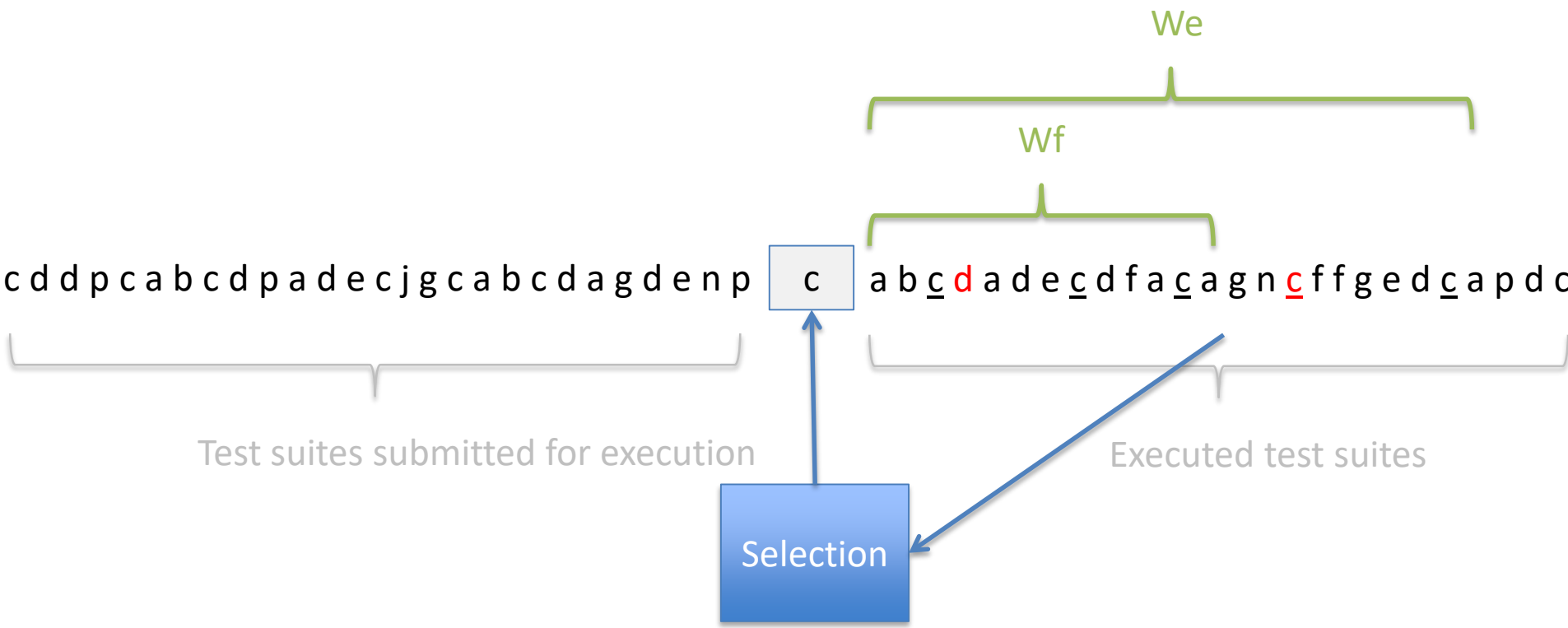

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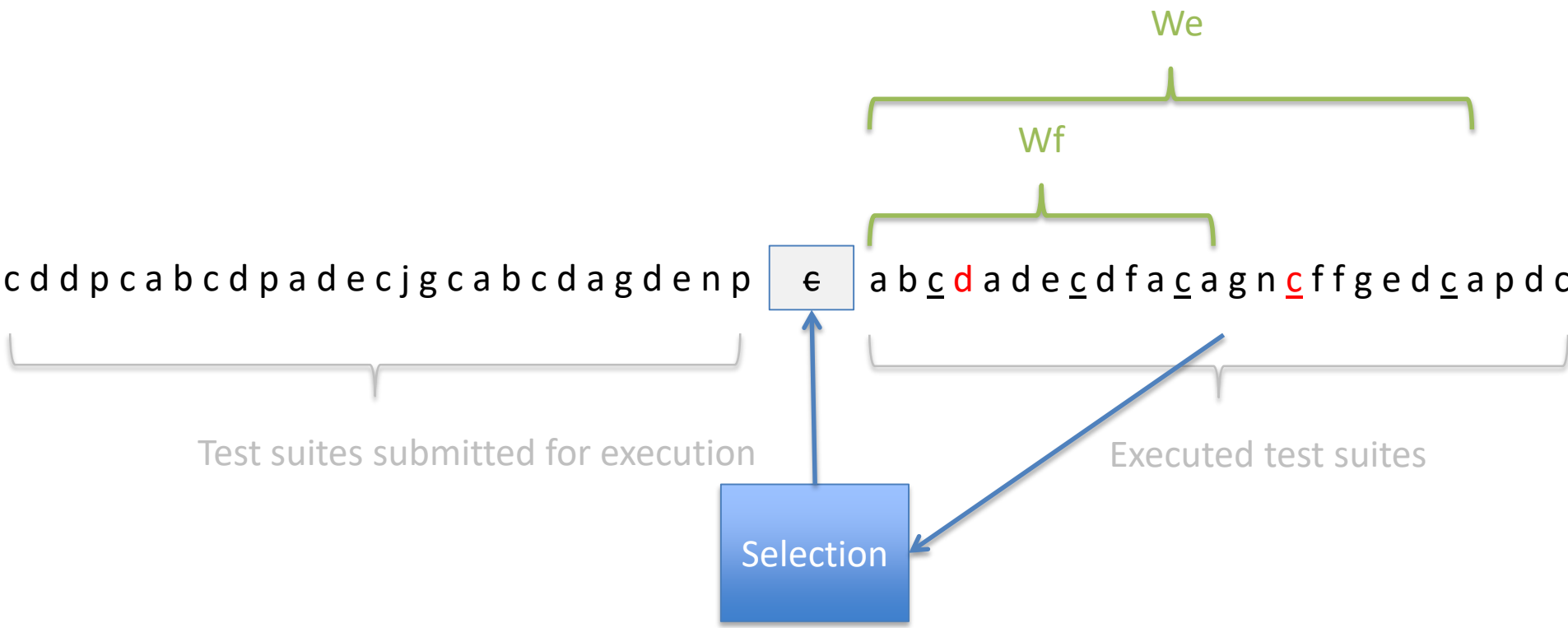

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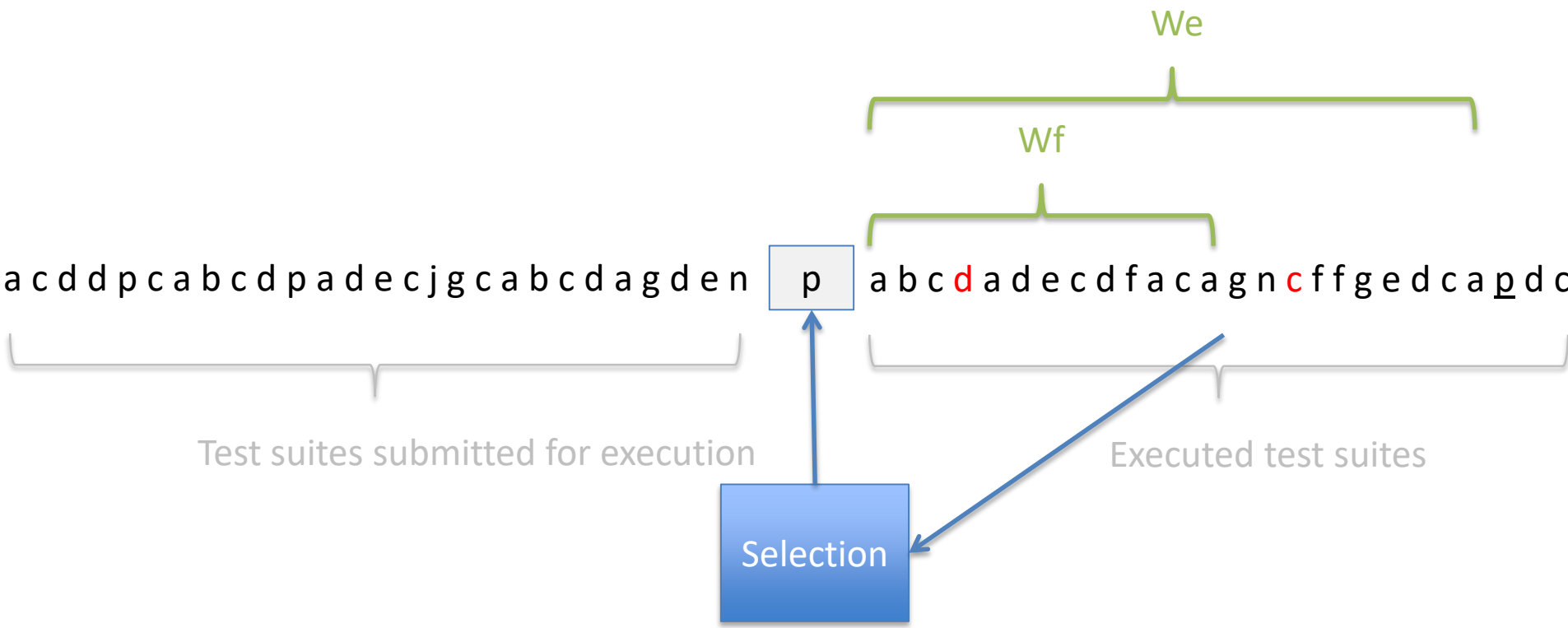

