

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

René Just^{1,2} & Gregory M. Kapfhammer³ & Franz Schweiggert²

¹University of Washington, USA

²Ulm University, Germany

³Allegheny College, USA

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Mutation Analysis Background

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

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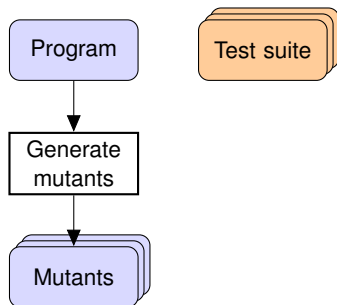
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Program

Test suite

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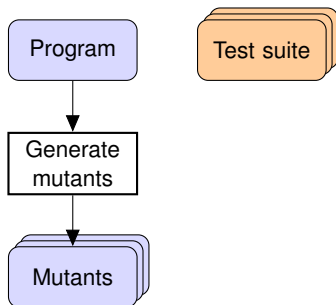


Mutation Analysis Background

```
public int max(int a, int b){  
    int max = a;  
    if (b>a){  
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    return max;  
}
```

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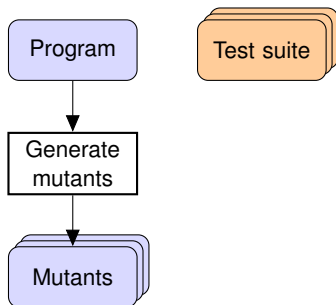


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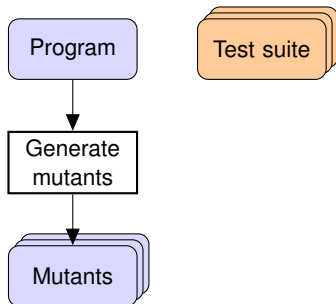
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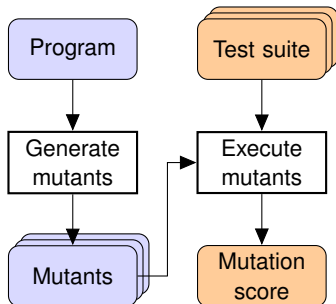
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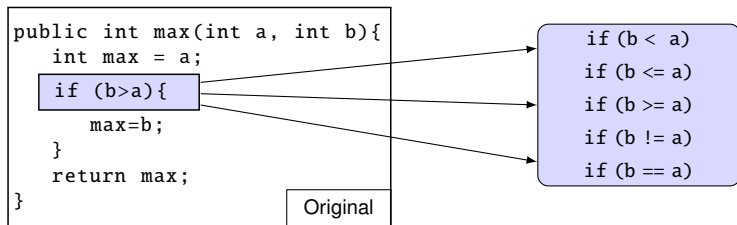


Mutation Analysis is Expensive

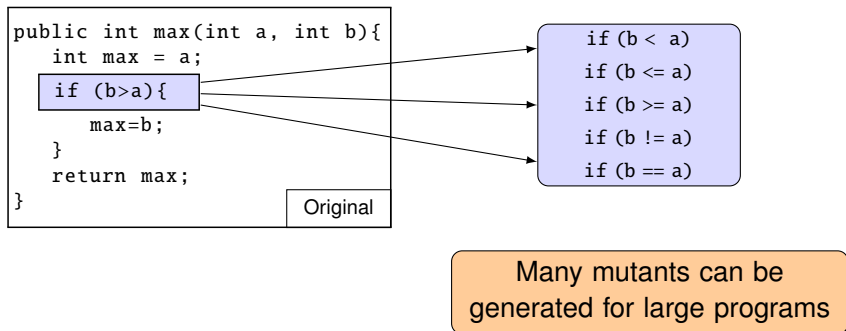
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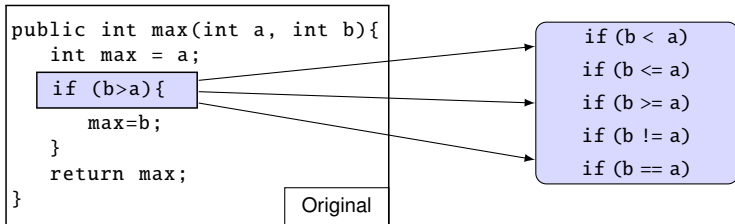
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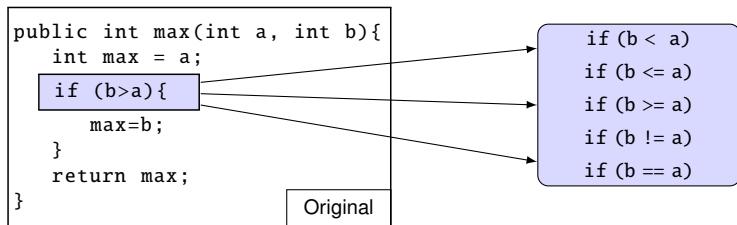
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Large programs include
comprehensive test suites

