Using Non-Redundant Mutation Operators and Test Suite Prioritization to Achieve Efficient and Scalable Mutation Analysis

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Mutation Analysis Background

Mutation analysis assesses the quality of a test suite with artificial faults (mutants)

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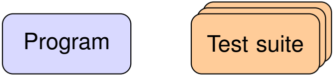

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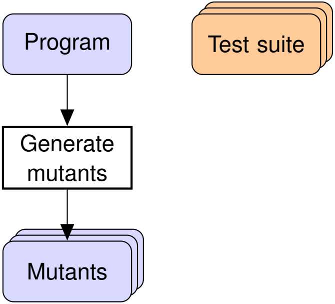

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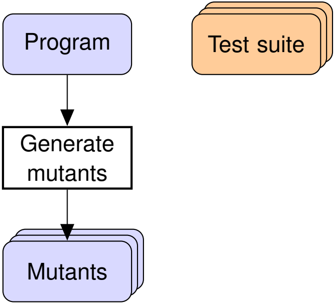

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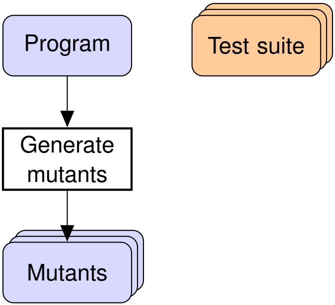

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Contains a small syntactic change

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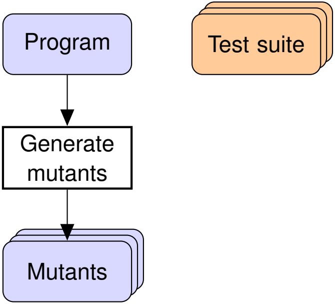

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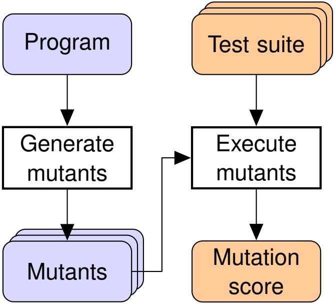

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Many mutants can be generated for large programs

Executing the entire test suite for all mutants in large programs is prohibitive!

Overview: Efficient Mutation Analysis

$\boxed{\text{Execute fewer mutants fewer times}}$

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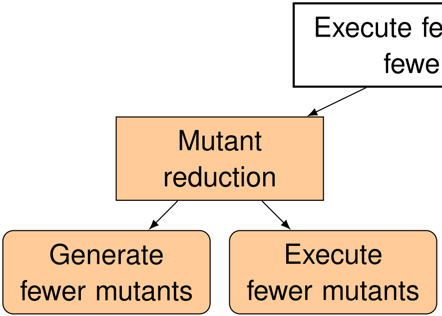

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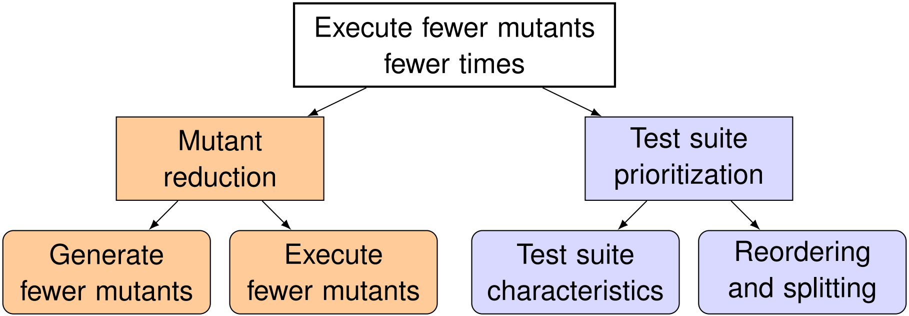