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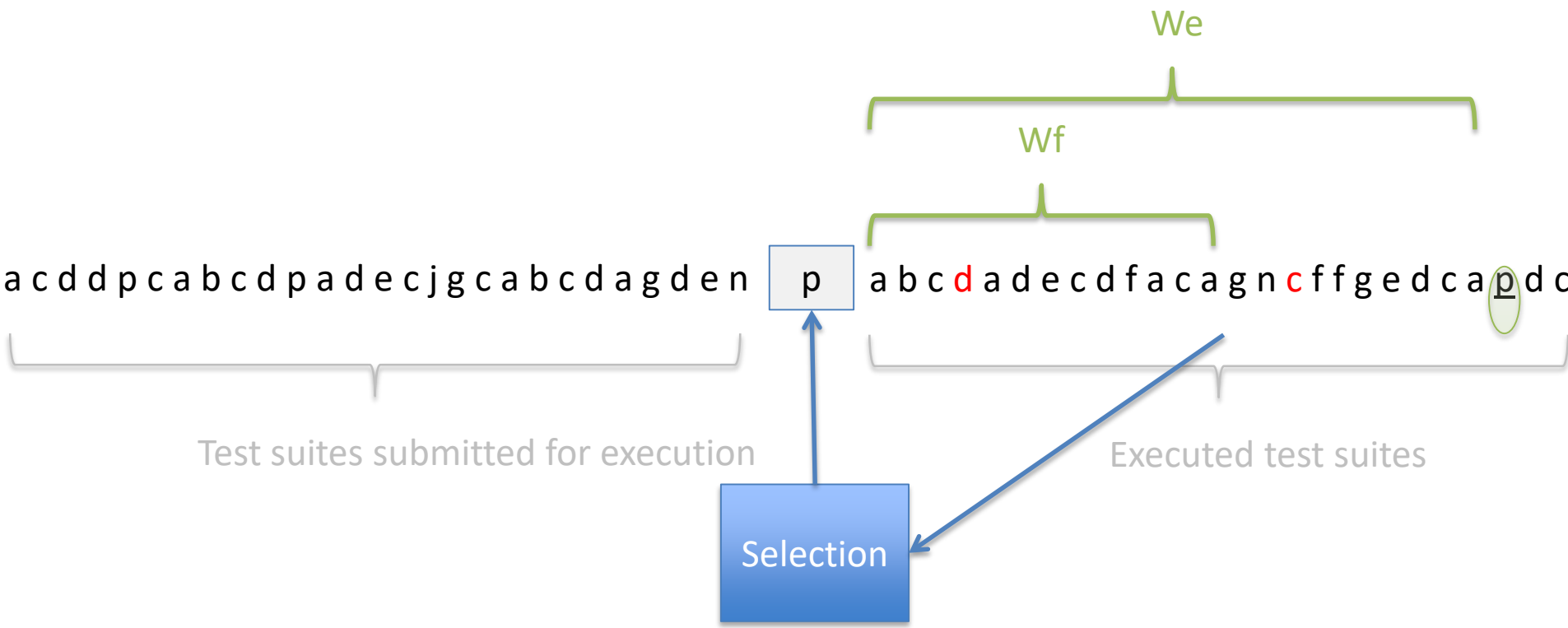

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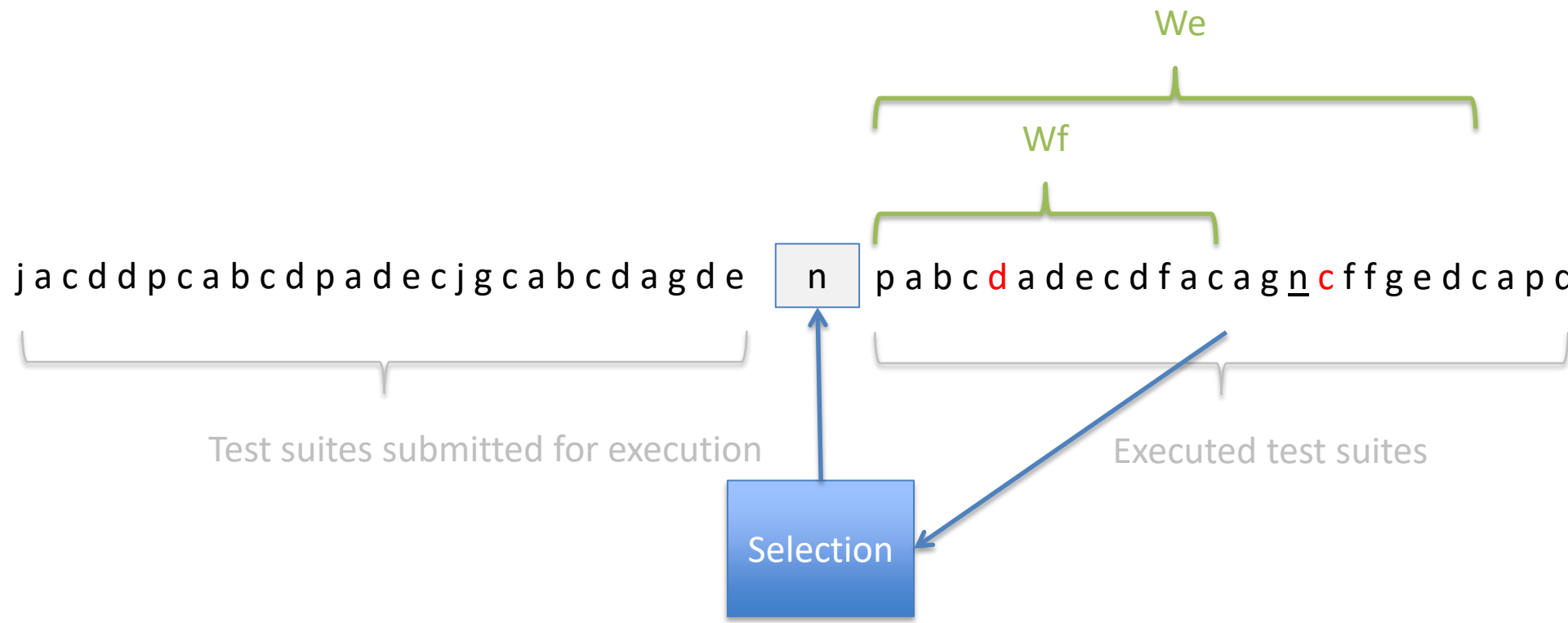

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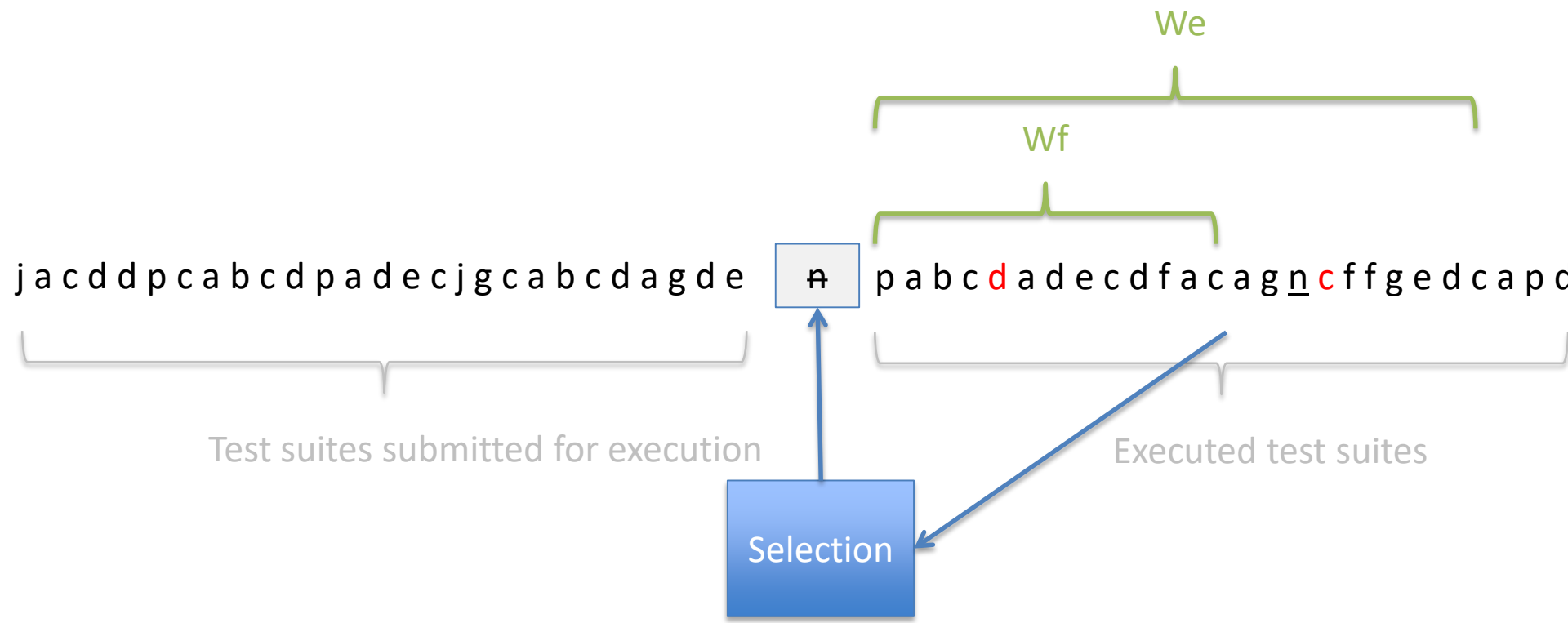