Many mutants can be
generated for large programs

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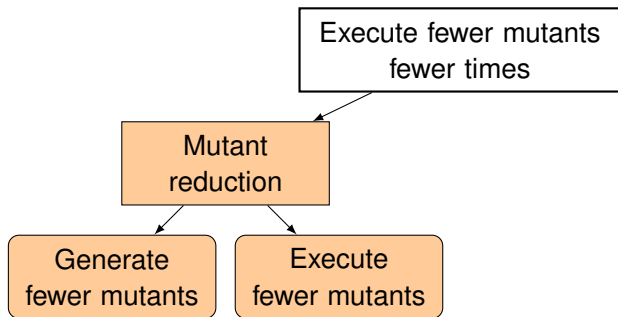
Many mutants can be
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Executing the entire test suite for all
mutants in large programs is prohibitive!

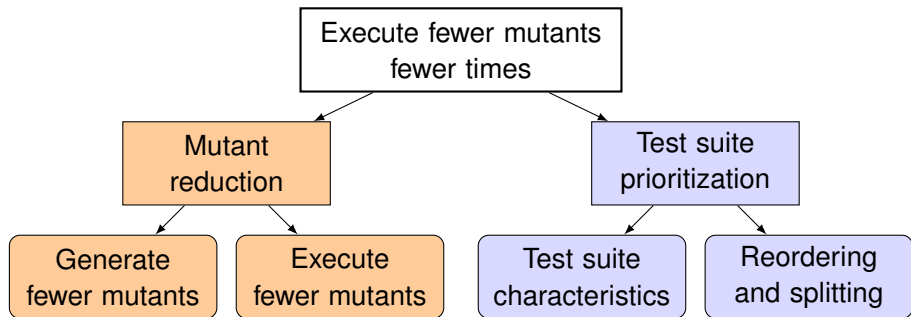
Overview: Efficient Mutation Analysis

Execute fewer mutants
fewer times

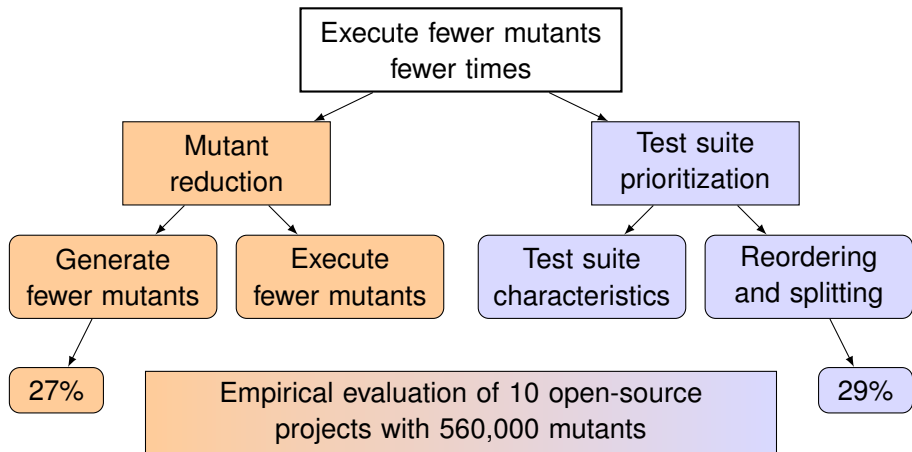
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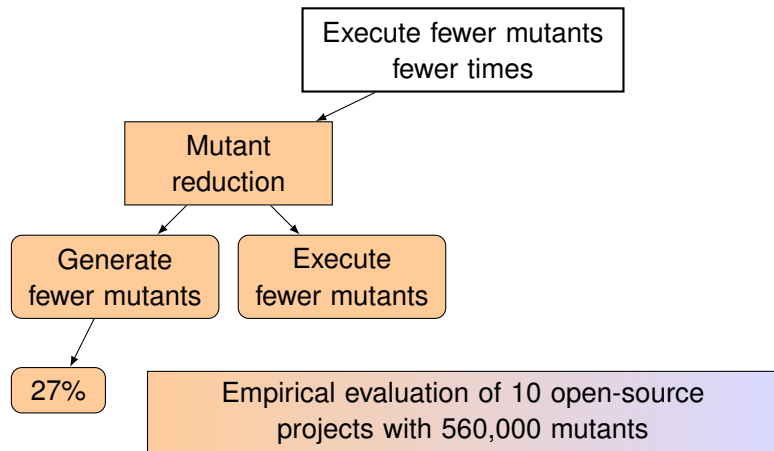
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Reduction of Mutants



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)
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Executing all non-redundant mutants is still prohibitive!