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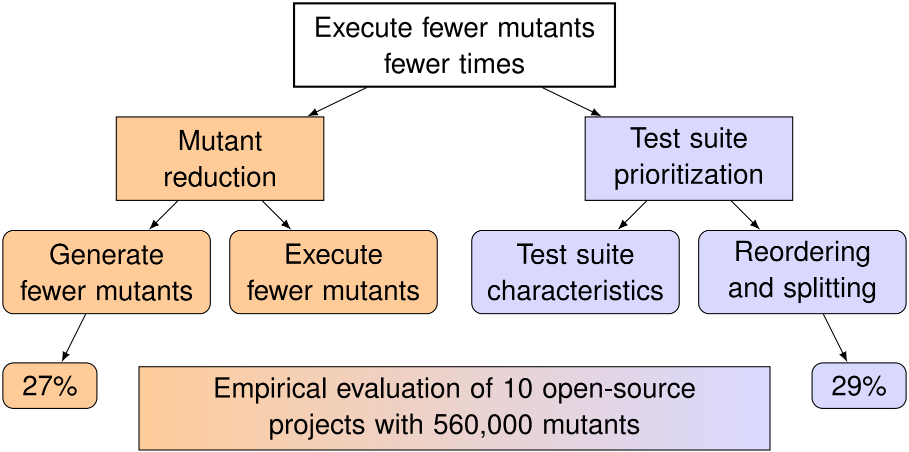
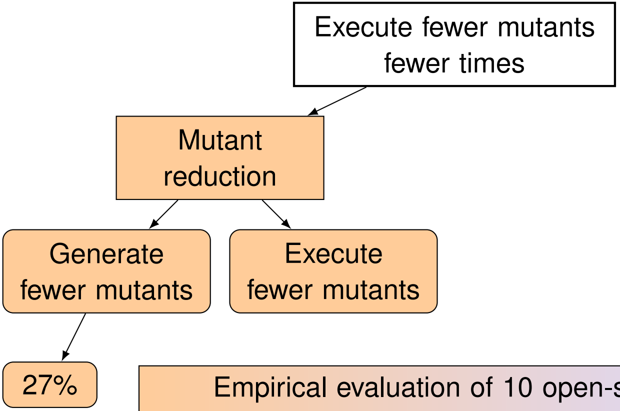


Reduction of Mutants



Empirical evaluation of 10 open-source projects with 560,000 mutants

Reduce Number of Generated Mutants

Mutation operators may introduce redundancy:

- Redundant mutants are subsumed by other mutants
  - `a + b` $\mapsto$ `a - b` (replace binary operator)
  - `a + b` $\mapsto$ `a + (-b)` (insert unary operator)
- Use only non-redundant mutation operators
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Executing all non-redundant mutants is still prohibitive!

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Exploit necessary conditions:

- Mutants not covered (reached) cannot be detected
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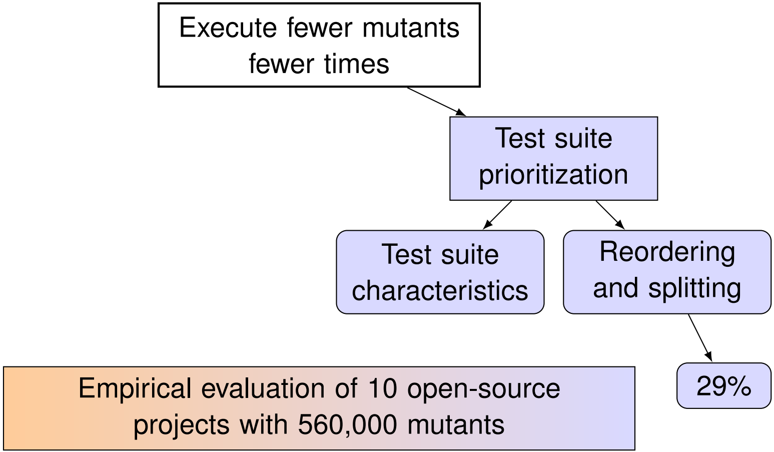
Further optimizations beyond the reduction of mutants are necessary!

Optimized Workflow for Mutation Analysis



Motivating Example for Reordering

Mutants:
1, 2, 3, 4, 5

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Mutants: 1, 2, 3, 4, 5	Test case t_1: 5 seconds	Test case t_2: 2 seconds	Test case t_3: 1 second

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Executed mutants and total runtime:

| t_1 | t_2 | t_3 | : |

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Covered:	1, 2, 3, 4, 5	1, 2, 3, 4	2, 3, 4, 5
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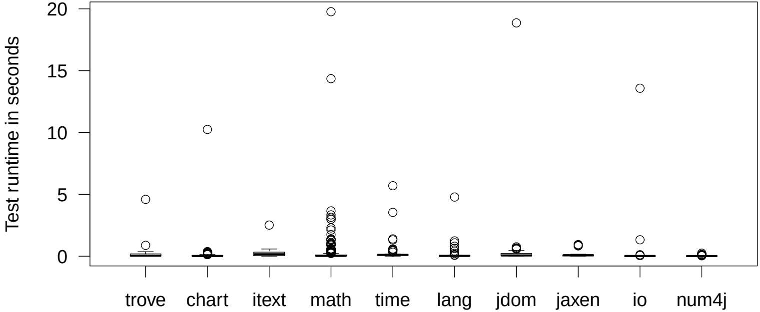