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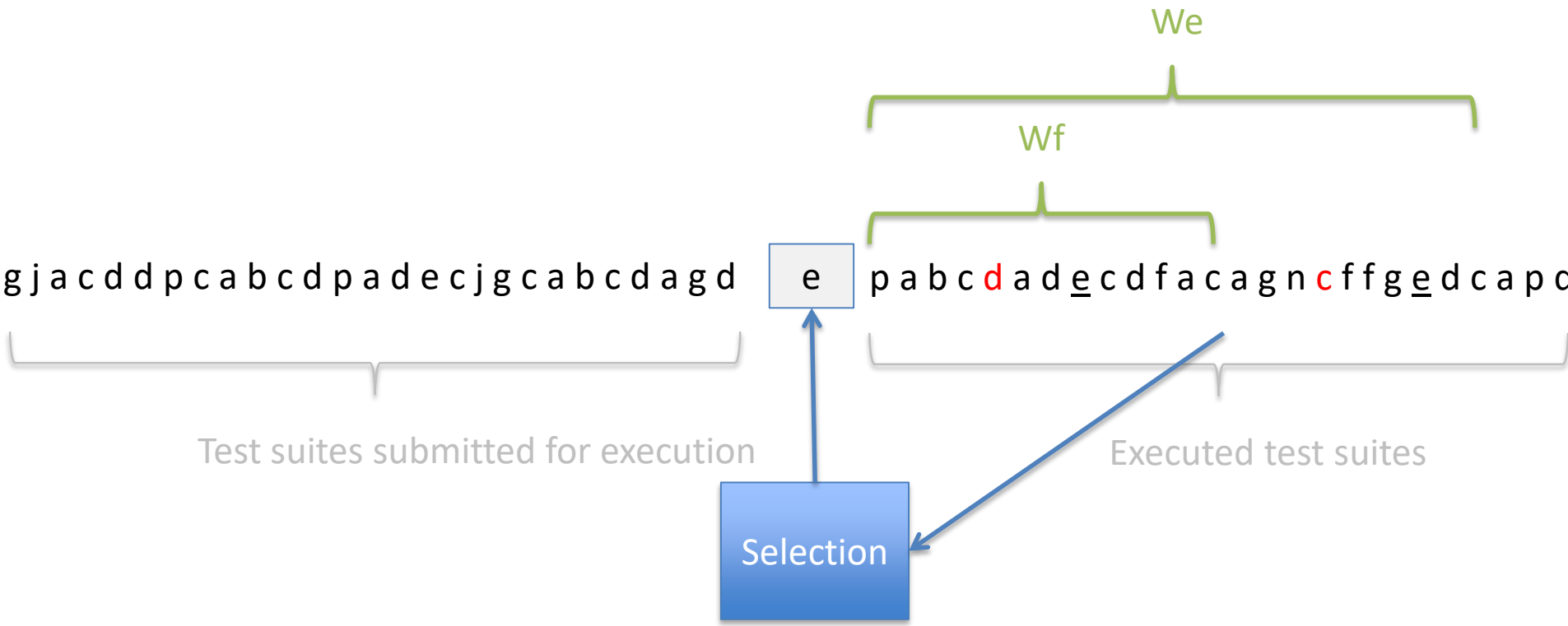

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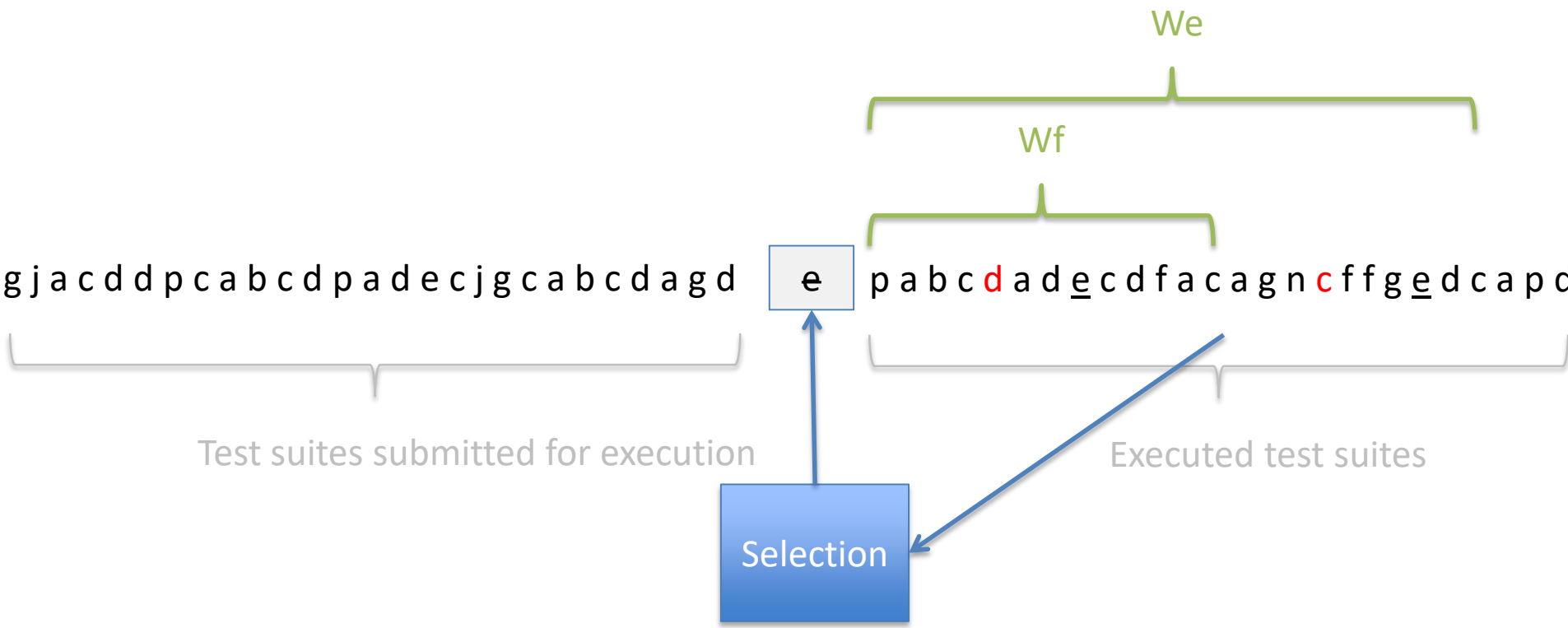

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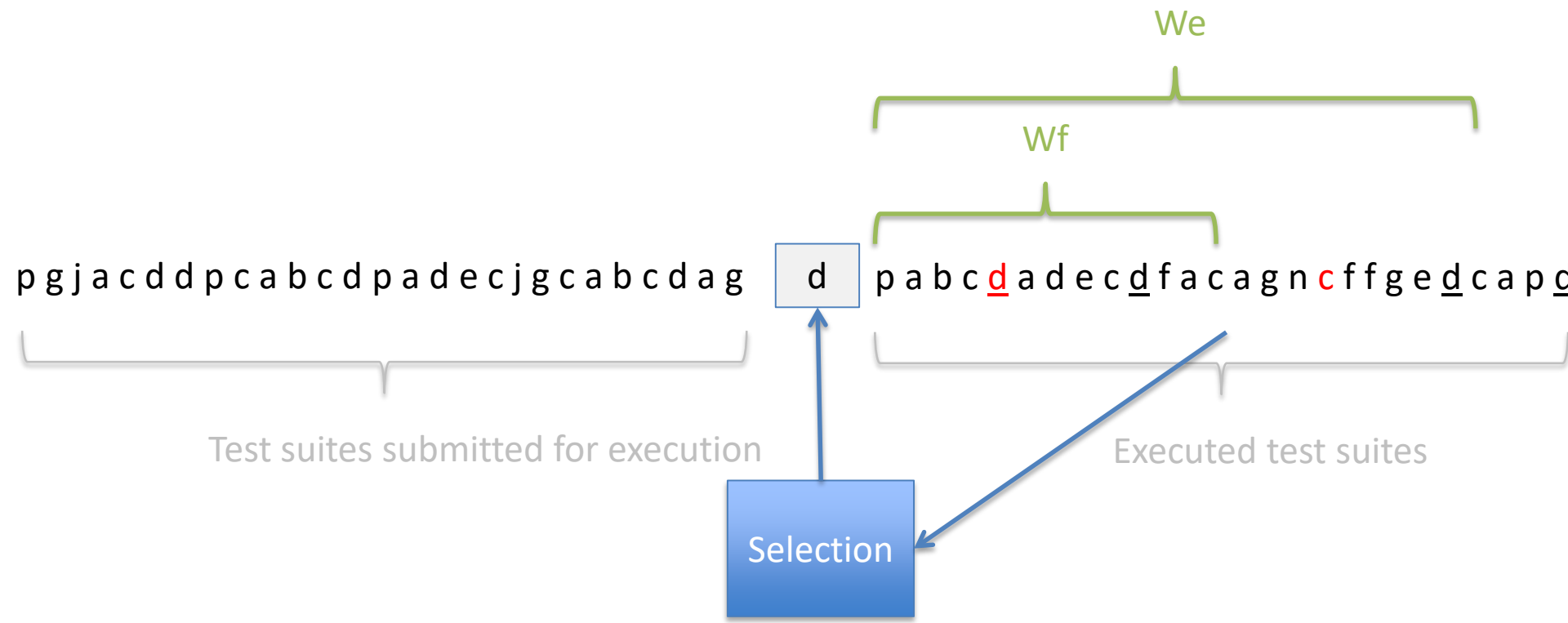