Reduce Number of Executed Mutants

Exploit necessary conditions:

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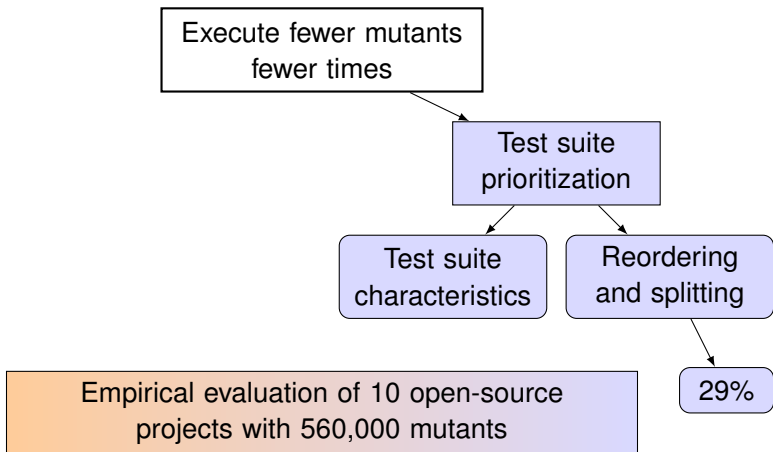
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Further optimizations beyond the reduction of mutants are necessary!

Optimized Workflow for Mutation Analysis



Motivating Example for Reordering

Mutants:

1, 2, 3, 4, 5

Motivating Example for Reordering

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Test case t_1 :

5 seconds

Test case t_2 :

2 seconds

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1 second

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1, 2, 3

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Detected:	1, 2, 5	1, 4	3

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Executed mutants and total runtime:

$t_1 t_2 t_3$:

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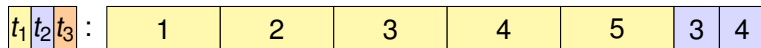
t_1	t_2	t_3	:	1	2	3	4	5
-------	-------	-------	---	---	---	---	---	---

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Detected:

1, 2, 5

Motivating Example for Splitting

Mutants: 1, 2, 3, 4, 5	Test case t_1 : 5 seconds	Test case t'_1 : 3 seconds	Test case t''_1 : 2 seconds
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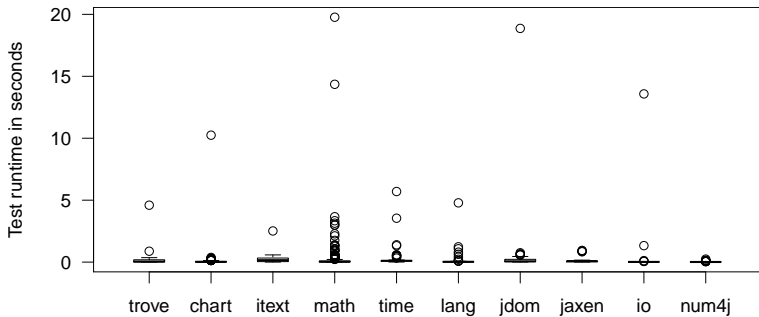
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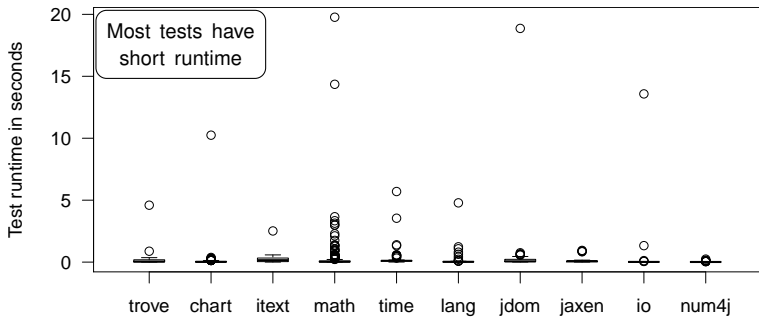
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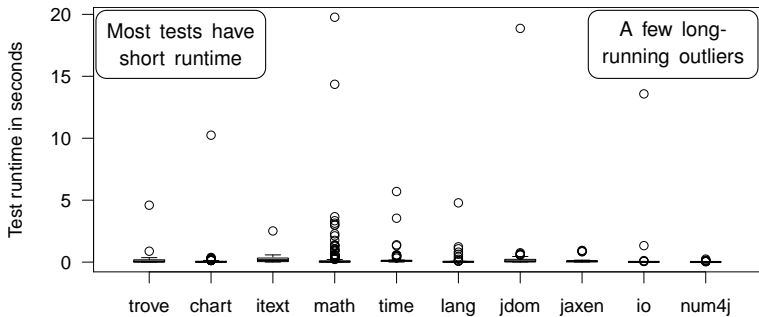
Runtime Distribution of Tests within Test Suites