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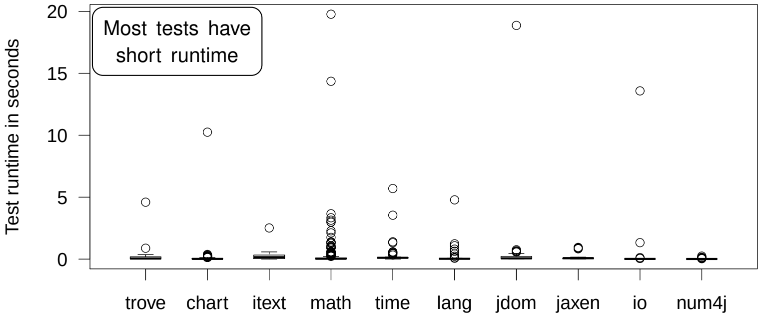

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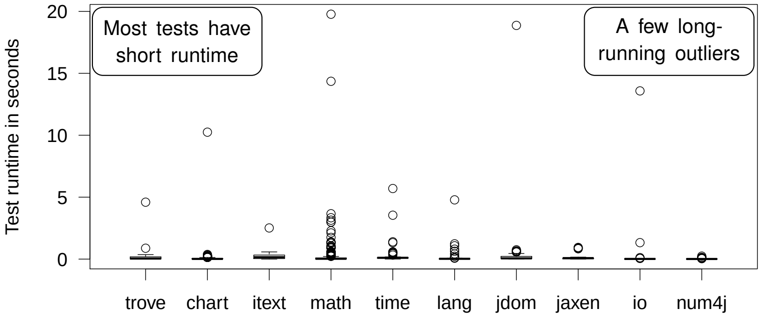

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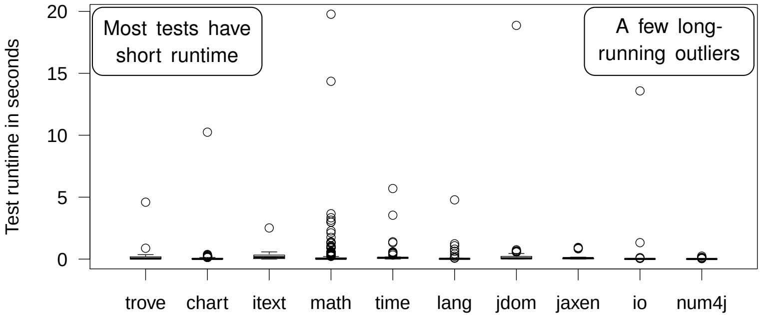

A few tests constitute most of the total runtime:
Reduce number of executions for these tests

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- Overlap measures the similarity of a test case with its enclosing test suite
- Pair-wise comparison of test cases is infeasible

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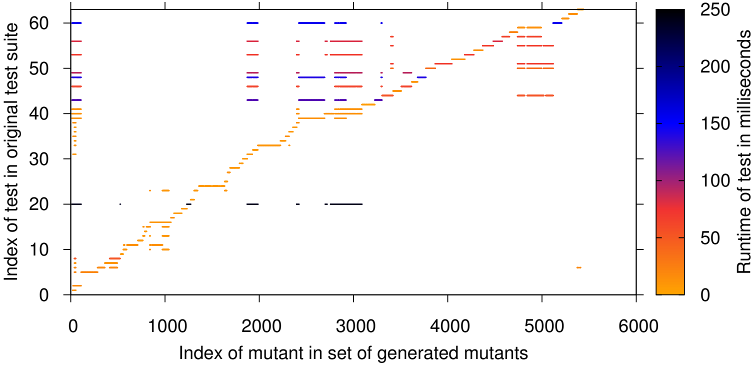
Most of the test cases exhibit high overlap:
Does test runtime correlate with overlap?