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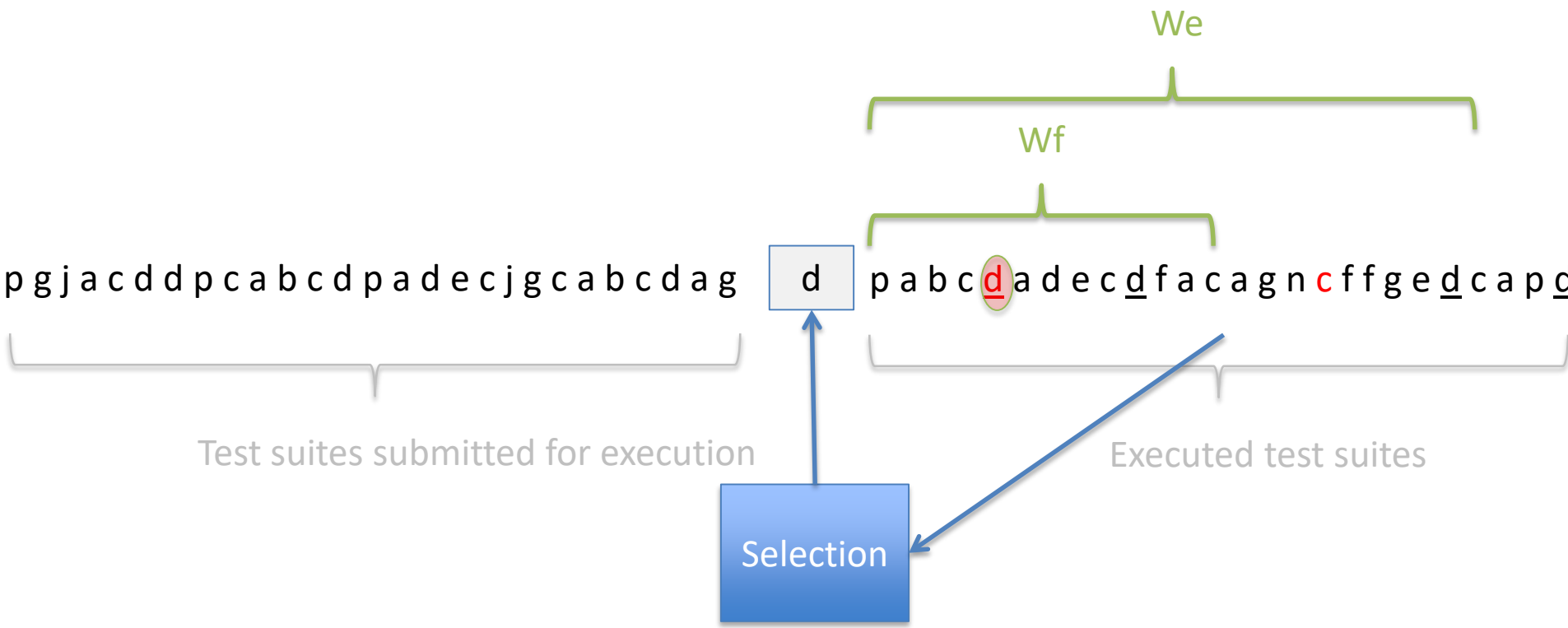

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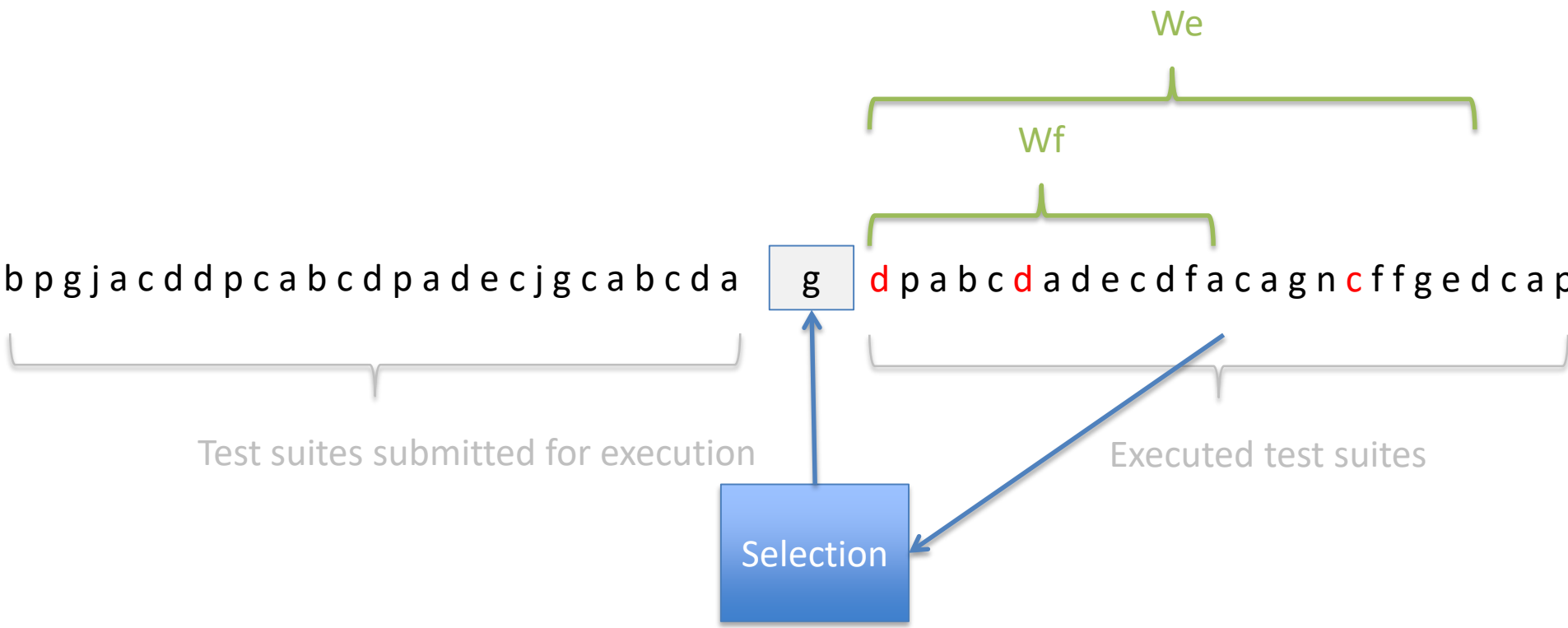
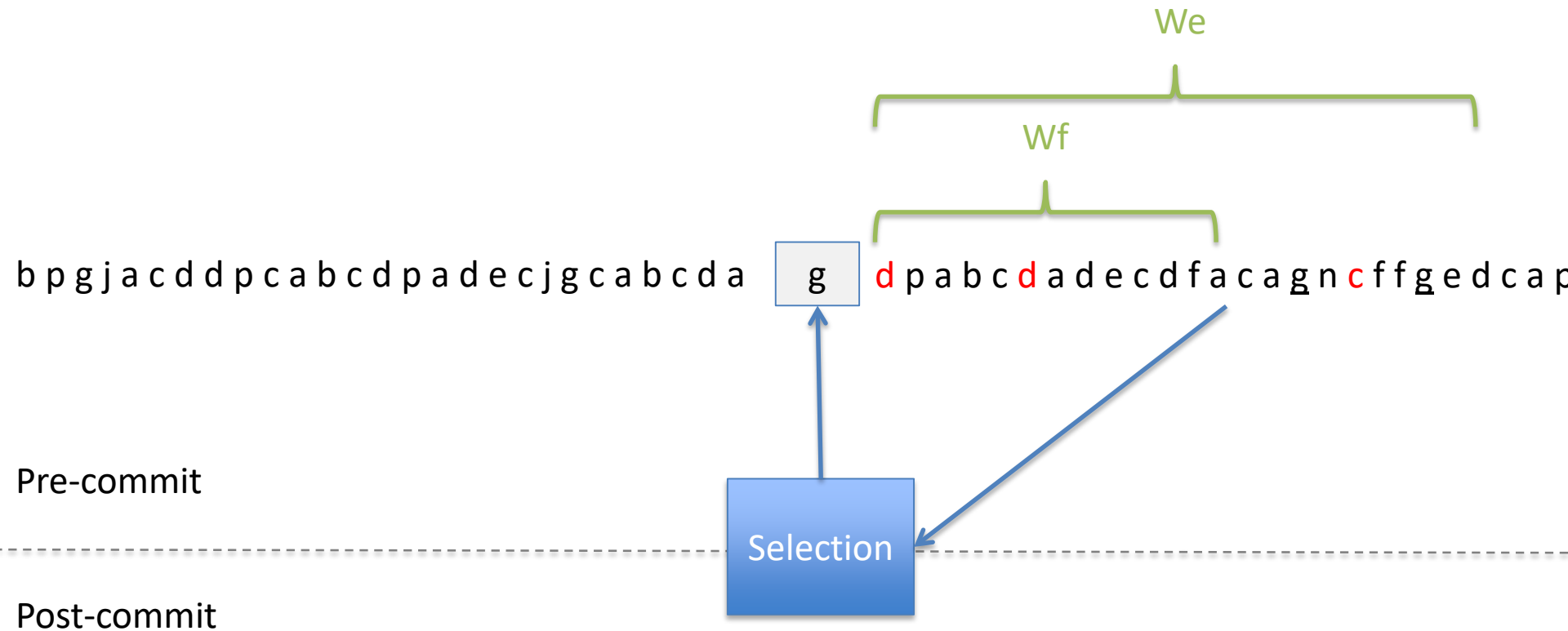