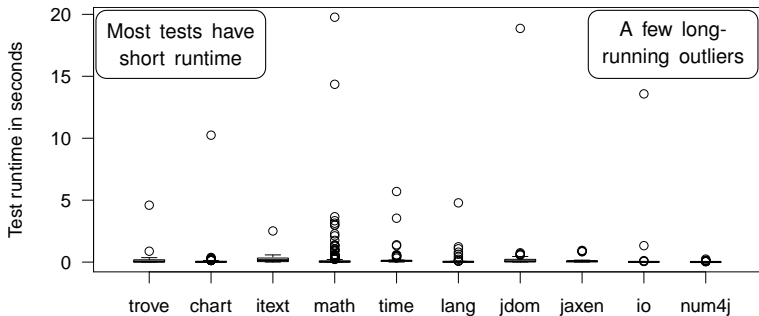
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A few tests constitute most of the total runtime:
Reduce number of executions for these tests

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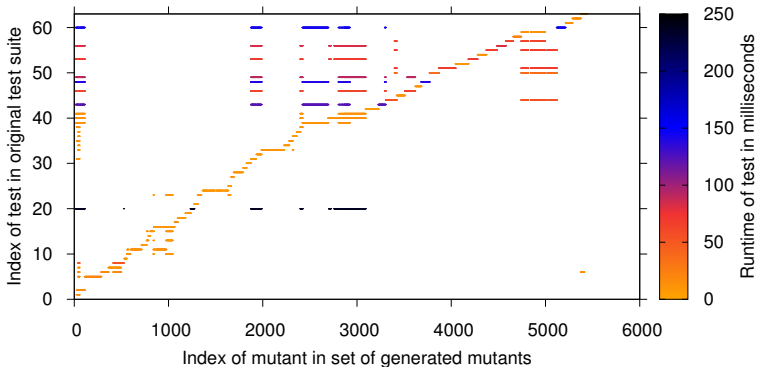
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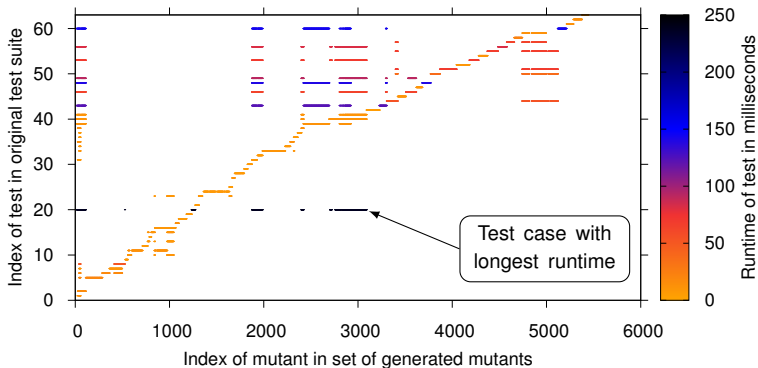
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Most of the test cases exhibit high overlap:
Does test runtime correlate with overlap?

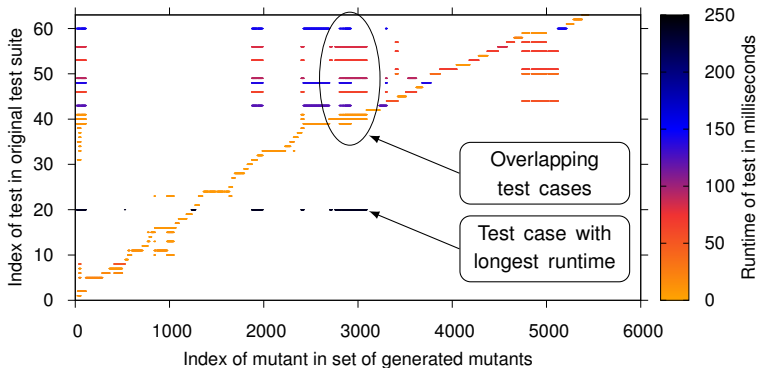
Correlation of Test Runtime and Mutation Coverage