Correlation of Test Runtime and Mutation Coverage



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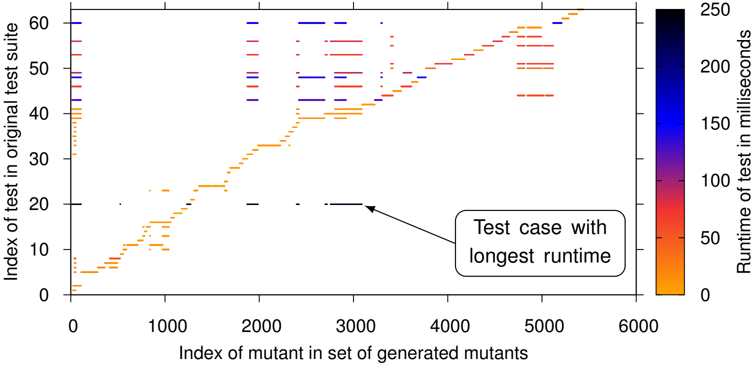

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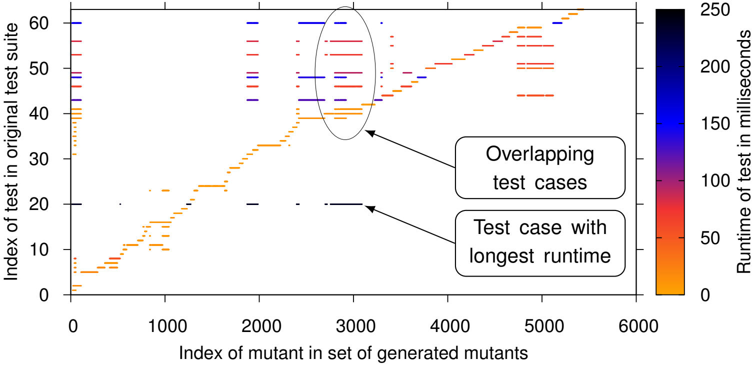

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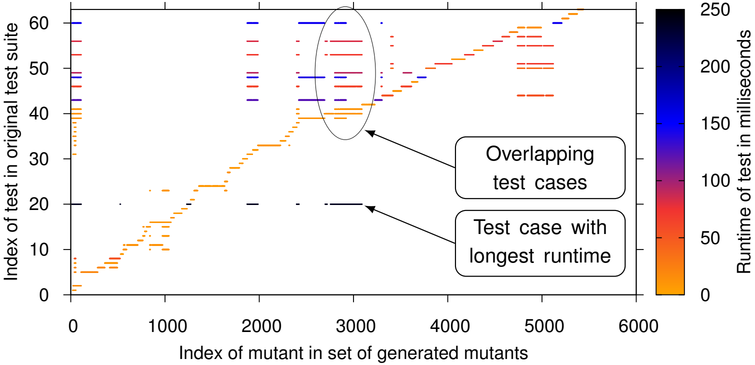

Reorder to exploit mutation coverage overlap

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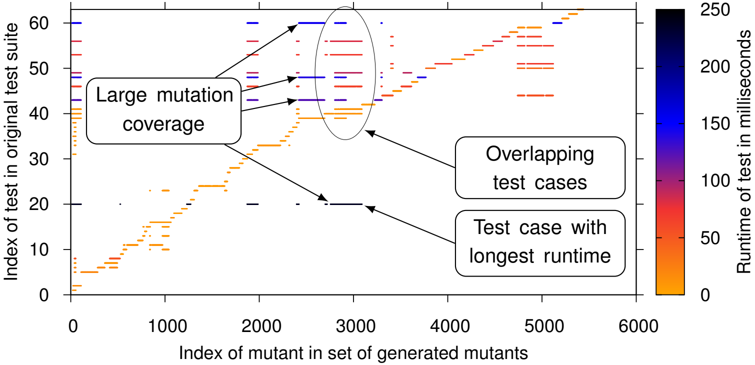