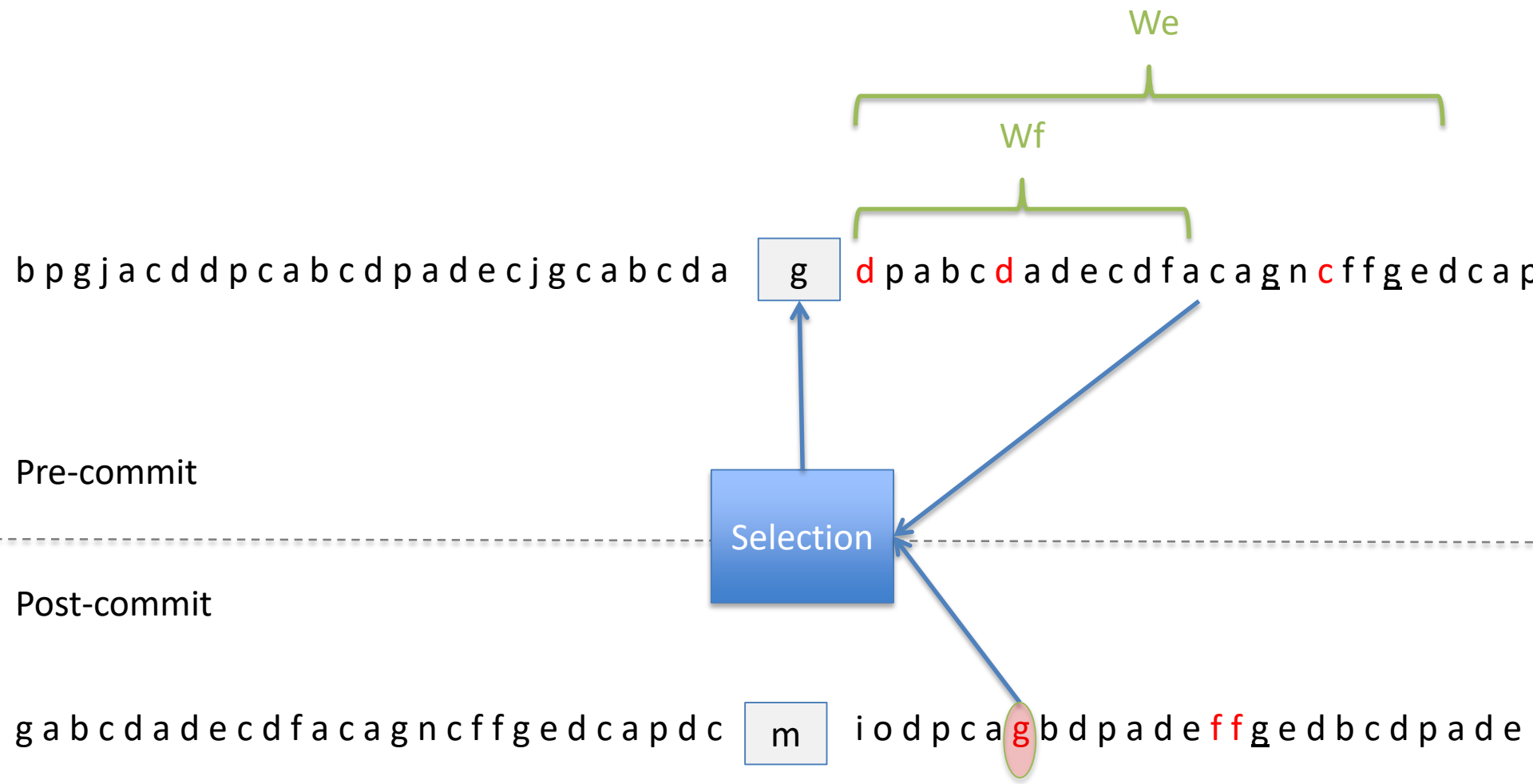
# Continuous-RTS Intuition II

- If a test suite is new
  - Execute it
- If a test suite has failed recently
  - May be associated with “hot” area, worth re-execution
- If a test suite has not executed in a while
  - Needs a “refresher”
- Else skip
  - Use the post-commit testing phase as a safety net and a source of information

# Continuous-RTS Example



# Continuous-RTS Example



# Continuous-RTS Algorithm

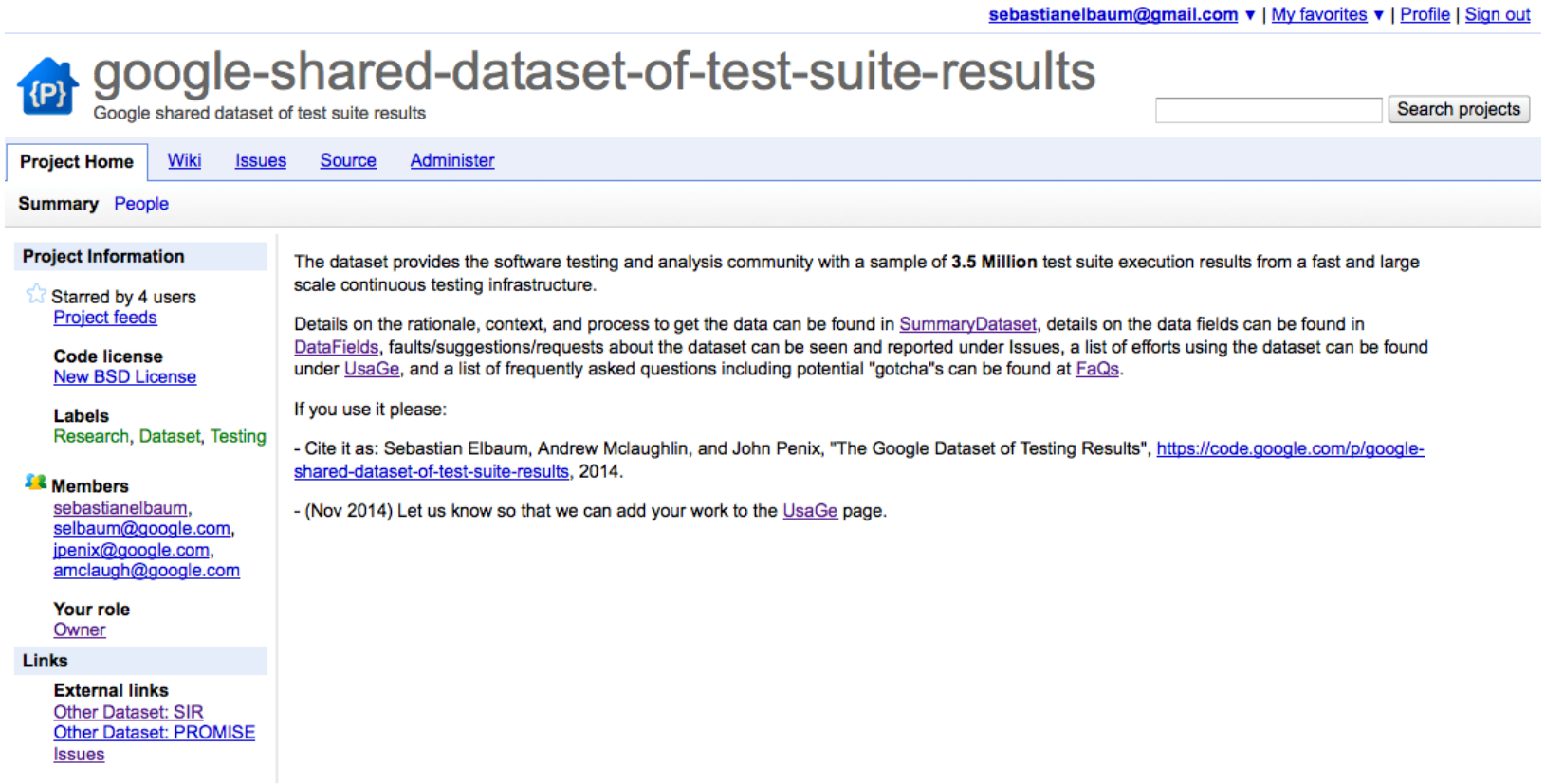
```
/*
*  Called After Every Pre-Commit Request
*/

CI-RTS (T, Wf , We)   // T: set of test suites associated with a commit

     forall Ti ∈T do
          if TimeSinceLastFailure(Ti) ≤ Wf or          // hot test suite
               TimeSinceLastExecution(Ti) > We or  // need refresher
                    Ti is new                                  // just added
                         then T' ← T' ∪ Ti
          end if
     end for
     return T'
```

# Research Question

- RQ: How cost-effective is CI-RTS, and how does its cost-effectiveness vary with different settings of Wf and We?

# Google Testing Dataset

3.5 million test executions gathered over 30 days on change requests, info on test times and phases when executed, test outcomes, test execution times. About 0.05% of the test executions result in *failures*.