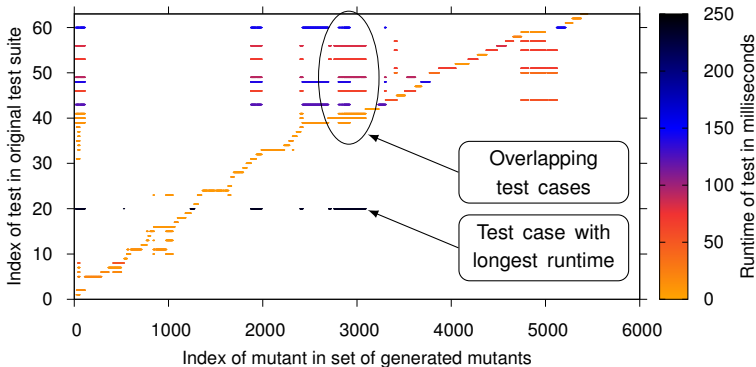
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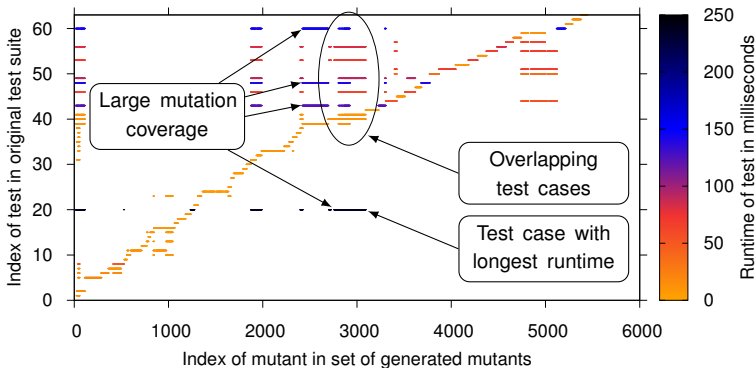


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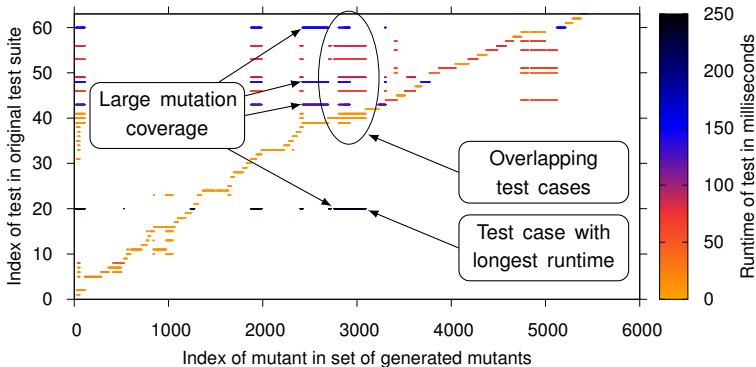
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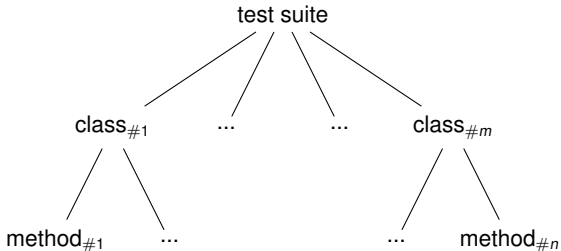
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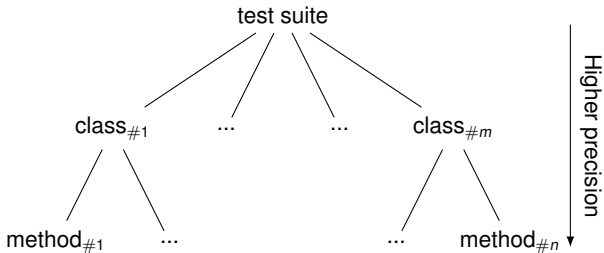
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Split test cases to increase
coverage precision