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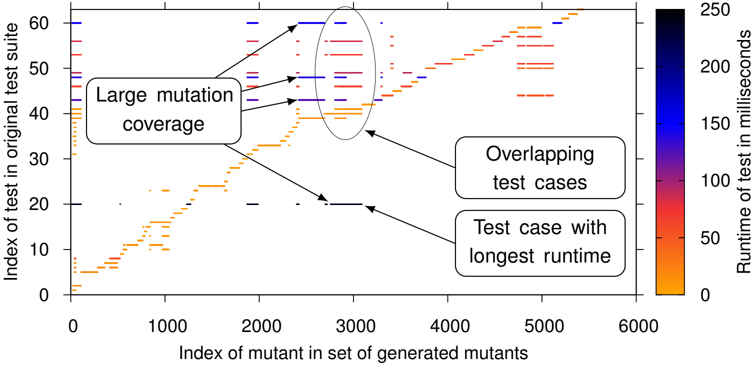
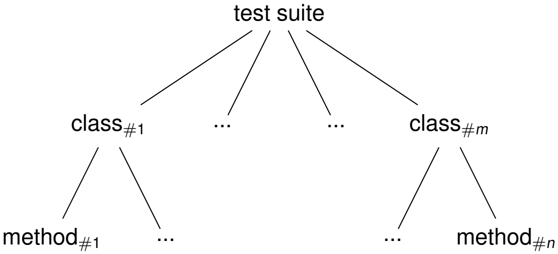


Reorder to exploit mutation coverage overlap

Split test cases to increase coverage precision

Mutation Coverage of Test suites



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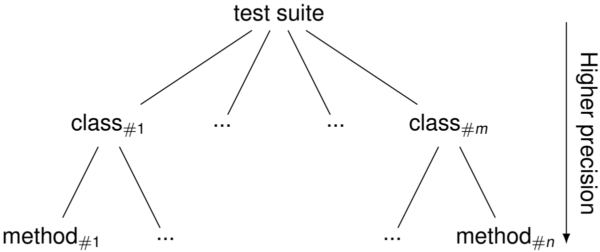

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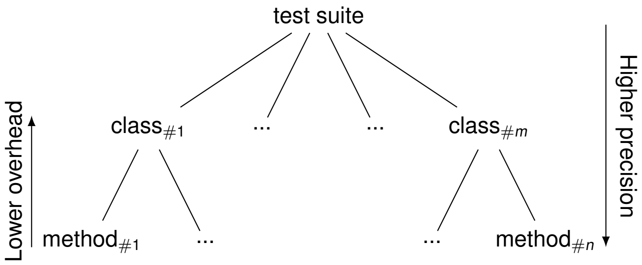

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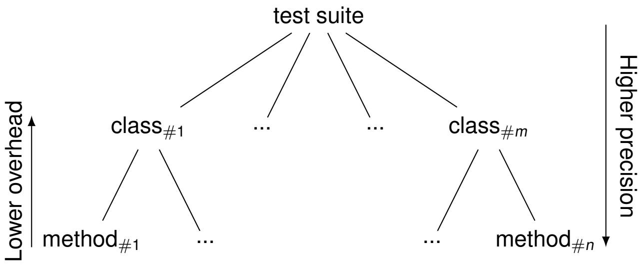

Only split long-running test classes

Splitting Test Classes

Two splitting strategies

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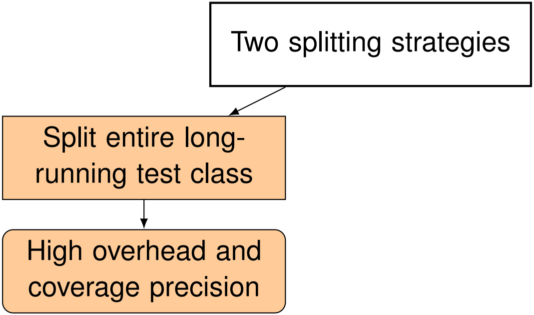

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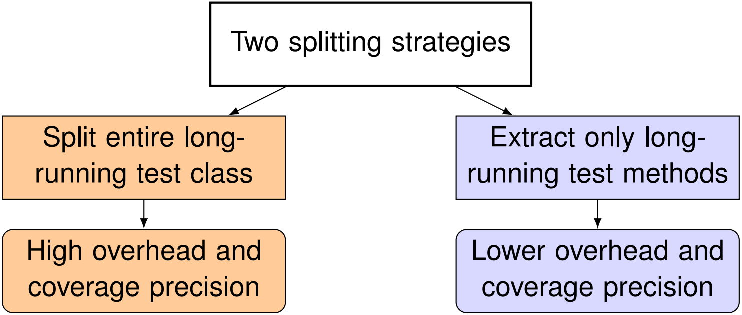