# Variables

- Independent
  - Technique: Continuous-RTS, Retest-all, Random
  - We: 24, 48, 96 (hours)
  - Wf: 0.25, 0.5, 1, 2, 4, 12, 24, 48, 96 (hours)
- Dependent
  - Percentage of failures detected
  - Percentage of test suite executed
  - Percentage of test suite execution time required

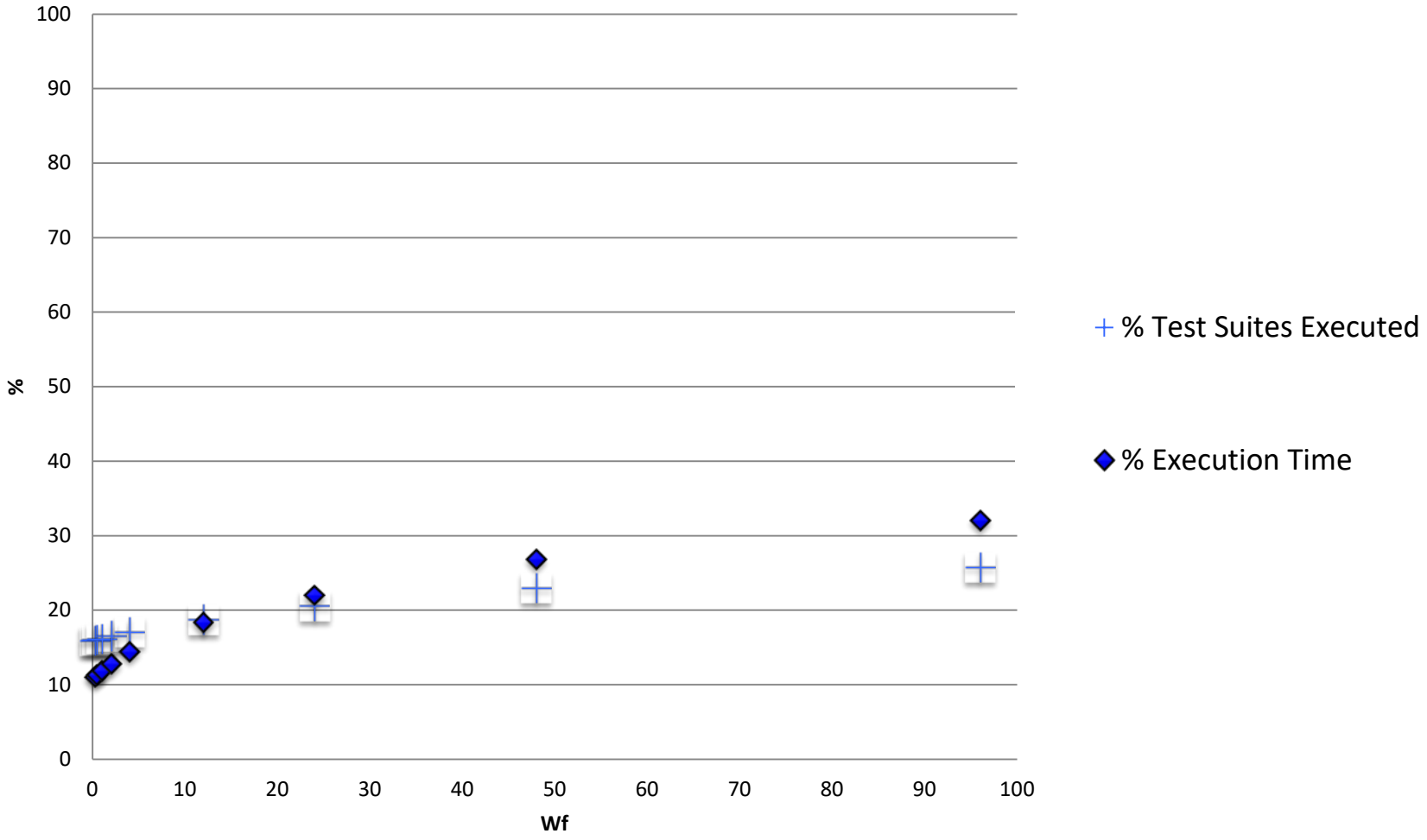
# Study Operation

- Implemented Continuous-RTS algorithm in Python
- Simulated techniques by walking through the Google Testing Dataset

# Threats to Validity

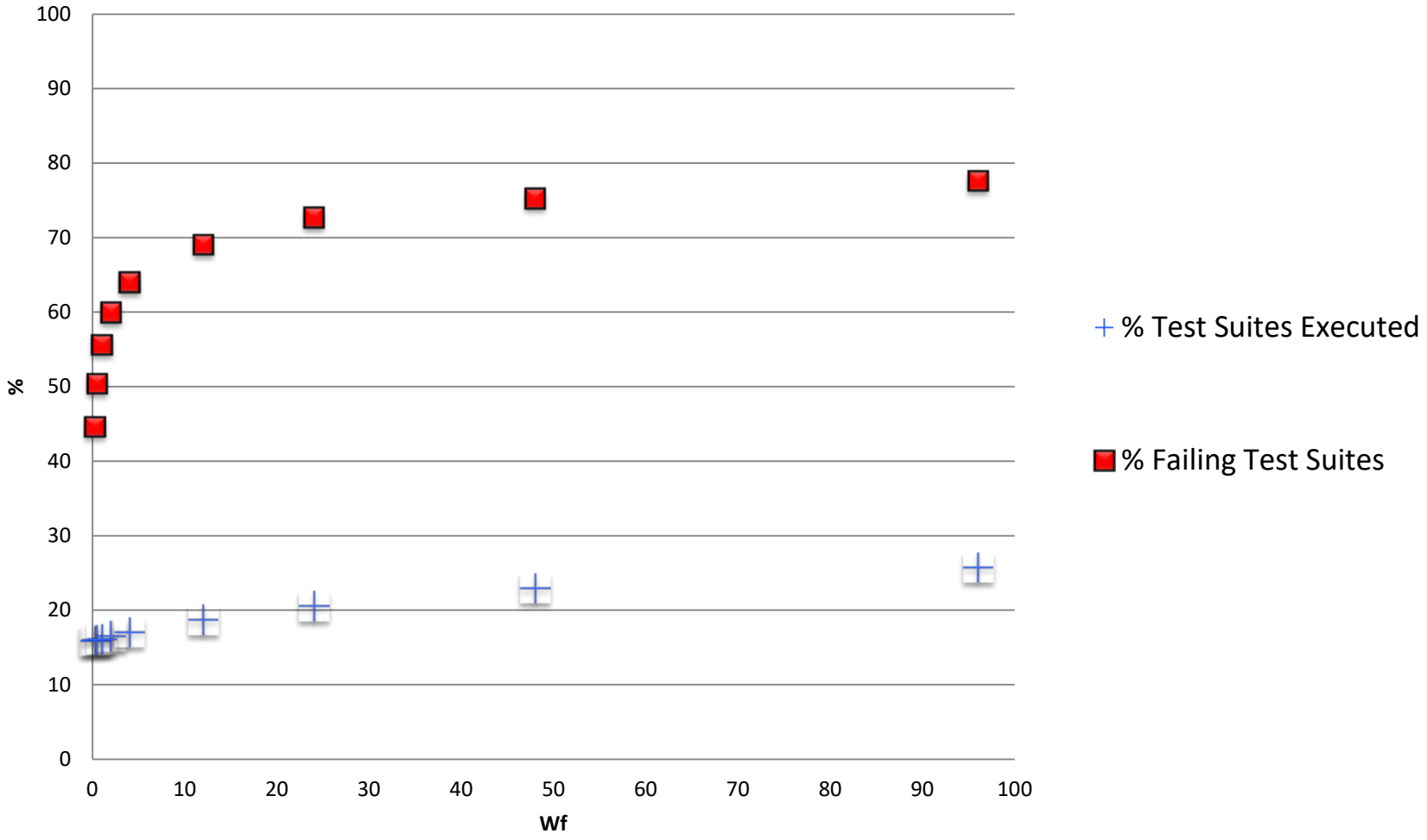
- External:
  - Only one dataset, only a few baselines, limited set of window sizes, no consideration of available computing infrastructure
- Internal:
  - Possible implementation errors
- Construct:
  - Measures such as costs in engineer time or delays in receiving feedback not considered