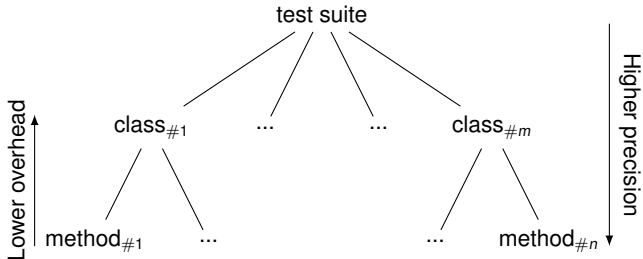
Mutation Coverage of Test suites



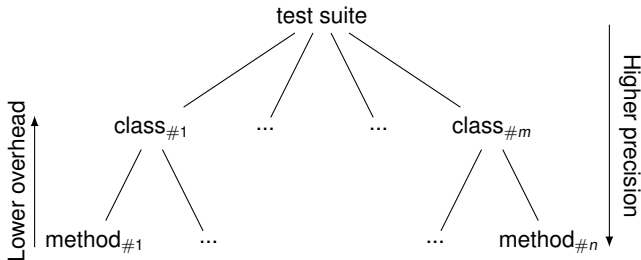
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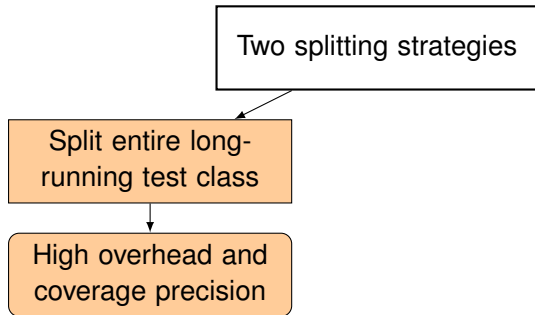


Only split long-running test classes

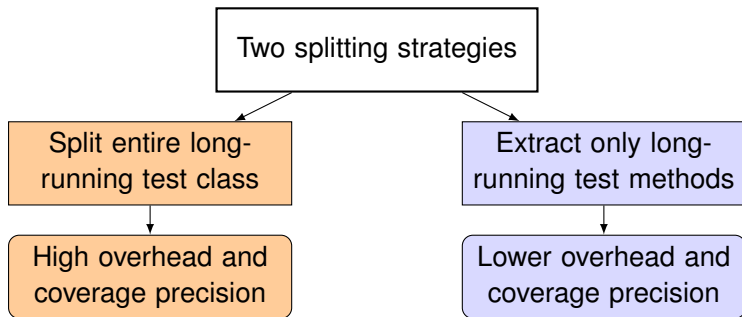
Splitting Test Classes

Two splitting strategies

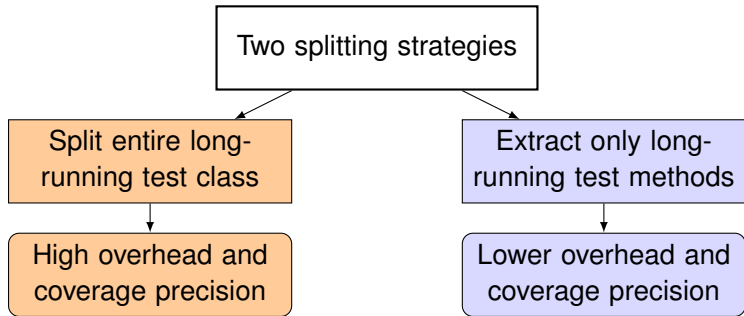
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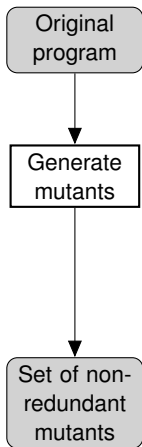


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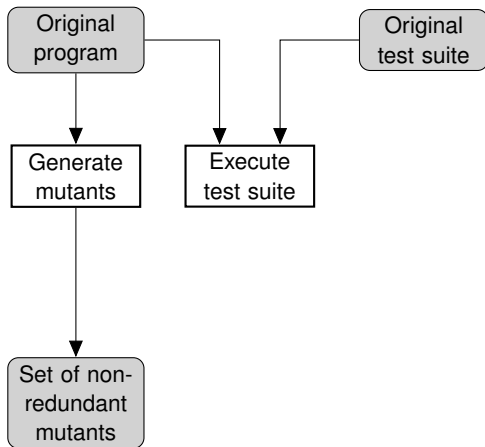


Trade-off between overhead and precision:
Splitting based on threshold for test runtime