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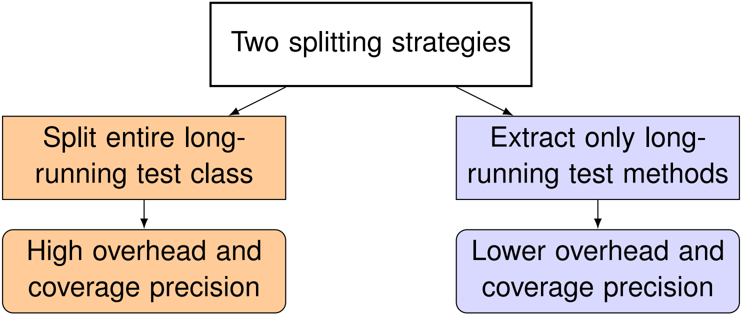
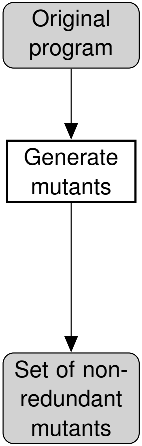


Trade-off between overhead and precision:
Splitting based on threshold for test runtime

Optimized workflow



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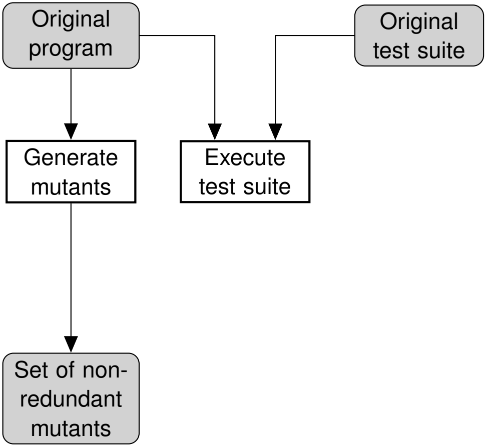
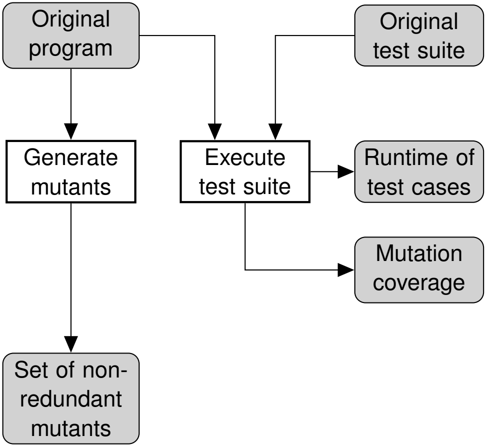


Optimized workflow



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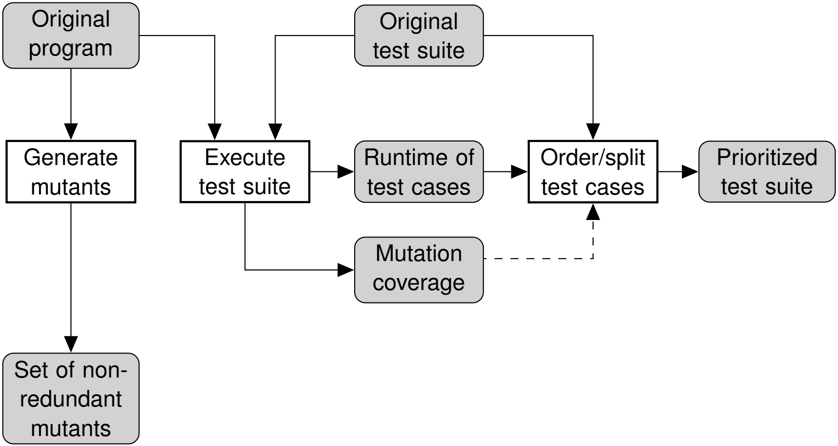