# Results: CI-RTS in Pre-Commit




We = 24 hours

# Results: CI-RTS in Pre-Commit

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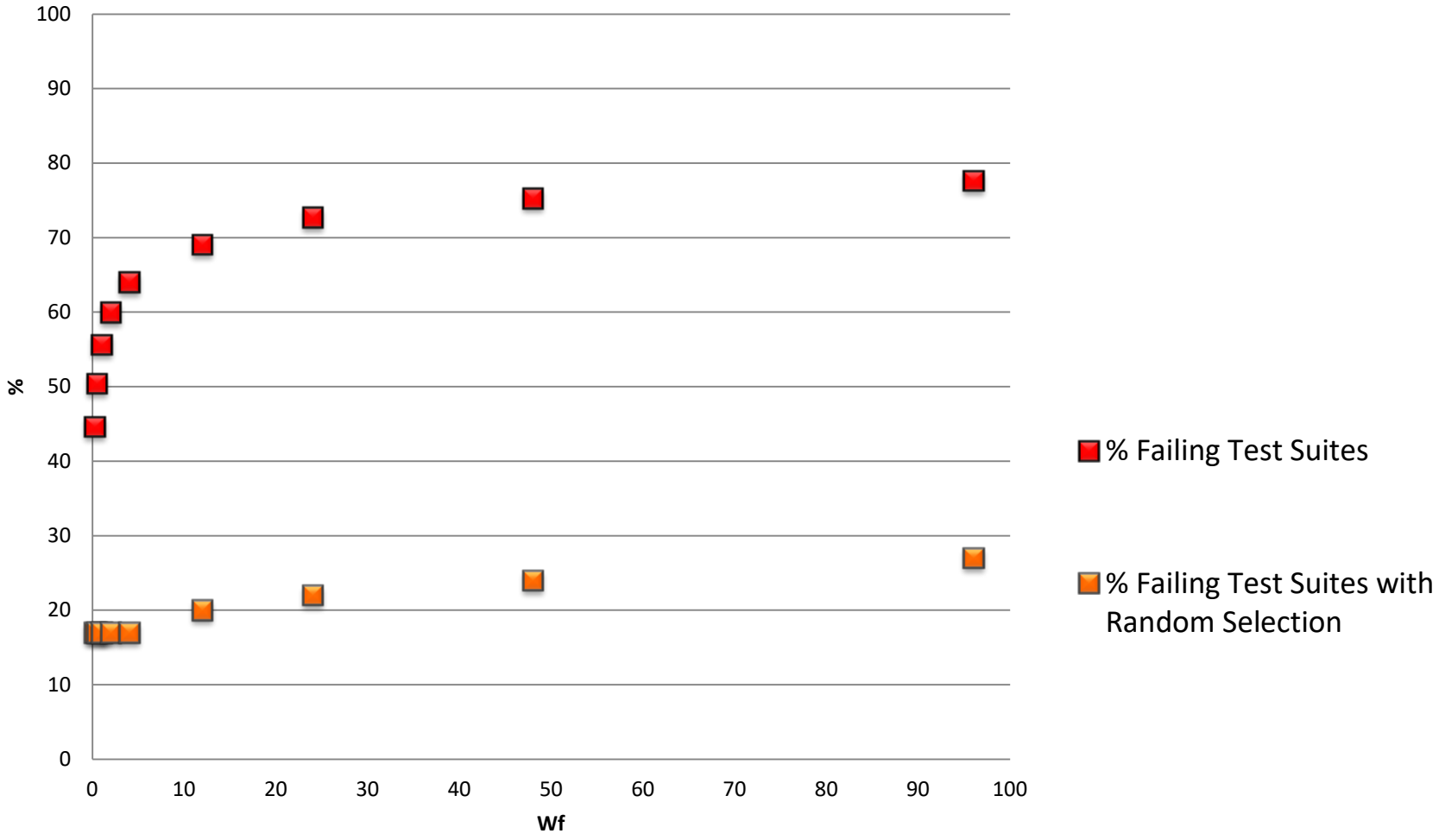


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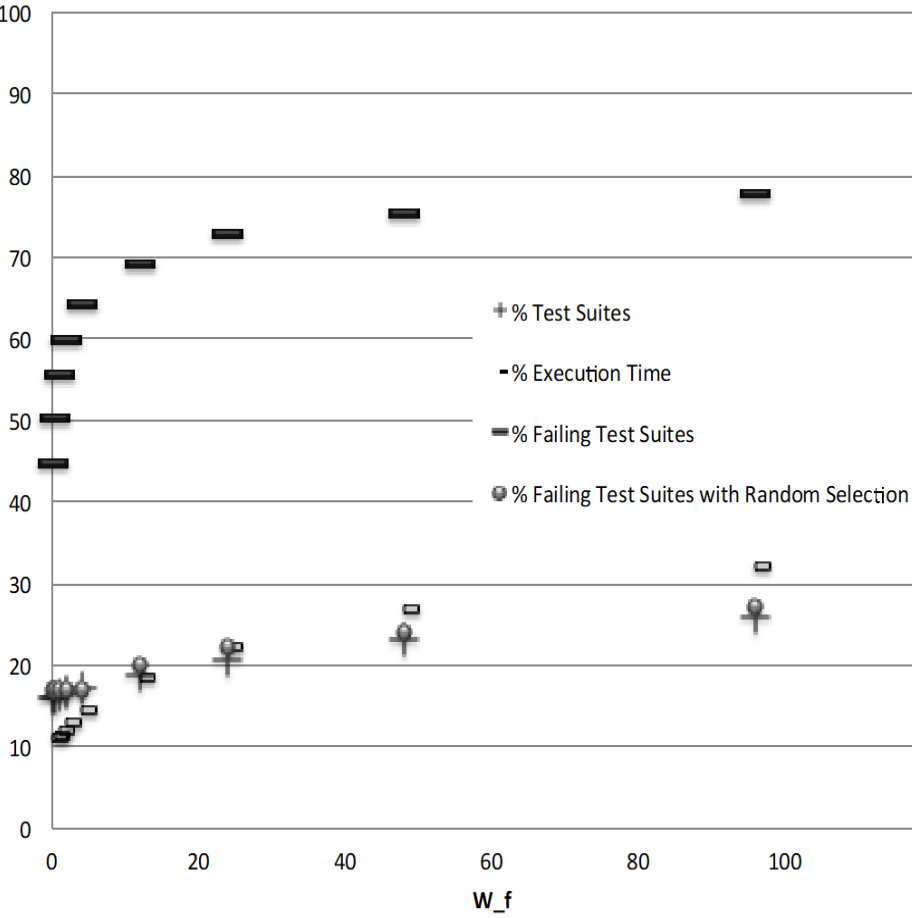
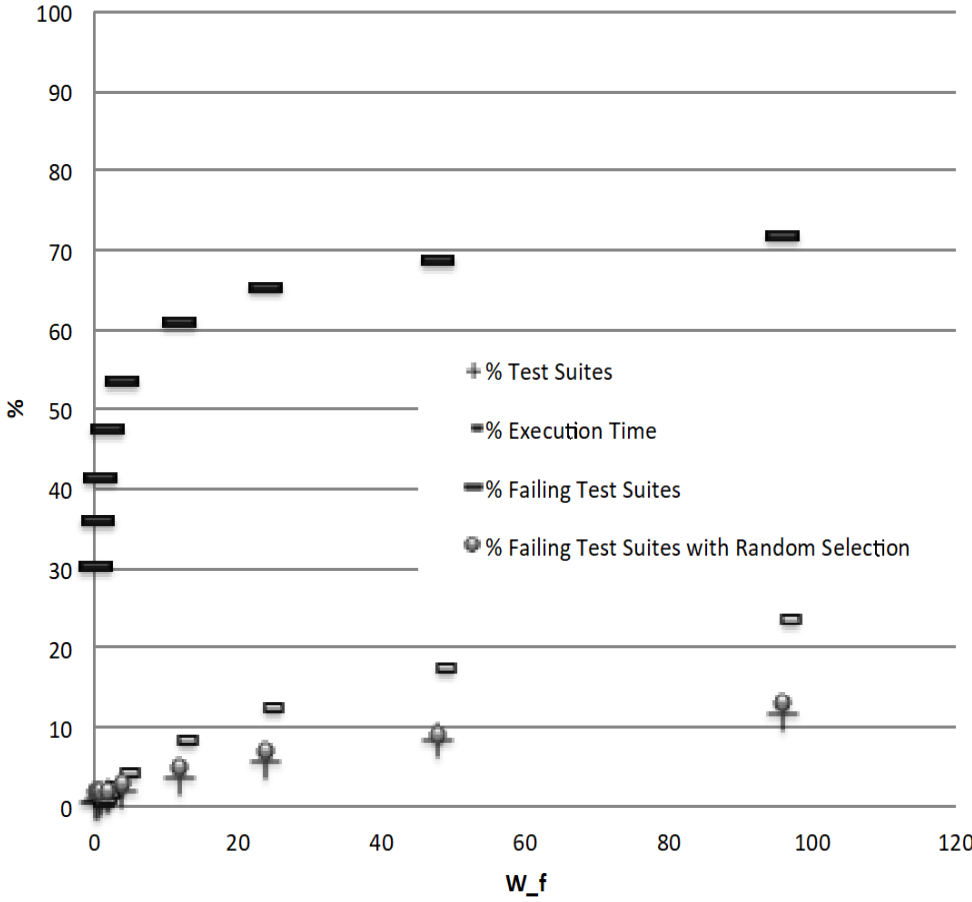