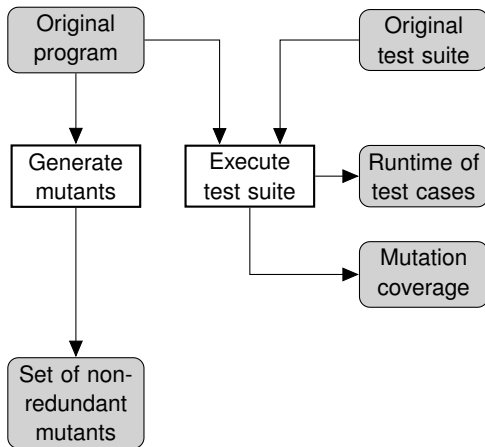
Optimized workflow



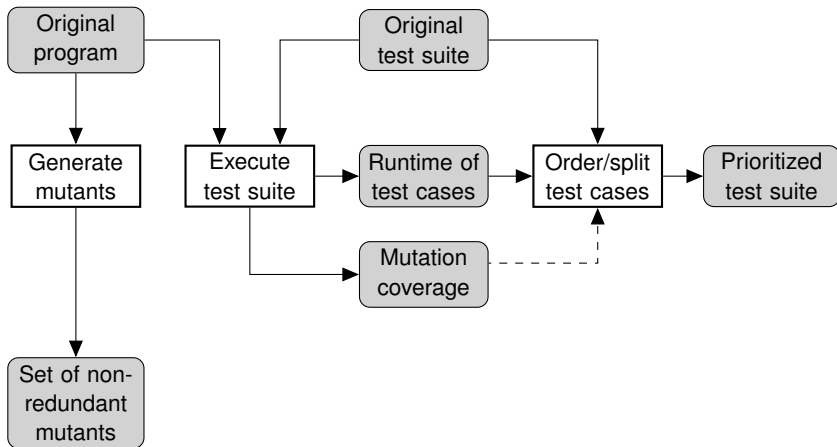
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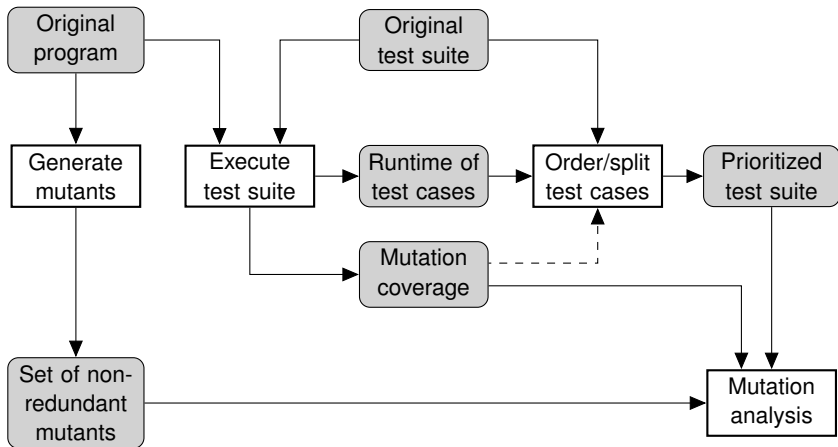
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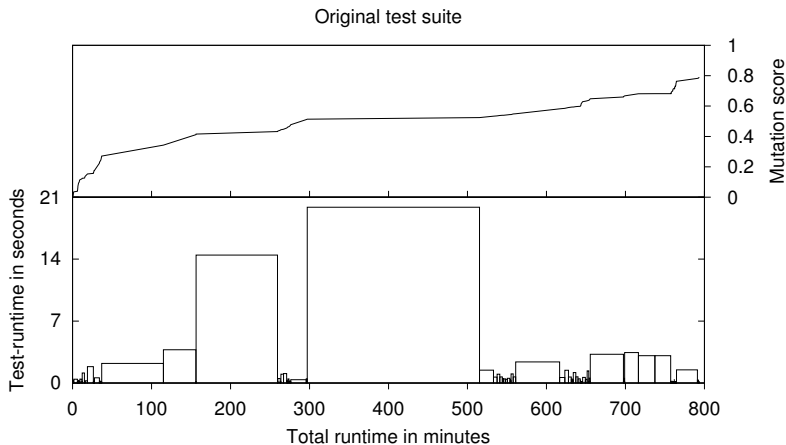
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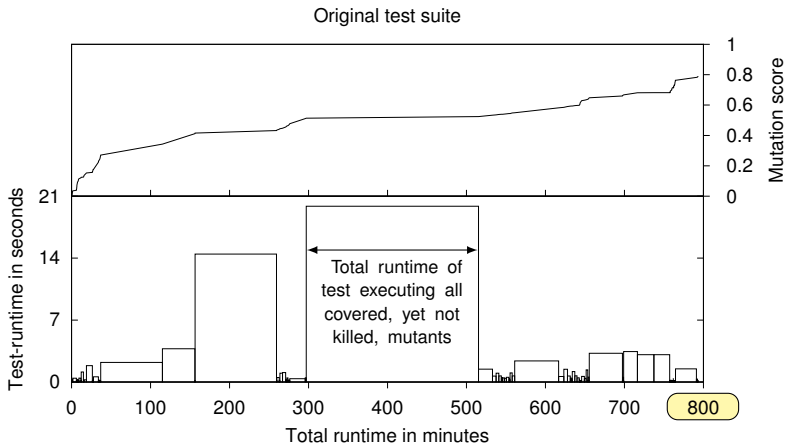
Example with Original Test Suite