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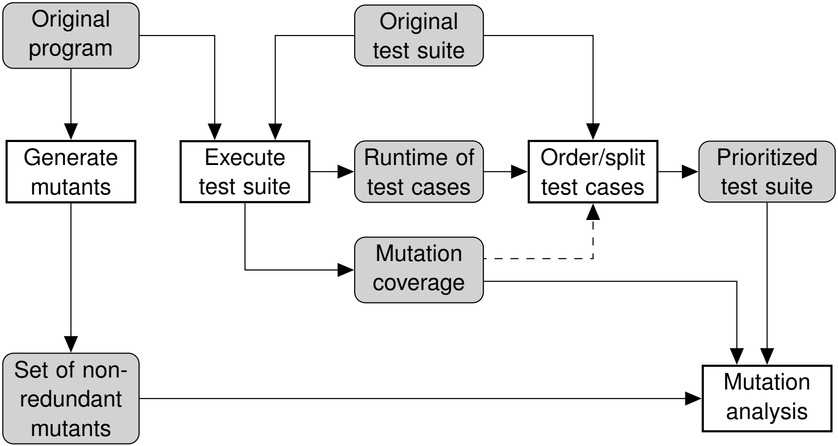
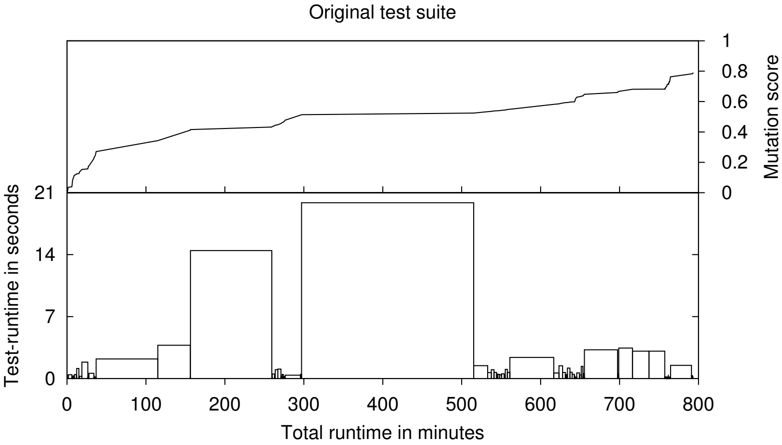


Example with Original Test Suite



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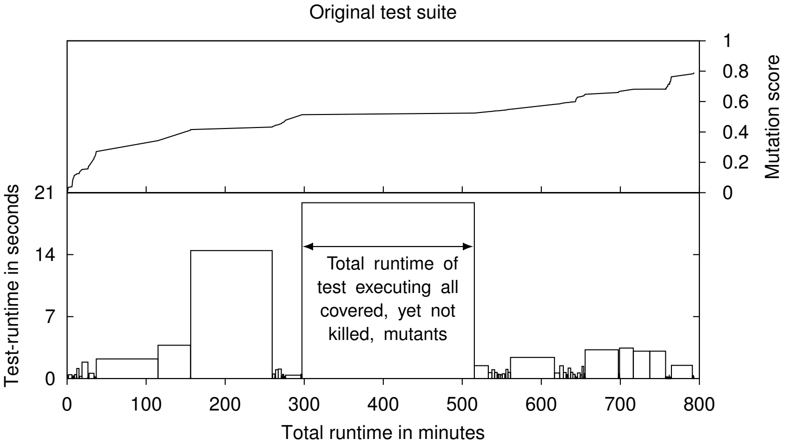

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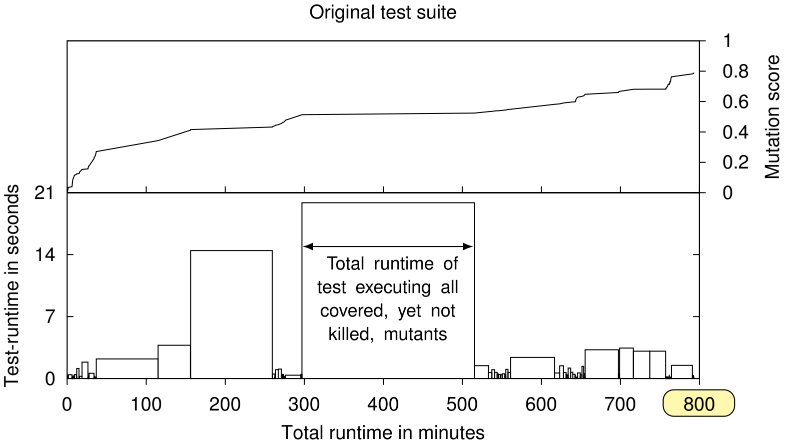