We = 24 hours




We = 48 hours

# Regression Testing Approaches for Continuous Integration Environments

## Part II: Post-Commit

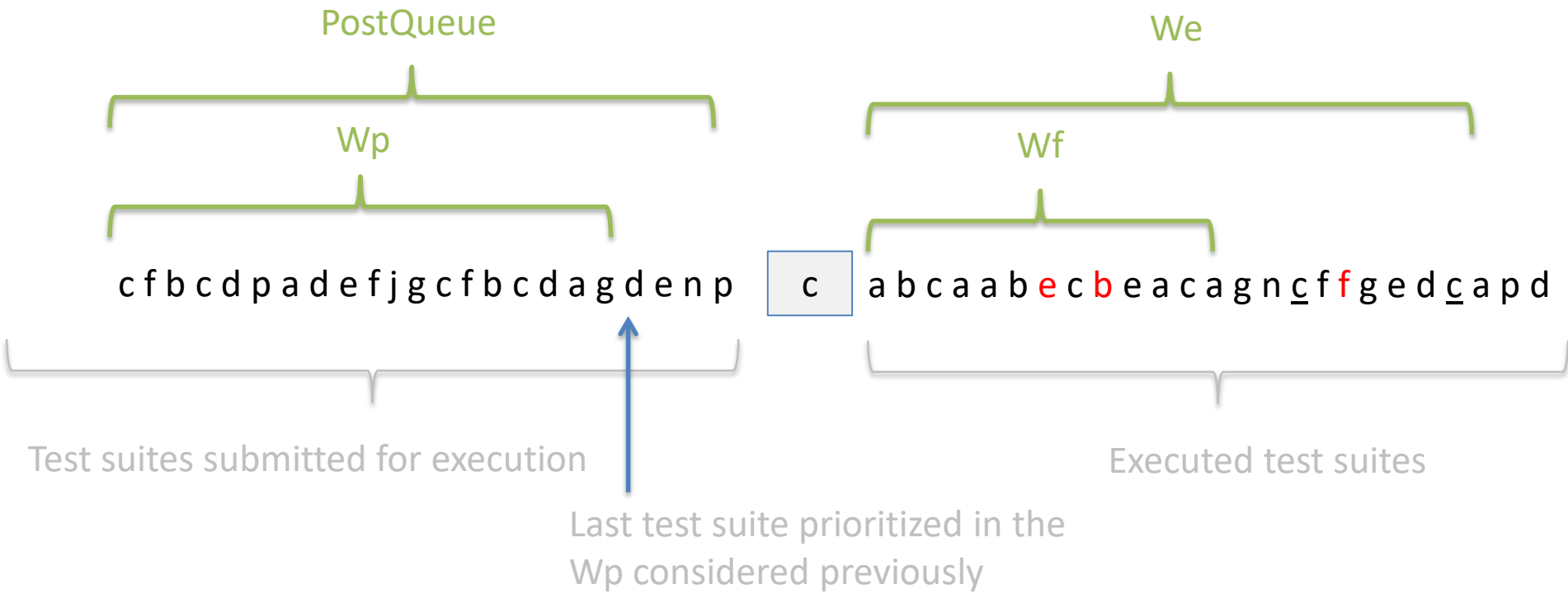
# Post-Commit: Continuous-TSP

- Test Suite Prioritization (TSP)
- At the level of test suites, not test cases
- Except that we cannot assume that:
  - We have reliable coverage information
  - We have time to perform heavyweight analyses
- Key insight: value of lightweight test history data
  - Test executions
  - Test failures
- Key difference from RTS: We can't prioritize per test suite arrival, we need to prioritize over a "batch" or "window" **Wp** of arrivals, found in a **PostQueue**

# Continuous-TSP Intuition

- If a test suite in Wp is new
  - It needs to be executed; rank “higher” than others
- If a test suite in Wp failed recently
  - May be associated with “hot” area; worth ranking “higher” than others
- If a test suite in Wp has not executed in a while
  - Needs a “refresher”; worth ranking “higher” than others
- Else rank it lower

# Continuous-TSP Example



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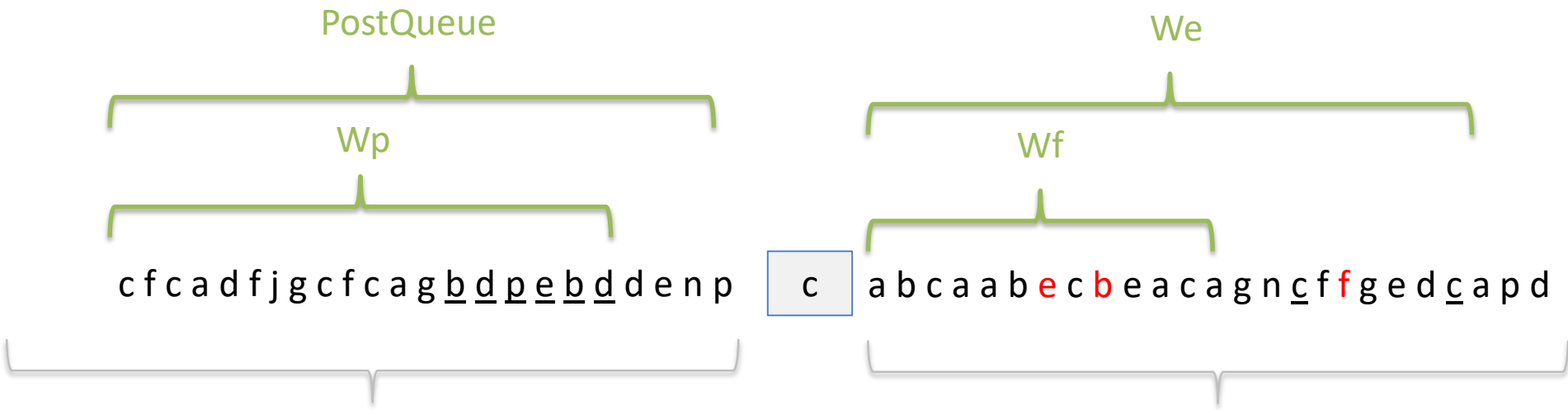


# Research Question

- RQ: How cost-effective is CI-TSP, and how does its cost-effectiveness vary with different settings of Wp?

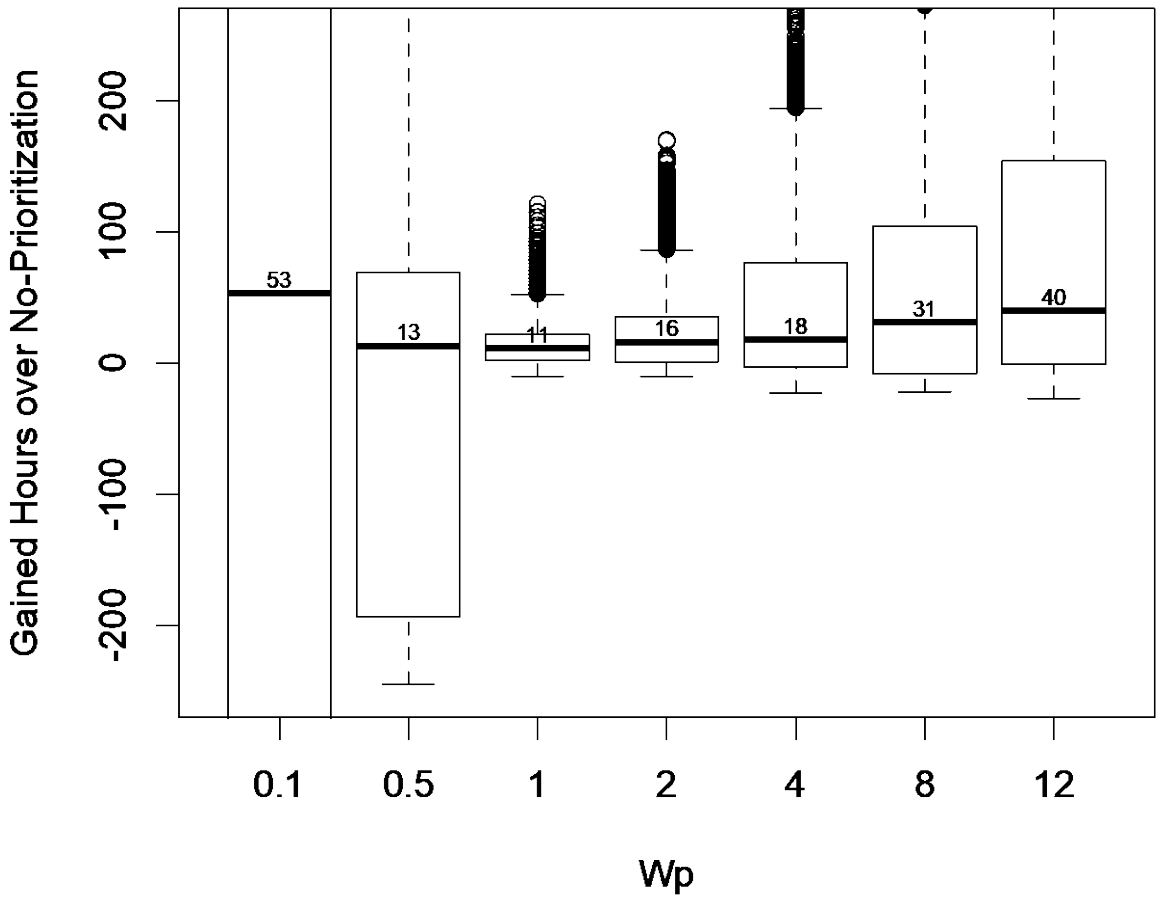
# Variables

- Independent
  - Technique: CI-TSP, Unprioritized
  - Wp: 0.1, 0.5, 1, 2, 4, 8, 12 (hours)
  - Wf set to 12, We set to 24 (hours)
- Dependent
  - Hours gained in exposing failures

# Study Operation

- Implemented C-TSP in Python
- Simulated techniques by walking through the Google Testing Dataset

# Results: CI-TCP in Post-Submit




- All instantiations of prioritization outperform no prioritization (medians)
- Lower Wp values lead to higher variance
- Higher Wp values boost hours gained

# Conclusion

- With CI, testing is no longer discrete and bounded
- Testing approaches that assume it is are not going to scale or keep up
- Need to perform “instantaneous” selection, prioritization, and analysis
- Our CI-RTS and CI-TSP approaches achieve this

# Ongoing and Future Work

- Additional studies on additional data sets
- More effective RTS/TCP techniques
  - Let windows represent numbers of tests, not time
  - Prioritize commits, not test suites*
  - Dynamically adjust windows (adapt) as throughput changes
  - Use additional sources of information
- Test suites can fail too. Use data on test suite modification as part of RTS/TCP
- Consider large-scale computing infrastructures
- Consider other variants of CI processes

- J. Liang, S. Elbaum, G. Rothermel, “Redefining Prioritization: Continuous Prioritization for Continuous Integration”, ICSE 2018

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