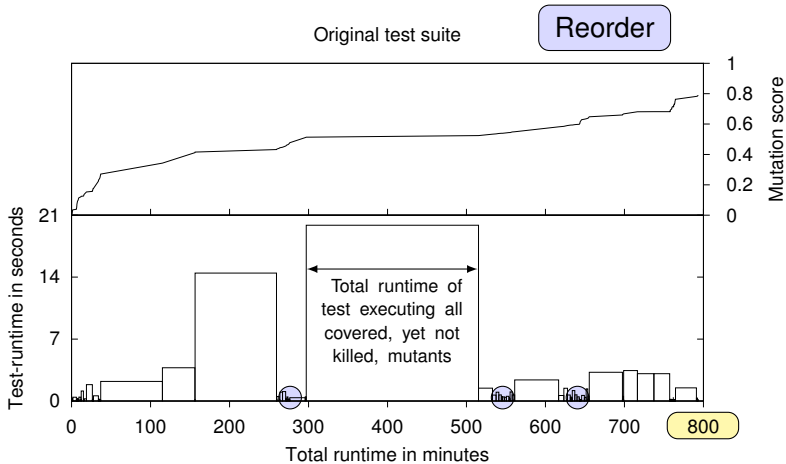
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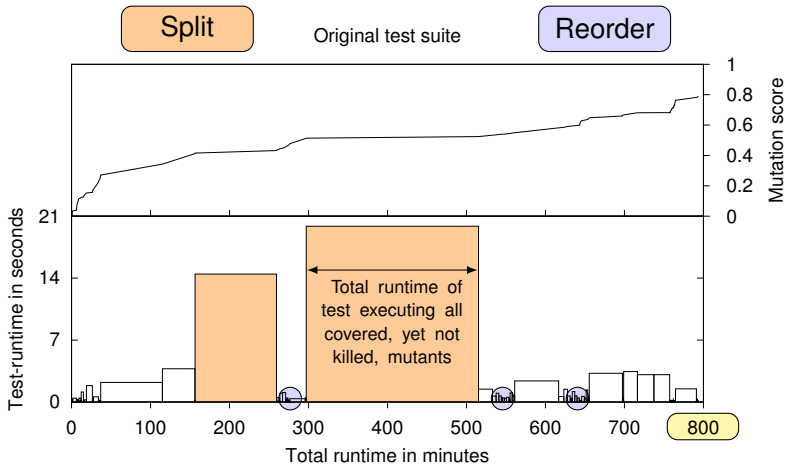
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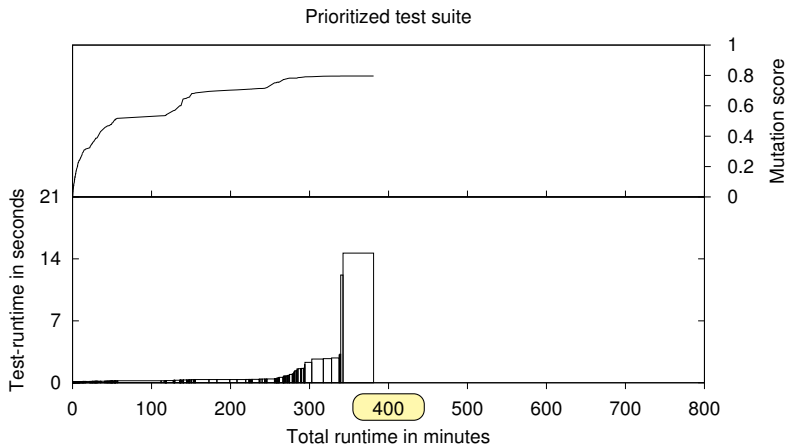
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Example with Original Test Suite



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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- Test methods exhibit huge mutation coverage overlap

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
 - Kaminski et al., AST'11
 - Just et al., Mutation'12

Mutation-based test suite optimization:

- Test case prioritization
 - Elbaum et al. TSE'02
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Do not address
efficiency

Conclusions

Reduction of mutants:

- Non-redundant operators reduce number of mutants by 27%

Test suite characteristics:

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

Optimized workflow:

- Exploits mutation coverage overlap and runtime differences
- Further reduces total runtime of mutation analysis by 29%

Conclusions

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