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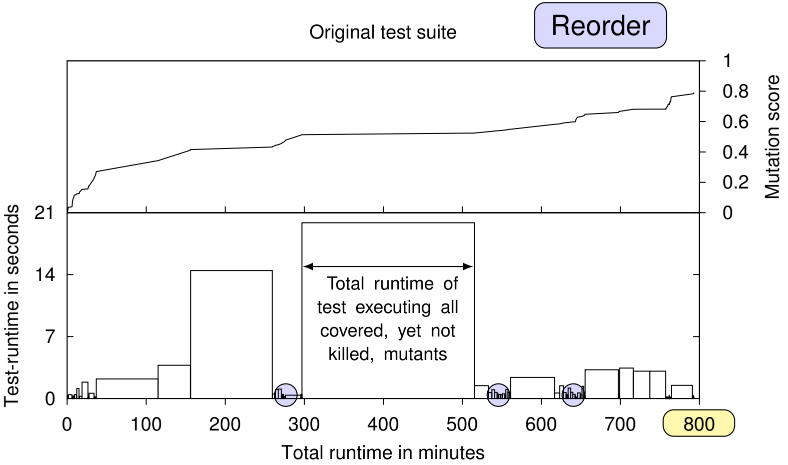

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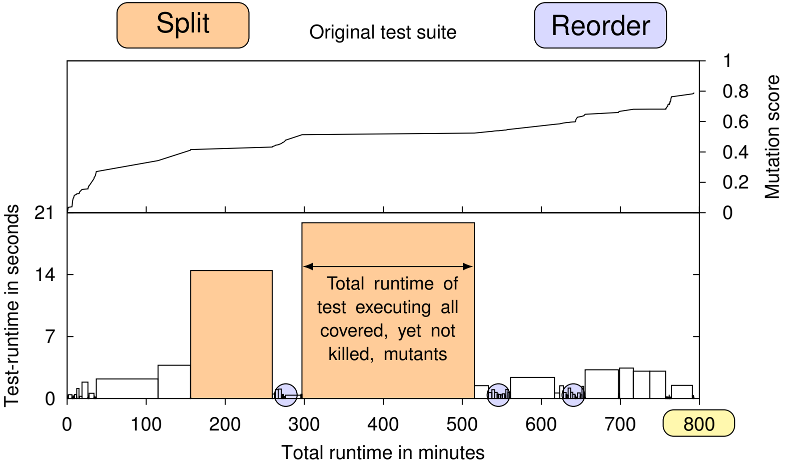
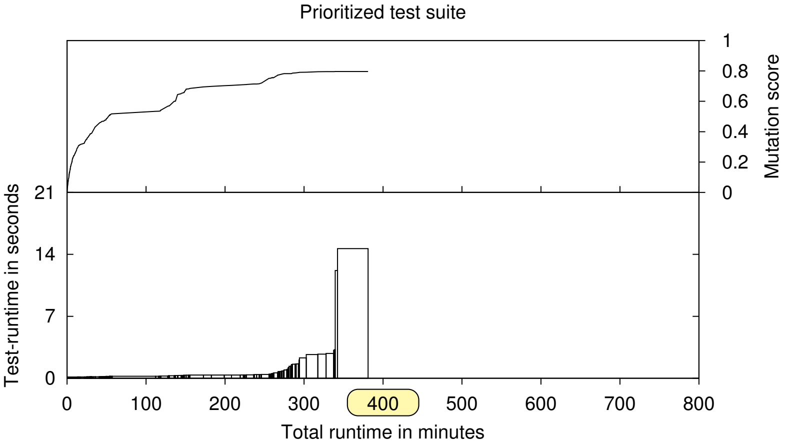


Example with Prioritized Test Suite



Empirical Results

Reordering:

- Reordering decreases the runtime by 20%

Splitting strategies:

- Extracting long test methods reduces the runtime by 29%
- Splitting entire test classes increases the runtime by 27%

Splitting may increase runtime if:

- Test suite has a very low mutation detection rate
- Test methods exhibit huge mutation coverage overlap

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Prioritizing test suites improves the efficiency of mutation analysis by 29% on average!

Related Work

Reduction of generated mutants:

- Sufficient mutation operators
  - Offutt et al., TOSEM'96
  - Namin et al., ICSE'08
- Non-redundant mutation operators
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- Test case prioritization
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Do not address efficiency

Conclusions

Reduction of mutants:

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Test suite characteristics:

- Most of the tests exhibit mutation coverage overlap
- Notable difference in runtime of tests

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Non-redundant operators and optimized workflow implemented in the MAJOR mutation system